These solutes may be homogeneous (soluble in water) or heterogeneous mass (insoluble in water) which forms the basis for its colloidal nature.

Physical Properties of Protoplasm

The protoplasm exist either in semisolid (jelly-like) state called '**gel**' due to suspended particles and various chemical bonds or may be liquid state called '**sol**'. The colloidal protoplasm which is in gel form can change into sol form by **solation** and the sol can change into gel by **gelation**. These gel-sol conditions of colloidal system are prime basis for mechanical behaviour of cytoplasm.

1. Protoplasm is translucent, odourless and polyphasic fluid.
2. It is a crystal colloid solution which is a mixture of chemical substances forming crystalloid i.e. true solution (sugars, salts, acids, bases) and others forming colloidal solution (Proteins and lipids)
3. It is the most important property of the protoplasm by which it exhibits three main phenomena namely Brownian movement, amoeboid movement and cytoplasmic streaming or cyclosis. Viscosity of protoplasm is 2–20 centipoises. The Refractive index of the protoplasm is 1.4.
4. The pH of the protoplasm is around 6.8, contain 90% water (10% in dormant seeds)
5. Approximately 34 elements are present in protoplasm but only 13 elements are main or universal elements i.e. C, H, O, N, Cl, Ca, P, Na, K, S, Mg, I and Fe. Carbon, Hydrogen, Oxygen and Nitrogen form the 96% of protoplasm.
6. Protoplasm is neither a good nor a bad conductor of electricity. It forms a delimiting membrane on coming in contact with water and solidifies when heated.
7. **Cohesiveness:** Particles or molecules of protoplasm are adhered with each other by forces, such as **Van der Waal's bonds**, that hold long chains of molecules together. This property varies with the strength of these forces.
8. **Contractility:** The contractility of protoplasm is important for the absorption and removal of water especially stomatal operations.
9. **Surface tension:** The proteins and lipids of the protoplasm have less surface tension, hence they are found at the surface forming the membrane. On the other hand the chemical substances (NaCl) have high surface tension, so they occur in deeper parts of the cell protoplasm.

6.3.4 Cell sizes and shapes

Cell greatly vary in size, shape and also in function. Group of cells with similar structures are called **tissue** they integrate together to perform similar function, group of tissue join together to perform similar function called **organ**, group of organs with related function called **organ system**, organ system coordinating together to form an **organism**.

Shape

The shape of cell vary greatly from organism to organism and within the organism itself. In bacteria cell shape

DO YOU KNOW?

1 cm = 1/100 meter

1 mm = 1/1000 meter =1/10 cm

1 µm = 1/1000,000 meter = 1/10,000 cm

1 nm = 1/1,000,000,000 meter = 1/10,000,000 cm

1 Å = 1/10,000,000,000 meter =1/100,000,000 cm

or

$1 \text{ m} = 10^2 \text{cm} = 10^3 \text{mm} = 10^6 \mu\text{m} = 10^9 \text{nm} = 10^{10} \text{Å}$

m = meter cm = centimetre mm = millimeter µm = micrometer

nm = nanometer Å=Angstrom

vary from round (**cocci**) to rectangular (**rod**). In virus, shape of the envelope varies from round to hexagonal or '**T**' shaped. In fungi, globular to elongated cylindrical cells and the spores of fungi vary greatly in shape. In plants and animals cells vary in shape according to cell types such as parenchyma, mesophyll, palisade, tracheid, fiber, epithelium and others (Figure 6.6).

Size:

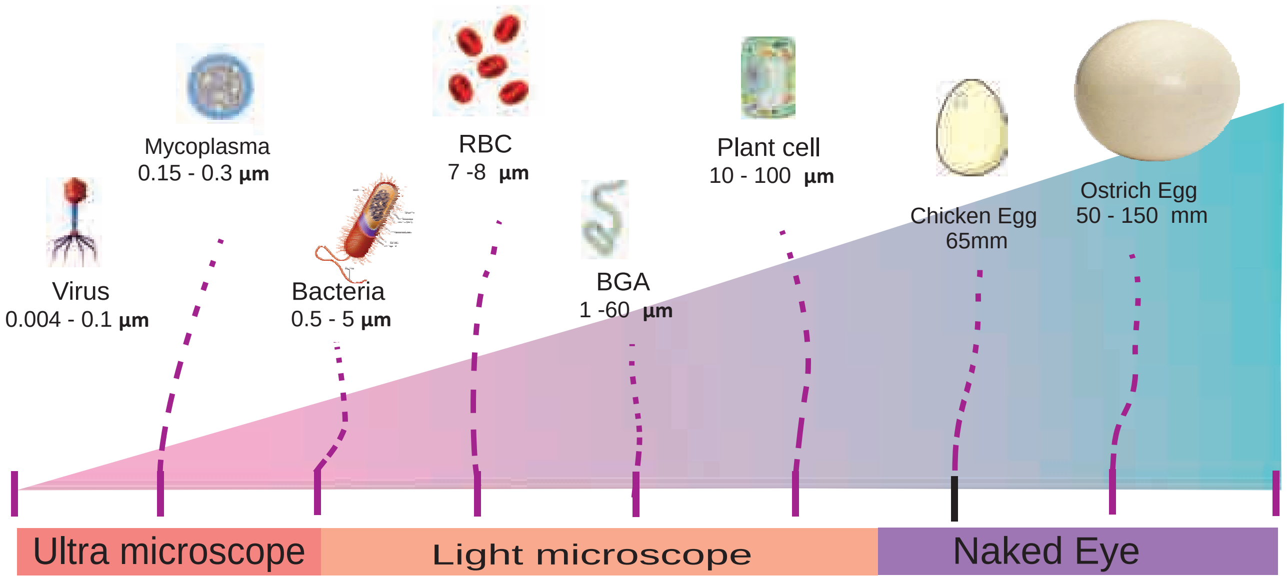


Figure 6.6: Cell size variation of few organisms

6.4. Types of cells

On the basis of the cellular organization and the nuclear characteristics, the cell can be divided into

- Prokaryotes
- Mesokaryotes and
- Eukaryotes

6.4.1 Prokaryotes

Those organisms with primitive nucleus are called as **prokaryotes** (*pro* – primitive; *karyon* – nucleus). The DNA lies in the 'nucleoid' which is not bound by the nuclear membrane and therefore it is not a true nucleus and is also a primitive type of nuclear material. The DNA is without histone proteins. Example: Bacteria, blue green algae, Mycoplasma, Rickettsiae and Spirochaetae.

6.4.2 Mesokaryotes

In the year 1966, scientist **Dodge** and his coworkers proposed another kind of organisms called **mesokaryotes**. These organisms which shares some of the characters of both prokaryotes and eukaryotes. In other words these are organisms intermediate between pro and eukaryotes. These contains well organized nucleus with nuclear membrane and the DNA is organized into chromosomes but without histone protein components divides through amitosis similar with prokaryotes. Certain Protozoa like **Noctiluca**, some phytoplanktons like *Gymnodinium*, *Peridinium* and Dinoflagellates are representatives of mesokaryotes.

6.4.3 Eukaryotes

Those organisms which have true nucleus are called **Eukaryotes** (*Eu* – True; *karyon* – nucleus). The DNA is associated with protein bound histones forming the chromosomes. Membrane bound organelles are present. Few organelles may be arisen by **endosymbiosis** which is a cell living inside another cell. The organelles like mitochondria and chloroplast well support this theory.

Comparison between types of cellular organisation

Features	Prokaryotes	Mesokaryotes	Eukaryotes
Size of the cell	~1-5µm	~5-10µm	~10-100µm
Nuclear character	Nucleoid, no true nucleus,	Nucleus with nuclear membrane	True nucleus with nuclear membrane
DNA	Usually circular without histone proteins	Usually linear but without histone proteins	Usually linear with histone proteins
RNA/Protein synthesis	Couples in cytoplasm	Similar with eukaryotes	RNA synthesis Inside nucleus/ Protein synthesis in cytoplasm
Ribosomes	50S+ 30S	60S + 40S	60S + 40S
Organelles	Absent	Present	Numerous
Cell movement	Flagella	Gliding and flagella	Flagella and cilia
Organization	Usually single cell	Single and colony	Single, colonial and multicellular
Cell division	Binary fission	Binary fission	Mitosis and meiosis
Examples	Bacteria and Archaea	Dinoflagellate, Protozoa	Fungi, plants and animals

Origin of Eukaryotic cell:

Endosymbiont theory: Two eukaryotic organelles believed to be the descendants of the endosymbiotic prokaryotes. The ancestors of the eukaryotic cell engulfed a bacterium and the bacteria continued to function inside the host cell.

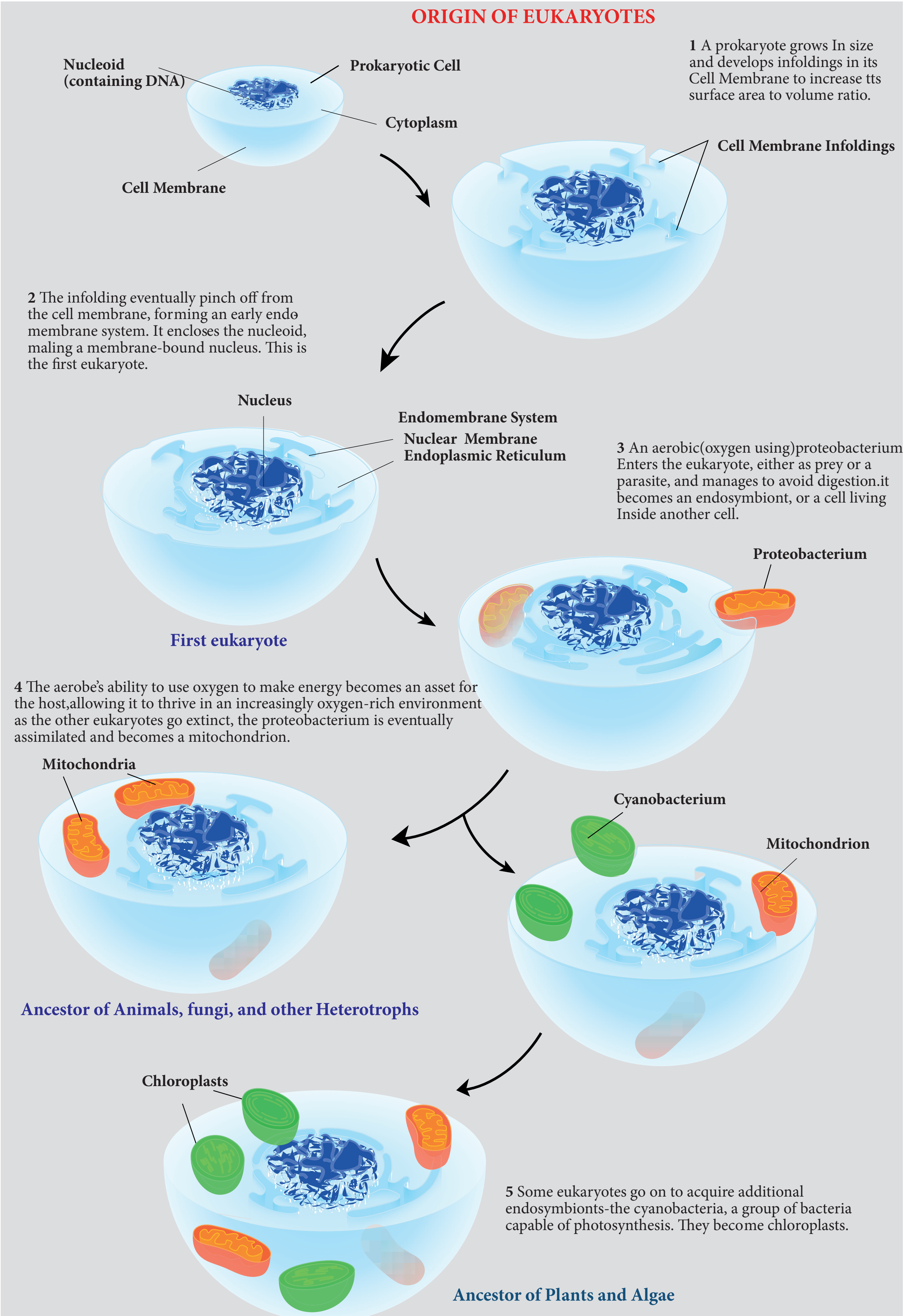


Figure 6.7: A model of endosymbiotic theory

The first cell might have evolved approximately 3.8 billion years ago. The primitive cell would have been similar to present day protists (Figure 6.7).

6.5. Plant and Animal cell

6.5.1 Ultra Structure of Eukaryotic Cell

The eukaryotic cell is highly distinct in its organisation. It shows several variations in different organisms. For instance, the eukaryotic cells in plants and animals vary greatly (Figure 6.8).

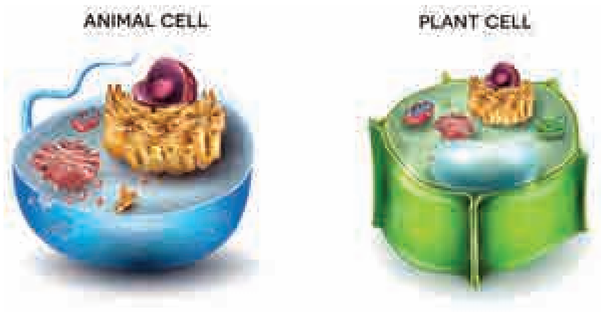


Figure 6.8: Animal and Plant cell

Animal Cell

Animal cells are surrounded by cell membrane or plasma membrane. Inside this membrane the gelatinous matrix called **protoplasm** is seen to contain nucleus and other organelles which include the endoplasmic reticulum, mitochondria, golgi bodies, centrioles, lysosomes, ribosomes and cytoskeleton.

Plant cell

A typical plant cell has prominent cell wall, a large central vacuole and plastids in addition to other organelles present in animal cell (Figure 6.9 and 6.10).

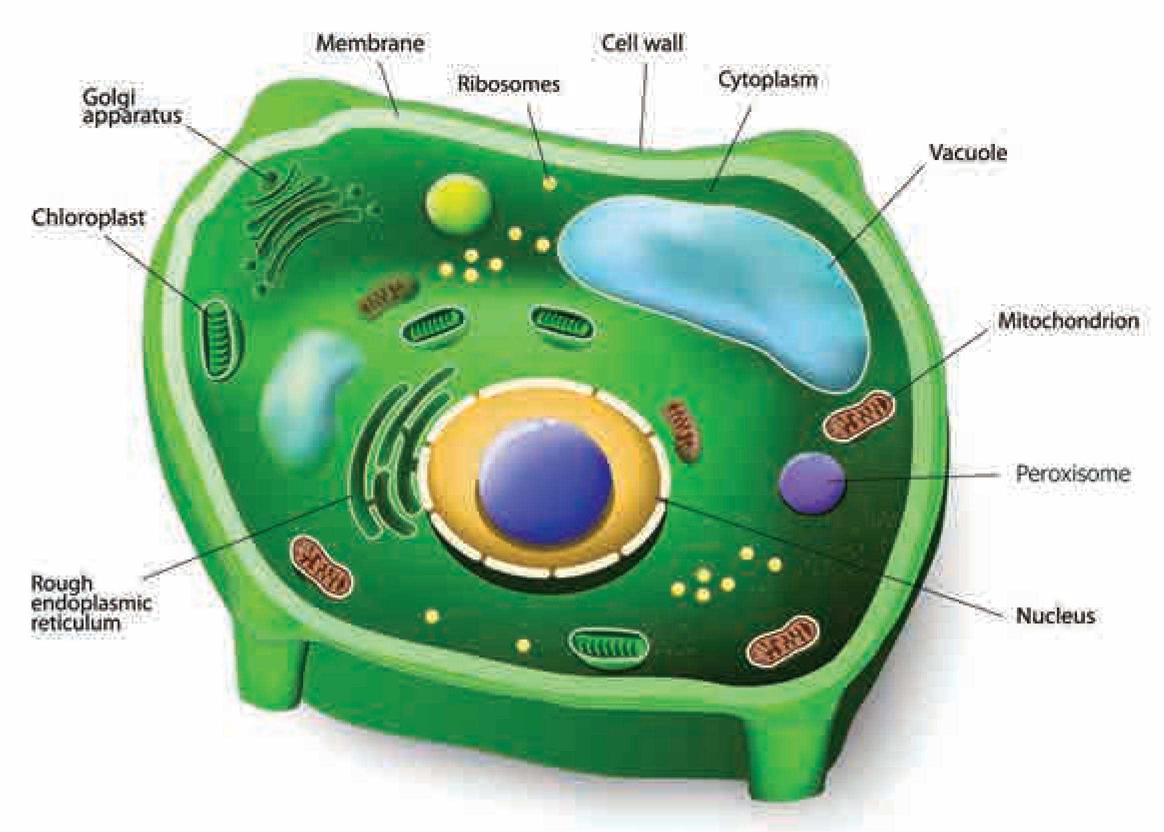


Figure 6.9: Ultra Structure of Plant Cell

Difference between plant and animal cells

S. No	Plant cell	Animal Cell
1	Usually they are larger than animal cells	Usually smaller than plant cells
2	Cell wall present in addition to plasma membrane and consists of middle lamellae, primary and secondary walls	Cell wall absent
3	Plasmodesmata present	Plasmodesmata absent
4	Chloroplast present	Chloroplast absent
5	Vacuole large and permanent	Vacuole small and temporary
6	Tonoplast present around vacuole	Tonoplast absent
7	Centrioles absent except motile cells of lower plants	Centrioles present
8	Nucleus present along the periphery of the cell	Nucleus at the centre of the cell
9	Lysosomes are rare	Lysosomes present
10	Storage material is starch grains	Storage material is a glycogen granules

6.5.2 Protoplasm

Protoplasm is the living content of the cell that is surrounded by plasma membrane. It is a colourless material that exists throughout the cell together with the cytoplasm, nucleus and other organelles. Protoplasm is composed of a mixture of small particles, such as ions, amino acids, monosaccharides, water, macromolecules like nucleic acids, proteins, lipids and polysaccharides. It appears colourless, jelly like gelatinous, viscous elastic and granular. It appears foamy due to the presence of large number of vacuoles. It responds to the stimuli like heat, electric shock, chemicals and so on.

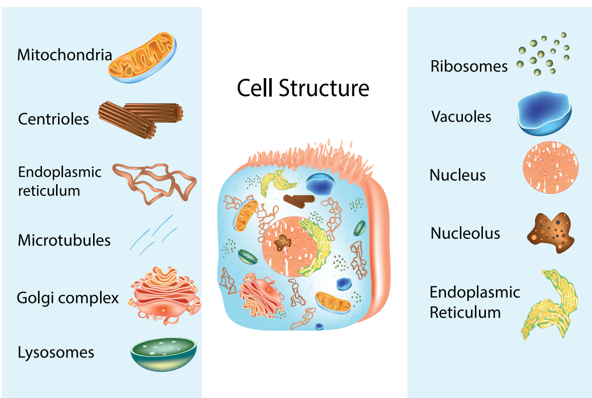


Figure 6.10: Cell structure and components

6.5.3 Cell Wall

Cell wall is the outermost protective cover of cell. It is present in bacteria, fungi and plants whereas it is absent in animal cell. It was first observed by **Robert Hooke**. It is an actively growing portion. It is made up of different complex material in various organism. In bacteria it is composed of peptidoglycan, in fungi chitin and fungal cellulose, in algae cellulose, galactans and mannans. In plants it is made up of cellulose, hemicellulose, pectin, lignin, cutin, suberin and silica.

In plant, cell wall shows three distinct regions (a) Primary wall (b) Secondary wall (c) Middle lamellae (Figure 6.11).

a. Primary wall

It is the first layer inner to middle lamellae, primarily consisting of loose network of cellulose microfibrils in a gel matrix. It is thin, elastic and extensible. In most plants the microfibrils are made up of cellulose oriented differently based on shape and thickness of the wall. The matrix of the primary wall is composed of hemicellulose, pectin, glycoprotein and water. Hemicellulose binds the microfibrils with matrix and glycoproteins control the orientation of microfibrils while pectin serves as filling material of the matrix. Cells such as parenchyma and meristems have only primary wall.

b. Secondary wall

Secondary wall is laid during maturation. It plays a key role in determining the shape of a cell. It is thick, inelastic and is made up of cellulose and lignin. The secondary wall is divided into three sublayers termed as S_1, S_2 and S_3 where the cellulose microfibrils are compactly arranged with different orientation forming a laminated structure and the cell wall strength is increased.

c. Middle lamellae

It is the outermost layer made up of calcium and magnesium pectate, deposited at the time of cytokinesis. It is a thin amorphous layer which cements two adjacent cells. It is optically inactive (isotropic).

Plasmodesmata and Pits

Plasmodesmata act as a channel between the protoplasm of adjacent cells through which many substances pass through. Moreover, at few regions the secondary wall layer is laid unevenly whereas the primary wall and middle lamellae are laid continuously such regions are called **pits**. The pits of adjacent cells are opposite to each other. Each pit has a pit chamber and a pit membrane. The pit membrane has many minute pores and thus they are permeable. The pits are of two types namely simple and bordered pit.

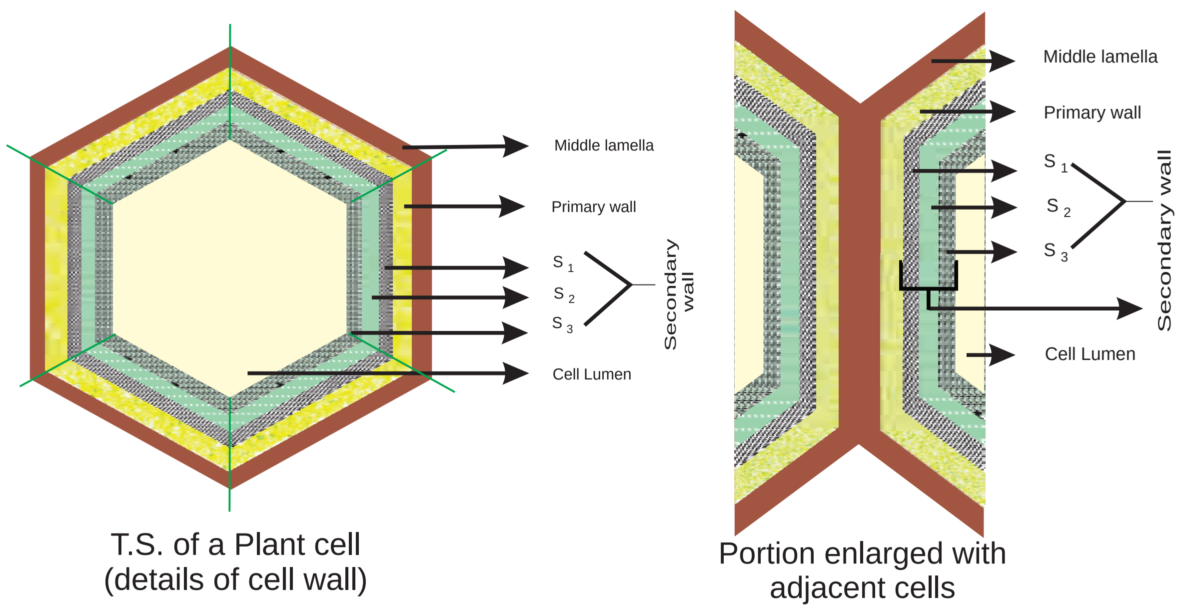


Figure 6.11: Plant cell wall

Functions of cell wall

The cell wall plays a vital role in holding several important functions given below

1. Offers definite shape and rigidity to the cell.
2. Serves as barrier for several molecules to enter the cells.
3. Provides protection to the internal protoplasm against mechanical injury.
4. Prevents the bursting of cells by maintaining the osmotic pressure.
5. Plays a major role by acting as a mechanism of defense for the cells.

6.5.4 Cell Membrane

The cell membrane is also called **cell surface** (or) **plasma membrane**. It is a thin structure which holds the cytoplasmic content called '**cytosol**'. It is extremely thin (less than 10nm).

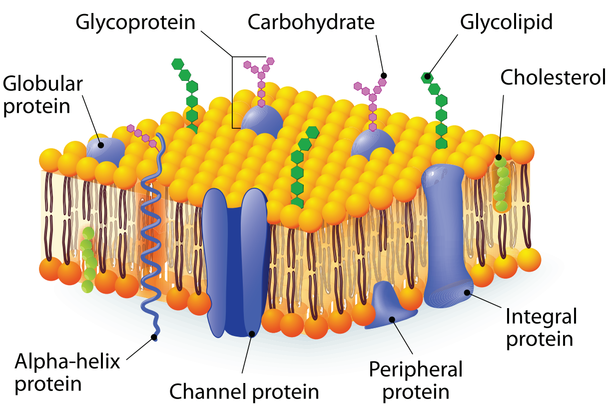


Figure 6.12: Model of Cell membrane

Fluid Mosaic Model

Jonathan Singer and **Garth Nicolson** (1972) proposed fluid mosaic model.

It is made up of lipids and proteins together with a little amount of carbohydrate. The lipid membrane is made up of phospholipid. The phospholipid molecule has a hydrophobic tail and hydrophilic head. The hydrophobic tail

DO YOU KNOW?

Water-loving polar molecule are called hydrophilic molecule. They have polar phosphate group responsible for attracting water.

Water hating non-polar molecule are called as hydrophobic molecule. They have fatty acid which is non-polar which cannot attract water

repels water and hydrophilic head attracts water. The proteins of the membrane are globular proteins which are found intermingled between the lipid bilayer most of which are projecting beyond the lipid bilayer. These proteins are called as **integral proteins**. Few are superficially attached on either surface of the lipid bilayer which are called as **peripheral proteins**. The proteins are involved in transport of molecules across the membranes and also act as enzymes, receptors (or) antigens.

The Carbohydrate molecules of cell membrane are short chain polysaccharides. These are either bound with '**glycoproteins**' or '**glycolipids**' and form a '**glyocalyx**' (Figure 6.12).

The movement of membrane lipids from one side of the membrane to the other side by vertical movement is called **flip flopping** or **flip flop movement**. This movement takes place more slowly than lateral diffusion of lipid molecule. The phospholipids can have flip flop movement because the phospholipids have smaller polar regions, whereas the proteins cannot flip flop because the polar region is extensive.

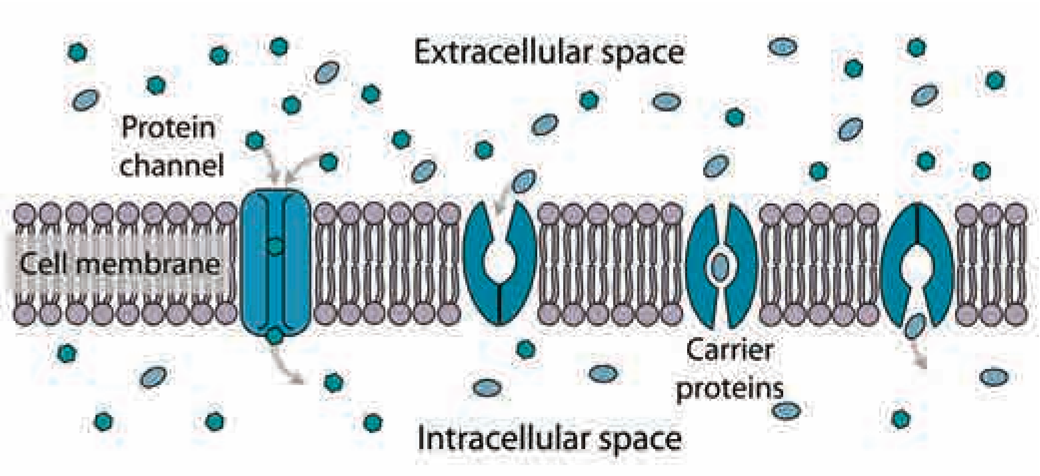


Figure 6.13: Transport of molecules through cell membrane

Function of Cell Membrane

The functions of the cell membrane is enormous which includes cell signalling, transporting nutrients and water, preventing unwanted substances entering into the cell, and so on.

Cell Transport

Cell membrane act as a channel of transport for molecules. The membrane is selectively permeable to molecules. It transports molecules through energy dependant process and energy independent process. The membrane proteins (channel and carrier) are involved in movement of ions and molecules across the membrane (Figure 6.13).

Endocytosis and Exocytosis

Cell surface membrane are able to transport individual molecules and ions. Through this special process Large quantity of solids and liquids are taken into cell (**endocytosis**) or out of cell (**exocytosis**) (Figure 6.14).

Endocytosis: During endocytosis the cell membrane infolds around the material to form a vacuole and brings it into

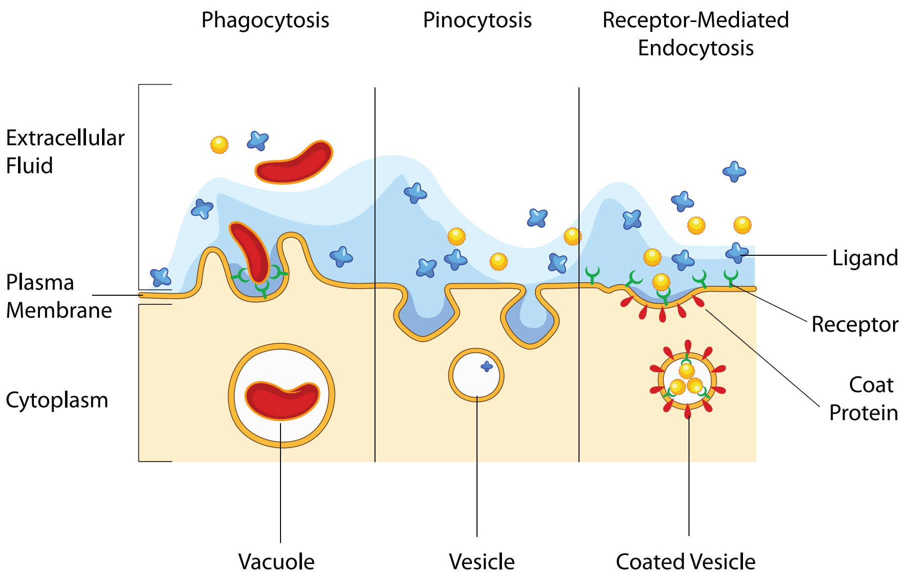


Figure 6.14: Endocytosis and exocytosis

cytoplasm. There are two types of endocytosis:

1. **Phagocytosis** – Solid Particles are engulfed by membrane, which folds around it and forms a vesicle. The enzymes digest the material and products are absorbed by cytoplasm.
2. **Pinocytosis** – Fluid droplets are engulfed by membrane, by forming vesicles around them.

Exocytosis: Vesicles fuse with plasma membrane and eject contents. This passage of material out of the cell is known as **exocytosis**. This material may be a secretion in the case of digestive enzymes, hormones or mucus.

Signal Transduction

The process by which the cell receive information from outside and respond is called **signal transduction**. Plants, fungi and animal cell use nitric oxide as one of the many signalling molecules. The cell membrane is the site of chemical interactions of signal transduction. Receptors receives the information from first messenger and transmit the message through series of membrane proteins. It activates second messenger which stimulates the cell to carry out specific function.

Cytoplasm

Cytoplasm is the main arena of various activities of a cell. It is the semifluid gelatinous substance that fills the cell. It is made up of eighty percent water and is usually clear and colourless. The cytoplasm is sometimes described as non nuclear content of protoplasm. The cytoplasm serves as a molecular soup where all the cellular organelles are suspended and bound together by a lipid bilayer plasma membrane. It constitutes dissolved nutrients, numerous salts and acids to dissolve waste products. It is a very good conductor of electricity. It gives support and protection to the cell organelles. It helps movement of the cellular materials around the cell through a process called **cytoplasmic streaming**. Further, most cellular activities such as many metabolic pathways including glycolysis and cell division occur in cytoplasm.

6.6 Cell Organelles

6.6.1 Endomembrane System

The system of membranes in a eukaryotic cell, comprising the plasma membrane, nuclear membrane, endoplasmic reticulum, golgi apparatus, lysosomes and vacuolar membranes (tonoplast). Endomembranes are made up of phospholipids with embedded proteins that are similar to cell membrane which occur within the cytoplasm. The endomembrane system is evolved from the inward growth of cell membrane in the ancestors of the first eukaryotes (Figure 6.15).

6.6.2 Endoplasmic Reticulum

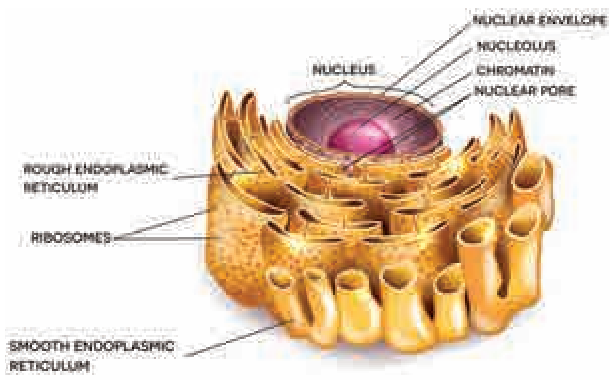


Figure 6.15: Structure of Endoplasmic reticulum

The largest of the internal membranes is called the **endoplasmic reticulum** (ER). The name endoplasmic reticulum was given by **K.R. Porter** (1948). It consists of double membrane. Morphologically the structure of endoplasmic reticulum consists of:

1. **Cisternae** are long, broad, flat, sac like structures arranged in parallel bundles or stacks to form lamella. The space between membranes of cisternae is filled with fluid.
2. **Vesicles** are oval membrane bound vacuolar structure.
3. **Tubules** are irregular shape, branched, smooth walled, enclosing a space

Endoplasmic reticulum is associated with nuclear membrane and cell surface membrane. It forms a network in cytoplasm and gives mechanical support to the cell. Its chemical environment enables protein folding and undergo modification necessary for their function. Misfolded proteins are pulled out and are degraded in endoplasmic reticulum. When ribosomes are present in the outer surface of the membrane it is called as **rough endoplasmic reticulum(RER)**, when the ribosomes are absent in the endoplasmic reticulum it is called as **smooth Endoplasmic reticulum(SER)**. Rough endoplasmic reticulum is involved in protein synthesis and smooth endoplasmic reticulum are the sites of lipid synthesis. The smooth endoplasmic reticulum contains enzymes that detoxify lipid soluble drugs, certain chemicals and other harmful compounds.

6.6.3 Golgi Body (Dictyosomes)

In 1898, **Camillo Golgi** visualized a netlike reticulum of fibrils near the nucleus, were named as **Golgi bodies.** In plant cells they are found as smaller vesicles termed as **dictyosomes**. Golgi apparatus is a stack of flat membrane enclosed sacs. It consist of cisternae, tubules, vesicles and golgi vacuoles. In plants the cisternae are 10-20 in number placed in piles separated from the cytoplasm of the cell. Peripheral edge of cisternae forms a network of tubules and vesicles. Tubules interconnect cisternae and are 30-50nm in dimension. Vesicles are large round or concave sac. They are pinched off from the tubules.They are smooth/secretary or coated type. Golgi vacuoles are large spherical filled with granular or amorphous substance, some function like lysosomes. The Golgi apparatus compartmentalises a series of steps leading to the production of functional protein.

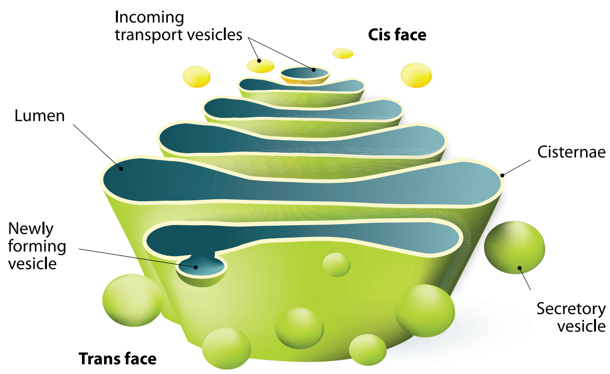


Figure 6.16: Structure of Golgi apparatus

Small pieces of rough endoplasmic reticulum are pinched off at the ends to form small vesicles. A number of these vesicles then join up and fuse together to make a Golgi body. Golgi complex plays a major role in post translational modification of proteins and glycosidation of lipids (Figure 6.16 and 6.17).

Functions:

- Glycoproteins and glycolipids are produced
- Transporting and storing lipids.

- Formation of lysosomes.
- Production of digestive enzymes.
- Cell plate and cell wall formation
- Secretion of Carbohydrates for the formation of plant cell walls and insect cuticles.
- **Zymogen granules** (proenzyme/pre-cursor of all enzyme) are synthesised.

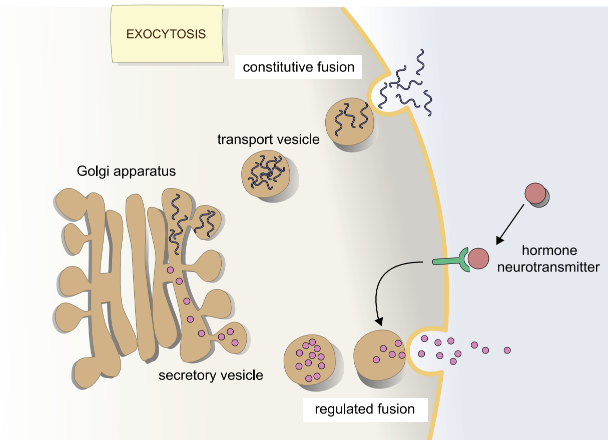


Figure 6.17: Exocytosis

6.6.4 Mitochondria

It was first observed by **A. Kolliker** (1880). **Altmann** (1894) named it as Bioplasts. **Later Benda** (1897, 1898), named as mitochondria. They are ovoid, rounded, rod shape and pleomorphic structures. Mitochondrion consists of double membrane, the outer and inner membrane. The outer membrane is smooth, highly permeable to small molecules and it contains proteins called **Porins**, which form channels that allows free diffusion of molecules smaller than about 1000 daltons and the inner membrane divides the mitochondrion into two compartments, outer chamber between two membranes and the inner chamber filled with matrix.

The inner membrane is convoluted (infoldings), called **crista** (plural: cristae). Cristae contain most of the enzymes for electron transport system. Inner chamber of the mitochondrion is filled with proteinaceous material called **mitochondrial matrix**. The inner membrane consists of stalked particles called **elementary particles** or **Fernandez Moran particles**, F1 particles or Oxysomes. Each particle consists of a base, stem and a round head. In the head ATP synthase is present for oxidative phosphorylation. Inner membrane is impermeable to most ions, small molecules and maintains the proton gradient that drives oxidative phosphorylation (Figure 6.18).

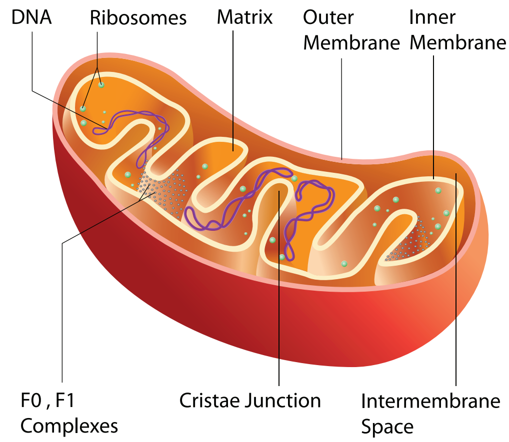


Figure 6.18: Structure of Mitochondria

Mitochondria contain 73% of proteins, 25-30% of lipids, 5-7 % of RNA, DNA (in traces) and enzymes (about 60 types). Mitochondria are called **Power house of a cell**, as they produce energy rich ATP.

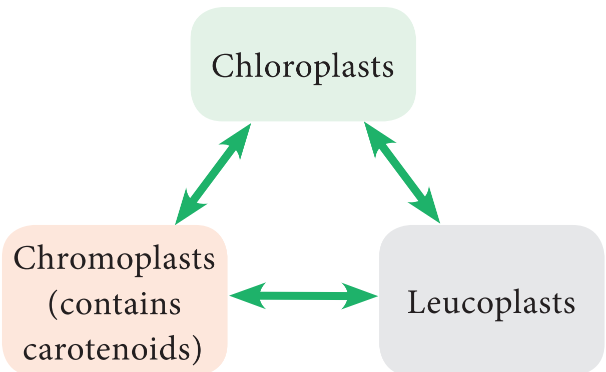
All the enzymes of Kreb's cycle are found in the matrix except succinate dehydrogenase. Mitochondria consist of circular DNA and 70S ribosome. They multiply by fission and replicates by strand displacement model. Because of the presence of DNA it is semi-autonomous organelle. Unique characteristic of mitochondria is that they are inherited from female parent only. Mitochondrial DNA comparisons are used to trace human origins. Mitochondrial DNA is used to track and date recent evolutionary time because it mutates 5 to 10 time faster than DNA in the nucleus.

6.6.5 Plastids

The term plastid is derived from the Greek word ***Platikas*** (formed/moulded) and used by **A.F.U. Schimper** in 1885. He classified plastids into following types according to their structure, pigments and function. Plastids multiply by fission.

Plastids	
Chromoplasts	**Leucoplasts**
(Coloured Plastids)	(Colourless Plastids store food materials)
Chloroplast Occurs in green algae and higher plants Pigments chlorophyll *a* and *b*	**Amyloplast** – stores – starch
Phaeoplast Brown algae and dinoflagellates Pigment fucoxanthin	**Elaioplast** – store – lipids (oils) Seed of monocot and dicots.
Rhodoplast Red algae Pigment Phycoerythrin	**Aleuroplast** (or) **Proteoplast** store – Protein

According to Schimper, different kind of plastids can transform into one another.



6.6.6 Chloroplast

Chloroplasts are vital organelle found in green plants. Chloroplast has a double membrane the outer membrane and the inner membrane separated by a space called **periplastidial space**. The space enclosed by the inner membrane of chloroplast is filled with gelatinous matrix, lipo-proteinaceous fluid called **stroma**. Inside the stroma there is flat interconnected sacs called **thylakoid**. The membrane of thylakoid enclose a space called **thylakoid lumen**.

Grana (singular: Granum) are formed when many of these thylakoids are stacked together like pile of coins. Light is absorbed and converted into chemical energy in the granum, which is used in stroma to prepare carbohydrates. Thylakoid contain chlorophyll pigments. The chloroplast contains osmophilic granules, 70s ribosomes, DNA (circular and non histone) and RNA. These chloroplast genome encodes approximately 30 proteins involved in photosynthesis including the components of photosystem I & II, cytochrome bf complex and ATP synthase. One of the subunits of Rubisco is encoded by chloroplast DNA. It is the major protein component of chloroplast stroma, single most abundant protein on earth. The thylakoid contain small, rounded photosynthetic units called **quantosomes**. It is a semi-autonomous organelle and divides by fission (Figure 6.19).

Functions:

- Photosynthesis
- Light reactions takes place in granum,
- Dark reactions take place in stroma,
- Chloroplast is involved in photo-respiration.

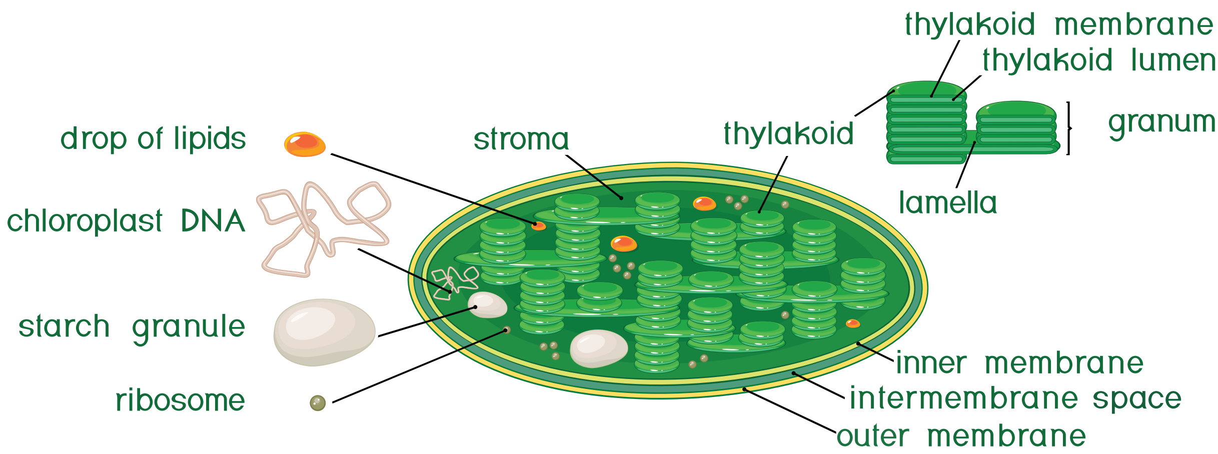


Figure 6.19: Structure of Chloroplast

6.6.7 Ribosome

Ribosomes were first observed by **George Palade** (1953) as dense particles or granules in the electron microscope. Electron microscopic observation reveals that ribosomes are composed of two rounded sub units, united together to form a complete unit. Mg^{2+} is required for structural cohesion of ribosomes. Biogenesis of ribosome are *denova* formation, auto replication and nucleolar origin. Each ribosome is made up of one small and one large sub-unit Ribosomes are the sites of protein synthesis in the cell. Ribosome is not a membrane bound organelle (Figure 6.20).

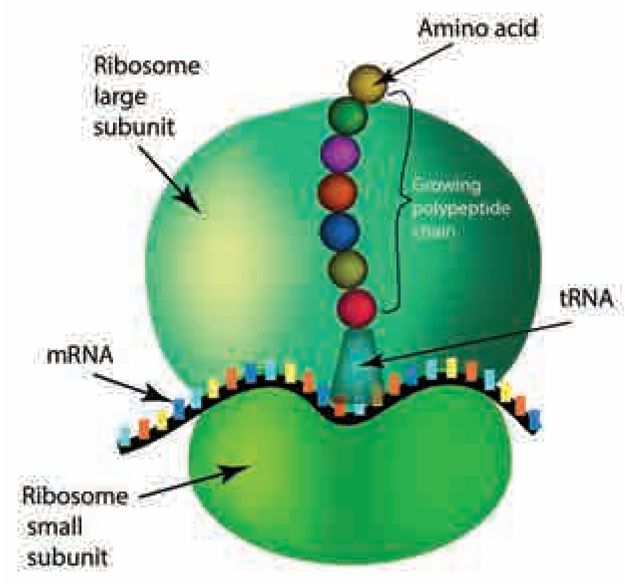


Figure 6.20: Structure of Ribosomes

Types of Ribosomes

70S Ribosomes (sub unit 30S and 50S)

3 RNA molecule
(i) 16SrRNA in 30S subunit
(ii) 23S and 5S in 50S large subunit

(Prokaryotic cells of Bluegreen algae Bacteria, Mitochondria and Chloroplast of many Algae and higher plants)

80S Ribosomes (sub units 40S and 60S)

4 RNA molecule
(i) 18SrRNA in 40S small subunit
(ii) 28S, 5.8S and 5S in larger 60S subunit

(Eukaryotic cells of Plants and animals)

DO YOU KNOW?

Svedberg unit (s).

The size of ribosomes and their subunits are usually given in Svedberg unit (named after Theoder Svedberg, Swedish Chemist Noble Laureate 1929), a measure of a particle size dependent on the speed with which particle sediment in the ultracentrifuge.

Ribosome consists of RNA and protein: RNA 60 % and Protein 40%. During protein synthesis many ribosomes are attached to the single mRNA is called **polysomes** or **polyribosomes**. The function of polysomes is the formation of several copies of a particular polypeptide during protein synthesis. They are free in non-protein synthesising cells. In protein synthesising cells they are linked together with the help of Mg^{2+} ions.

6.6.8 Lysosomes (Suicidal Bags of Cell)

Lysosomes were discovered by **Christian de Duve** (1953), these are known as **suicidal bags**. They are spherical bodies enclosed by a single unit membrane. They are found in eukaryotic cell. Lysosomes are small vacuoles formed when small pieces of golgi body are pinched off from its tubules.

They contain a variety of hydrolytic enzymes, that can digest material within the cell. The membrane around lysosome prevent these enzymes from digesting the cell itself (Figure 6.21).

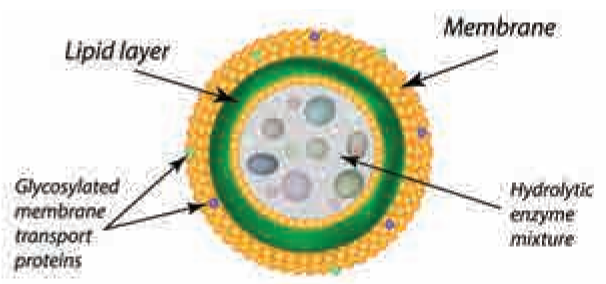


Figure 6.21: Structure of Lysosome

Functions:

- **Intracellular digestion:** They digest carbohydrates, proteins and lipids present in cytoplasm.
- **Autophagy:** During adverse condition they digest their own cell organelles like mitochondria and endoplasmic reticulum
- **Autolysis:** Lysosome causes self destruction of cell on insight of disease they destroy the cells.
- **Ageing:** Lysosomes have autolytic enzymes that disrupts intracellular molecules.
- **Phagocytosis:** Large cells or contents are engulfed and digested by macrophages, thus forming a phagosome in cytoplasm. These phagosome fuse with lysosome for further digestion.
- **Exocytosis:** Lysosomes release their enzymes outside the cell to digest other cells (Figure 6.22).

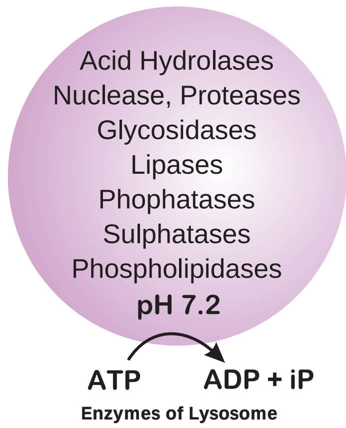


Figure 6.22: Enzymes of Lysosome

6.6.9 Peroxisomes

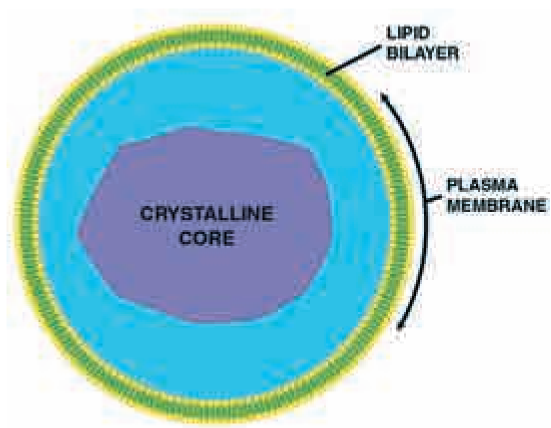


Figure 6.23: Structure of Peroxisome

Peroxisomes were identified as organelles by **Christian de Duve** (1967). Peroxisomes are small spherical bodies and single membrane bound organelle. It takes part in photorespiration and associated with glycolate metabolism. In plants, leaf cells have many peroxisomes. It is also commonly found in liver and kidney of mammals. These are also found in cells of protozoa and yeast (Figure 6.23).

6.6.10 Glyoxysomes

Glyoxysome was discovered by **Harry Beevers** (1961). Glyoxysome is a single membrane bound organelle. It is a sub cellular organelle and contains enzymes of glyoxylate pathway. β-oxidation of fatty acid occurs in glyoxysomes of germinating seeds Example: Castor seeds.

6.6.11 Microbodies

Eukaryotic cells contain many enzyme bearing membrane enclosed vesicles called **microbodies**. They are single unit membrane bound cell organelles: Example: peroxisomes and glyoxysomes.

6.6.12 Sphaerosomes

It is spherical in shape and enclosed by single unit membrane. Example: Storage of fat in the endosperm cells of oil seeds.

6.6.13 Centrioles

Centriole consist of nine triplet peripheral fibrils made up of tubulin. The central part of the centriole is called **hub**, is connected to the tubules of the peripheral triplets by radial spokes (9+0 pattern). The centriole form the basal body of cilia or flagella and spindle fibers which forms the spindle apparatus in animal cells. The membrane is absent in centriole (non-membranous organelle) (Figure 6.24).

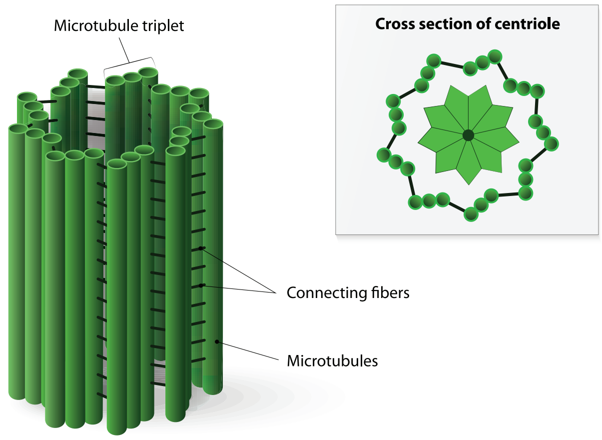


Figure 6.24: Structure of Centriole

6.6.14 Vacuoles

In plant cells vacuoles are large, bounded by a single unit membrane called **Tonoplast**. The vacuoles contain cell sap, which is a solution of sugars, amino acids, mineral salts, waste chemical and anthocyanin pigments. Beetroot cells contains anthocyanin pigments in their vacuoles. Vacuoles accumulate products like tannins. The osmotic expansion of a cell kept in water is chiefly regulated by vacuole and the water enters the vacuoles by osmosis.

The major function of plant vacuole is to maintain water pressure known as **turgor pressure**, which maintains the plant structure. Vacuoles organises itself into a storage/sequestration compartment. Example: Vacuoles store, most of the sucrose of the cell.

i. Sugar in *Sugar beet* and *Sugar cane.*
ii. Malic acid in Apple.
iii. Acids in *Citrus* fruits.
iv. Flavonoid pigment Cyanidin 3 rutinoside in the petals of *Antirrhinum*.

v. Tannins in *Mimosa pudica*.

vi. Raphide crystals in *Dieffenbachia*.

vii. Heavy metals in Mustard (*Brassica*).

viii. Latex in Rubber tree and *Dandelion stem*.

Cell Inclusions

The cell inclusions are the non-living materials present in the cytoplasm. They are organic and inorganic compounds.

Inclusions in prokaryotes

In prokaryotes, reserve materials such as phosphate granules, cyanophycean granules, glycogen granules, poly β-hydroxy butyrate granules, sulphur granules, carboxysomes and gas vacuoles are present. Inorganic inclusions in bacteria are polyphosphate granules (volutin granules) and sulphur granules. These granules are also known as **metachromatic granules.**

Inclusions in Eukaryotes

- Reserve food materials: Starch grains, glycogen granules, aleurone grains, fat droplets
- Secretions in plant cells are essential oil, resins, gums, latex and tannins
- **Inorganic crystals** – plant cell have calcium carbonate, calcium oxalate and silica
- **Cystolith** – hypodermal leaf cells of *Ficus bengalensis*, calcium carbonate
- **Sphaeraphides** – star shaped calcium oxalate, *Colocasia*
- **Raphides** – calcium oxalate, *Eichhornia*
- **Prismatic crystals** – calcium oxalate, dry scales of *Allium cepa*

6.7. Nucleus

Nucleus is an important unit of cell which control all activities of the cell. Nucleus holds the hereditary information. It is the largest among all cell organelles. It may be spherical, cuboidal, ellipsoidal or discoidal.

It is surrounded by a double membrane structure called **nuclear envelope**, which has the inner and outer membrane. The inner membrane is smooth without ribosomes and the outer membrane is rough by the presence of ribosomes and is continues with irregular and infrequent intervals with the endoplasmic reticulum. The membrane is perforated by pores known as **nuclear pores** which allows materials such as mRNA, ribosomal units, proteins and other macromolecules to pass in and out of the nucleus. The pores enclosed by circular structures called **annuli**. The pore and annuli forms the **pore complex**. The space between two membranes is called **perinuclear space**.

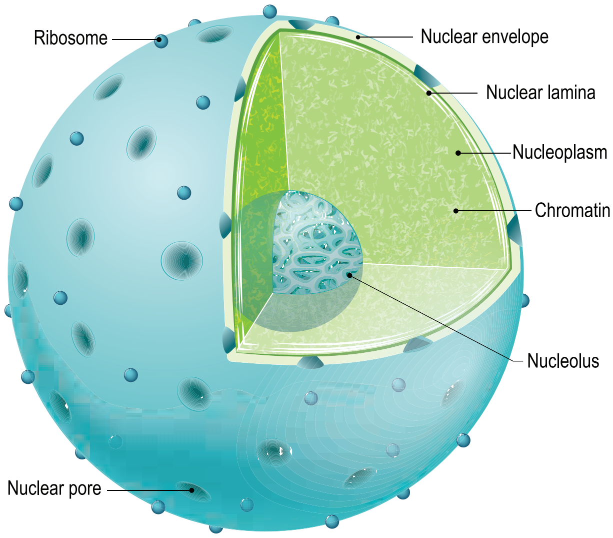


Figure 6.25: Structure of a Nucleus

Nuclear space is filled with **nucleoplasm**, a gelatinous matrix has uncondensed

chromatin network and a conspicuous **nucleoli**. The chromatin network is the uncoiled, indistinct and remain thread like during the interphase. It has little amount of RNA and DNA bound to histone proteins in eukaryotic cells (Figure 6.25).

> **DO YOU KNOW?**
>
> **Chromatin** is a viscous gelatinous substance that contains DNA, histone & non–histone proteins and RNA. H1, H2A, H2B, H3 and H4 are the different histones found in chromatin. It is formed by a series of repeated units called nucleosomes. Each nucleosome has a core of eight histone subunits.

During cell division chromatin is condensed into an organized form called **chromosome**. The portion of Eukaryotic chromosome which is transcribed into mRNA contains active genes that are not tightly condensed during interphase is called **Euchromatin**. The portion of a Eukaryotic chromosome that is not transcribed into mRNA which remains condensed during interphase and stains intensely is called **Heterochromatin.** I **Nucleolus** is a small, dense, spherical structure either present singly or in multiples inside nucleus and it's not membrane bound. Nucleoli possesses genes for rRNA and tRNA.

Functions of the nucleus

- Controlling all the cellular activities
- Storing the genetic or hereditary information.
- Coding the information in the DNA for the production of enzymes and proteins.
- DNA duplication and transcription takes place in the nucleus.
- In nucleolus ribosomal biogenesis takes place.

6.7.1 Chromosomes

Strasburger (1875) first reported its present in eukaryotic cell and the term 'chromosome' was introduced by **Waldeyer** in 1888. **Bridges** (1916) first proved that chromosomes are the physical carriers of genes. It is made up of DNA and associated proteins.

Structure of chromosome

The chromosomes are composed of thread like strands called **chromatin** which is made up of DNA, protein and RNA. Each chromosome consists of two symmetrical structures called **chromatids**. During cell division the chromatids forms well organized chromosomes with definite size and shape. They are identical and are called **sister chromatids**. A typical chromosome has narrow zones called **constrictions**. There are two types of constrictions namely primary constriction and secondary constriction. The **primary constriction** is made up of **centromere** and kinetochore. Both the chromatids are united at centromere, whose number varies. The **monocentric** chromosome has one centromere and the **polycentric** chromosome has many centromeres. The centromere contains a complex system of protein fibres called **kinetochore**. Kinetochore is the region of chromosome which is attached to the spindle fibre during mitosis.

Besides primary there are **secondary constrictions,** represented with few occurrence. Nucleoli develop from these secondary constrictions are called **nucleolar organizers**. Secondary constrictions contains the genes for ribosomal RNA which induce the formation of nucleoli and are called **nucleolar organizer regions** (Figure 6.26).

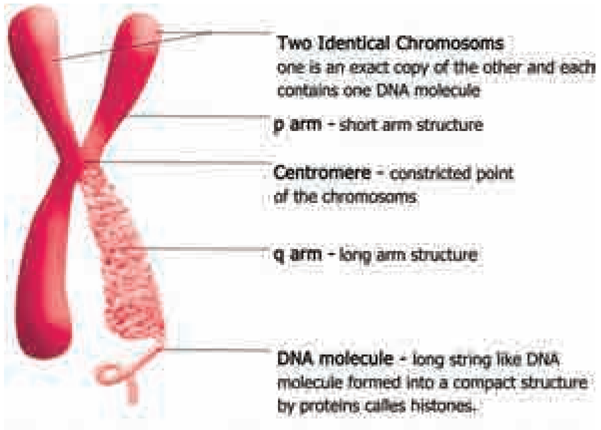


Figure 6.26: Structure of a Chromosome

A **satellite** or SAT Chromosome are short chromosomal segment or rounded body separated from main chromosome by a relatively elongated secondary constriction. It is a morphological entity in certain chromosomes.

Based on the position of centromere, chromosomes are called **telocentric** (terminal centromere), **Acrocentric** (terminal centromere capped by telomere), **Sub metacentric** (centromere subterminal) and **Metacentric** (centromere median). The eukaryotic chromosomes may be rod shaped (telocentric and acrocentric), L-shaped (sub-metacentric) and V-shaped (metacentric) (Figure 6.27).

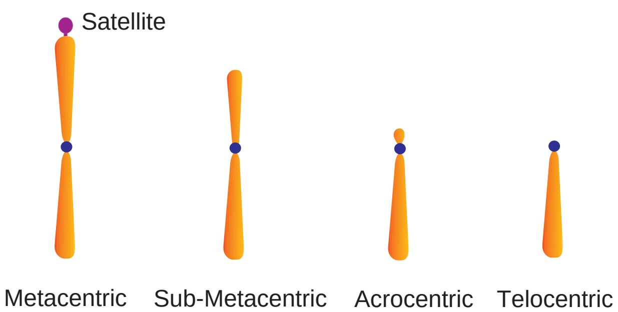


Figure 6.27: Types of chromosomes based on centromere

DO YOU KNOW?

Chromonema fiber: It is a chromatin fibre, 100 – 130 nm in diameter thought to be an element of higher order packing of chromatin within chromosome. During prophase the chromosomal material becomes visible as very thin filaments called chromonemata, which is called as chromatids in early stages of condensation. Chromatid and chromonema are the two names for the same structure a single linear DNA molecule with its associated proteins

Chromomeres: Chromomeres are bead like accumulations of chromatin material which are visible along interphase chromosomes. They can be seen in polytene chromosomes. At metaphase they are not visible.

Telomere is the terminal part of chromosome. It offers stability to the chromosome. DNA of the telomere has specific sequence of nucleotides. Telomere in all eukaryotes are composed of many repeats of short DNA sequences (**5'TTAGGG3'** sequence in *Neurospora crassa* and human beings). Maintenance of telomeres appears to be an important factor in determining the life span and reproductive capacity of cells so studies of telomeres and telomerase have the promise of providing new insights into conditions such as ageing and cancer. Telomeres prevents the fusion of chromosomal ends with one another.

Holocentric chromosomes have centromere activity distributed along the whole surface of the chromosome during mitosis. Holocentric condition can be seen in *Caenorhabditis elegans* (nematode) and many insects. There are three types of centromere in eukaryotes. They are as follows:

Point centromere: the type of centromere in which the kinetochore is assembled as a result of protein recognition of specific DNA sequences. Kinetochores assembled on point centromere bind a single microtubule. It is also called as **localized centromere**. It occurs in budding yeasts

Regional centromere: In regional centromere where the kinetochore is assembled on a variable array of repeated DNA sequences. Kinetochore assembled on regional centromeres bind multiple microtubules. It occurs in fission yeast cell, humans and so on.

Holocentromere- The microtubules bind all along the mitotic chromosome. Example: *Caenorhabditis elegans* (nematode) and many insects.

Based on the functions of chromosome it can be divided into **autosomes** and **sex chromosomes**.

Autosomes are present in all cells controlling somatic characteristics of an organism. In human diploid cell, 44 chromosomes are autosomes whereas two are sex chromosomes. Sex chromosomes are involved in the determination of sex.

Special types of chromosomes are found only in certain special tissues. These chromosomes are larger in size and are called **giant chromosomes** in certain plants and they are found in the suspensors of the embryo. The polytene chromosome and lamp brush chromosome occur in animals and are also called as **giant chromosomes.**

Polytene chromosomes observed in the salivary glands of Drosophila (fruit fly) by **C.G. Balbiani** in 1881. In larvae of many flies, midges (*Dipthera*) and some insects the interphase chromosomes duplicates and reduplicates without nuclear division. A single chromosome which is present in multiple copies form a structure called **polytene chromosome** which can be seen in light microscope. They are genetically active. There is a distinct alternating dark bands and light inter-bands. About 95% of DNA are present in bands and 5% in inter-bands. The polytene chromosome has extremely large puff called **Balbiani rings** which is seen in Chironomous larvae. It is also known as **chromosomal puff**. Puffing of bands are the sites of intense RNA synthesis. As this chromosome occurs in the salivary gland it is known as **salivary gland chromosomes**. Polyteny is achieved by repeated replication of chromosomal DNA several times without nuclear division and the daughter chromatids aligned side by side and do not separate (called **endomitosis**). Gene expression, transcription of genes and RNA synthesis occurs in the bands along the polytene chromosomes. Maternal and paternal homologues remain associated side by side is called somatic pairing.

Lampbrush chromosomes occur at the diplotene stage of first meiotic prophase in oocytes of an animal **Salamandar** and in giant nucleus of the unicellular alga *Acetabularia*. It was first observed by **Flemming** in 1882. The highly condensed chromosome forms the chromosomal axis, from which lateral loops of DNA extend as a result of intense RNA synthesis.

6.8. Flagella

6.8.1 Prokaryotic Flagellum

Check your grasp ?

When E-coli are cultured in medium rich in glucose they lack flagella. When grown in nutritionally poor medium they possess flagella. What does this indicate about the value of flagella?

Flagella is essential to seek out a nutritionally more favourable environment

Bacterial flagella are helical appendages helps in motility. They are much thinner than flagella or cilia of eukaryotes. The filament contains a protein called **flagellin**. The structure consists of a basal body associated with cytoplasmic membrane and cell wall with short hook and helical filament. Bacteria rotates their helical flagella and propels rings present in the basal body which are involved in the rotary motor that spins the flagellum.

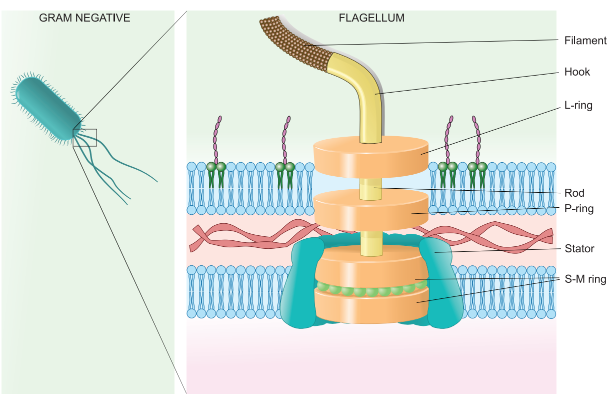


Figure 6.28: Structure of Bacterial Flagellum

Structure of flagella in Bacteria

The gram positive bacteria contain only two basal rings. S-ring is attached to the inside of peptidoglycan and M-ring is attached to the cell membrane. In Gram negative bacteria two pairs of rings proximal and distal ring are connected by a central rod. They are L-Lipopolysaccharide ring P-Peptidoglycan ring, S-Super membrane ring and M-membrane ring. The outer pair L and P rings is attached to cell wall and the inner pair S and M rings attached to cell membrane (Figure 6.28).

Mechanism of flagellar movement – proton motive force

In flagellar rotation only proton movements are involved and not ATP. Protons flowing back into the cell through the basal body rings of each flagellum drives it to rotate. These rings constitute the rotary motor. The proton motive force (The force derived from the electrical potential and the hydrogen ion gradient across the cytoplasmic membrane) drives the flagellar motor. For the rotation of flagellum the energy is derived from proton gradient across the plasma membrane generated by oxidative phosphorylation. In bacteria flagellar motor is located in the plasma membrane where the oxidative phosphorylation takes place. Therefore, plasma membrane is a site of generation of proton motive force.

6.8.2 Eukaryotic Flagellum– Cell Motility

Structure

Eukaryotic Flagella are enclosed by unit membrane and it arises from a basal body.

Flagella is composed of outer nine pairs of microtubules with two microtubules in its centre (9+2 arrangement). Flagella are microtubule projection of the plasma membrane. Flagellum is longer than cilium (as long as 200µm). The structure of flagellum has an axoneme made up microtubules and protein tubulin (Figure 6.29).

Movement

Outer microtubule doublet is associated with axonemal dynein which generates force for movement. The movement is ATP driven. The interaction between tubulin and dynein is the mechanism for the contraction of cilia and flagella. Dynein molecules uses energy from ATP to shift the adjacent microtubules. This movement bends the cilium or flagellum.

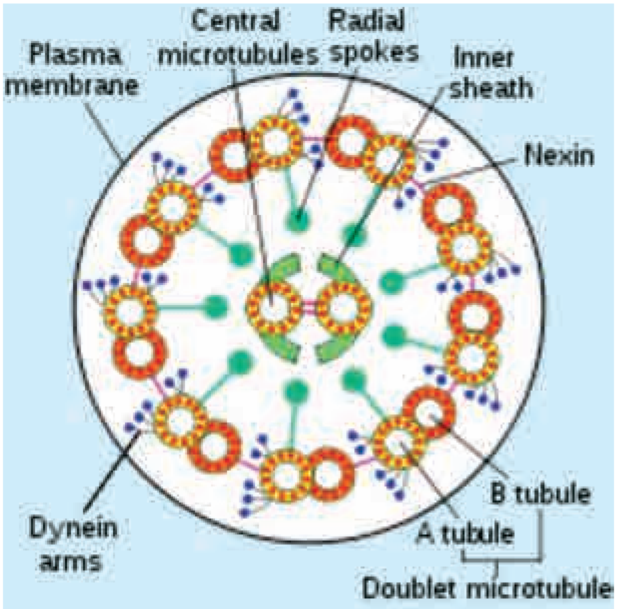


Figure 6.29: Structure of Eukaryotic flagellum

6.8.3 Cilia

Cilia (plural) are short cellular, numerous microtubule bound projections of plasma membrane. Cilium (singular) is membrane bound structure made up of basal body, rootlets, basal plate and shaft. The shaft or **axoneme** consists of nine pairs of microtubule doublets, arranged in a circle along the periphery with a two central tubules, **(9+2)** arrangement of microtubules is present. Microtubules are made up of tubulin. The motor protein **dynein** connects the outer microtubule pair and links them to the central pair. Nexin links the peripheral doublets of microtubules (Figure 6.30).

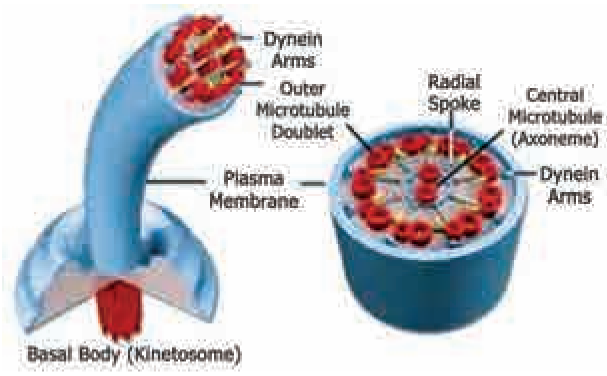


Figure 6.30: Structure of Cilia & flagella

6.9. Cytological Techniques

6.9.1 Preparation of Slides

There are different types of mounting based on the portion of a specimen to be observed

a. **Whole mount:** The whole organism or smaller structure is mounted over a slide and observed.

b. **Squash**: Is a preparation where the material to be observed is crushed/ squashed on to a slide so as to reveal their contents. Example: Pollen grains, mitosis and meiosis in root tips and flower buds to observe chromosomes.

c. **Smears:** Here the specimen is in the fluid (blood, microbial cultures etc.,) are scraped, brushed or aspirated from surface of organ. Example: Epithelial cells.

d. **Sections:** Free hand sections from a specimen and thin sections are selected, stained and mounted on a slide. Example: Leaf and stem of plants.

6.9.2 Recording the Observations

The observations made through a microscope can be recorded by hand diagrams or through microphotographs.

Hand diagrams: Hand diagrams are drawn using ordinary pencil by observing the slide and drawing manually.

Microphotograph: Images of structures observed through microscopes can be further magnified, projected and saved by attaching a camera to the microscope by a microscope coupler or eyepiece adaptor. Picture taken using a inbuilt camera in a microscope is called **microphotography** or **microphotograph**.

6.9.3 Staining Techniques

Staining is very important to observe different components of the cell. Each component of the cell has different affinity towards different stains. The technique of staining the cells and tissue is called '**histochemical staining**' or '**histochemistry**'.

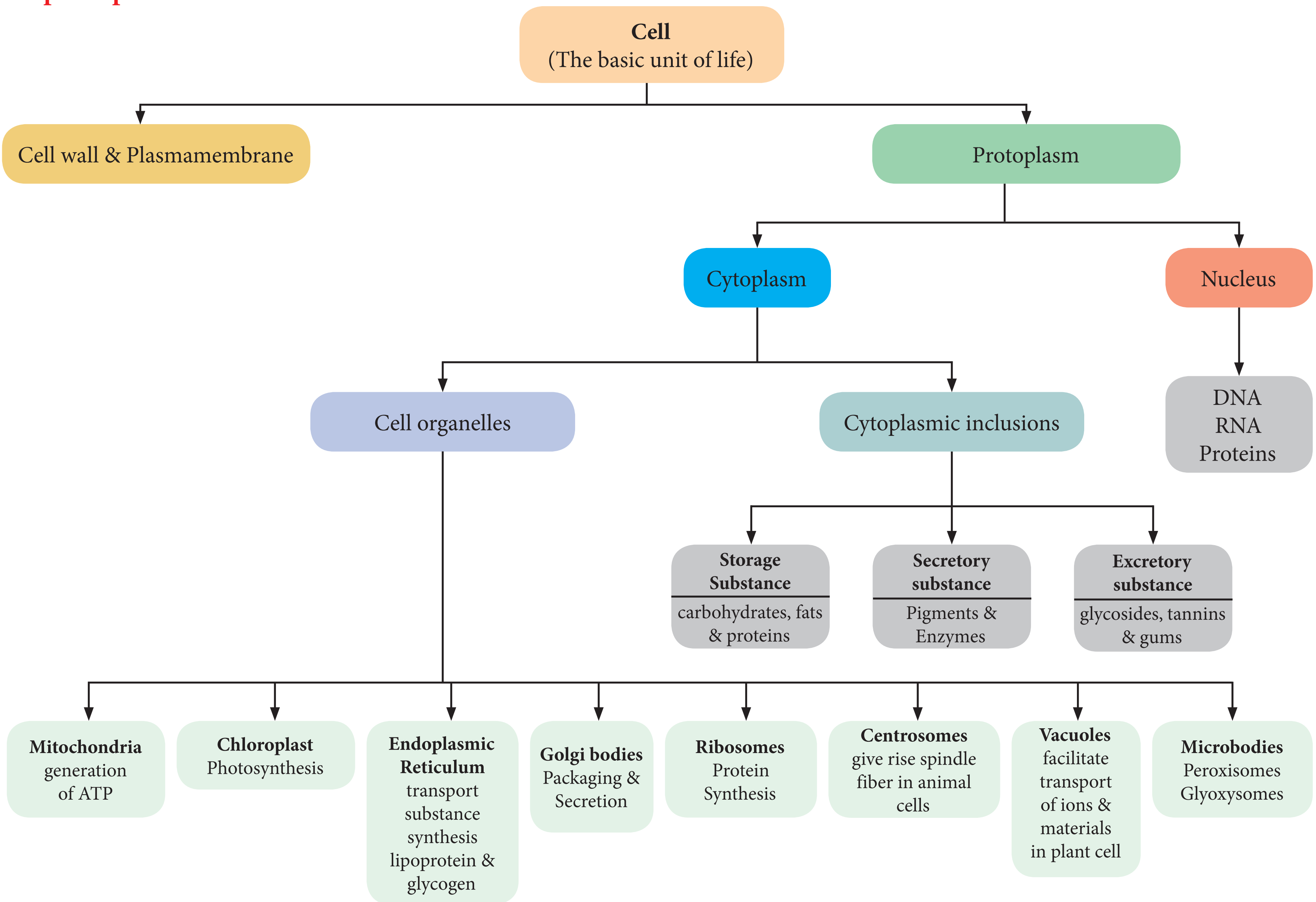
Common stains used in Histochemistry

S. No.	Stain	Colour of staining	Affinity
1.	Eosin	Pink, Red	Cytoplasm, cellulose
2.	Acetocarmine/ Haematoxylin	Pink/ Red	Nucleus, Chromosomes
3.	Methylene Blue	Blue	Nucleus
4.	Saffranine	Red	Cell wall (Lignin)
5.	Cotton blue	Blue	Fungal Hyphae
6.	Sudan IV, Sudan Black	Scarlet Red/Black	Lipids
7.	Coomasie brilliant Blue	Blue	Protein
8.	Janus Green	Greenish Blue	Mitochondria
9.	I_2KI	Bluish black to brown	Starch
10.	Toluidine blue	Blue, greenish blue	Xylem, Parenchyma & Epidermis

Summary

Cell is the fundamental unit of all organisms which was identified 300 years ago. Microscope offers scope for observing smaller objects and organisms. It works on the principle of light and lenses. Different microscope offers clarity in observing objects depending on the features to be observed. Micrometric techniques are used in measurement of microscopic objects. Electron microscopes are used in understanding the ultra-structural details of cell. Cell theory and doctrine states that all organism are made up of cell and it contains genetic material. Protoplasm theory explains nature and different properties of protoplasm. Cell size and shape differ from type of tissue or organs and organisms. Based on cellular organization and nuclear characters the

Concept Map


Cell
(The basic unit of life)
Cell wall & Plasmamembrane
Protoplasm
Cytoplasm
Nucleus
DNA
RNA
Proteins
Cell organelles
Cytoplasmic inclusions
Storage Substance
carbohydrates, fats & proteins
Secretory substance
Pigments & Enzymes
Excretory substance
glycosides, tannins & gums
Mitochondria
generation of ATP
Chloroplast
Photosynthesis
Endoplasmic Reticulum
transport substance synthesis lipoprotein & glycogen
Golgi bodies
Packaging & Secretion
Ribosomes
Protein Synthesis
Centrosomes
give rise spindle fiber in animal cells
Vacuoles
facilitate transport of ions & materials in plant cell
Microbodies
Peroxisomes
Glyoxysomes

organisms are classified into prokaryote, eukaryote and mesokaryote.

The eukaryotic cells originated by endosymbiosis of prokaryotic organism. Key difference between plant cell and animal cell is the cell wall. Protoplasm is the colourless mass includes the cytoplasm, cell organelles and nucleus. Cell wall is the outermost protective covering with three regions primary, secondary wall and middle lamellae. Cell membrane holds the cytoplasmic content called **cytosol**. Cytoplasm includes the matrix and the cell organelles excluding nucleus. Endomembrane system includes endoplasmic reticulum, golgi apparatus, chloroplast, lysosomes, vacuoles, nuclear membrane and plasma membrane. Nucleus is the control unit of the cell, it carries hereditary information. Chromosomes are made up of DNA and associated proteins. Bacterial flagella are made up of helical polymers of a protein called **flagellin**. Proton motive force are involved in flagellar rotation. In Eukaryotes flagella are made up microtubules and protein called **dynein** and **nexin** and the movement is driven by ATP. Cytological techniques include preparation of slides, staining and recording the observation.

5RKECJ

Evaluation

1. The two subunits of ribosomes remain united at critical ion level of
   a. Magnesium b. Calcium
   c. Sodium d. Ferrous
2. Sequences of which of the following is used to know the phylogeny
   a. mRNA b. rRNA
   c. tRNA d. Hn RNA
3. Many cells function properly and divide mitotically even though they do not have
   a. Plasma membrane b. cytoskeleton
   c. mitochondria d. Plastids
4. Keeping in view the fluid mosaic model for the structure of cell membrane, which one of the following statements is correct with respect to the movement of lipids and proteins from one lipid monolayer to the other
   a. Neither lipid nor proteins can flip-flop
   b. Both lipid and proteins can flip flop
   c. While lipids can rarely flip-flop proteins cannot
   d. While proteins can flip-flop lipids cannot
5. Match the columns and identify the correct option:

Column-I	Column-II
(a) Thylakoids	(i) Disc-shaped sacs in Golgi apparatus
(b) Cristae	(ii) Condensed structure of DNA
(c) Cisternae	(iii) Flat membranous sacs in stroma
(d) Chromatin	(iv) Infoldings in mitochondria

	(a)	(b)	(c)	(d)
(1)	(iii)	(iv)	(ii)	(i)
(2)	(iv)	(iii)	(i)	(ii)
(3)	(iii)	(iv)	(i)	(ii)
(4)	(iii)	(i)	(iv)	(ii)

6. Bring out the significance of phase contrast microscopy
7. State the protoplasm theory
8. Distinguish between prokaryotes and eukaryotes
9. Difference between plant and animal cell
10. Draw the ultra structure of plant cell

ICT Corner

Cell structure

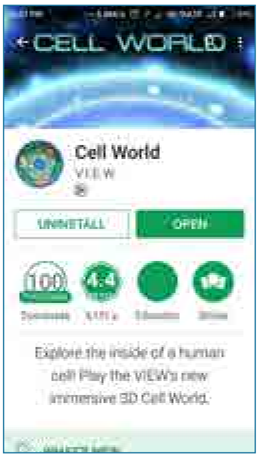
Cell-The unit of Life →

Steps

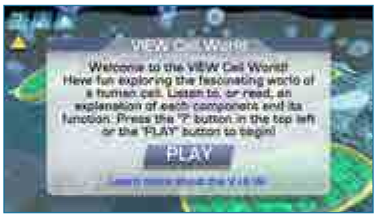
- Scan the QR code & install the app from Android app store
- Open the app & move the cell organelles by moving left bottom button
- Select the cell organelles by pointer
- Play the audio notes of cell organelles by click the right center button
- Use pointer & observe the structure of cell organelles

Activity

- Observe the structures of cell organelles and record it.

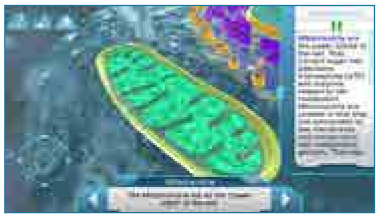


Step 1



Step 2

Step 3



Step 4

Step 5

URL:

https://play.google.com/store/apps/details?id=com.VIEW.CellWorld&hl=en

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* Pictures are indicative only

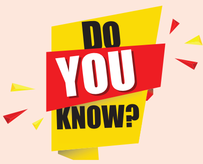
Chapter 7

Cell Cycle

Learning Objectives

The learner will be able to,

- *Outline the cell cycle and different stages in cell division.*
- *Recognise the importance of mitosis in the production of genetically identical cells.*
- *Have an insight on the significant of mitosis and meiosis.*
- *Understand how a single cell divides to a whole organism.*
- *Familiarize the behaviour of chromosomes in plants and animal cells during meiosis.*
- *Know about crossing over and random assortment of homologous chromosomes and its importance.*



Neurons can be replaced!

Stem cells in the human brain - most neurons are in G_0 and do not divide. As neurons and neuroglia die or injured they are replaced by neural stem cells

Chapter Outline

7.1 History of cell division
7.2 Cell cycle
7.3 Cell Division
7.4 Difference between Mitosis and Meiosis
7.5 Mitogens

One of the most important features of the living cells is their power to grow and divide. New cells are formed by the division of pre-existing cells. Cells increase in number by cell division. The parent cell divides and passes on genetic material to the daughter cells.

Edouard Van Beneden, a Belgian cytologist, embryologist and marine biologist. He was Professor of Zoology at the University of Liège. He contributed to cytogenetics by his works on the roundworm *Ascaris*. In his work he discovered how chromosomes organized meiosis (the production of gametes).

7.1 History of a Cell

Table 7.1: History of Cell

Year	Scientist	Events
1665	Robert Hooke	Coined word "Cell"
1670–74	Antonie van Leeuwenhoek	First living cells observed in microscope - Structure of bacteria
1831–33	Robert Brown	Presence of nucleus in cells of orchid roots
1839	Jan Evangelista Purkyne (J.E. Purkinje)	Coined "protoplasm"
1838–39	Schleiden & Schwann	Cell theory
1858	Rudolph Ludwig Carl Virchow	Cell theory '*omnis cellula e cellula*'
1873	Anton Schneider	Described chromosomes (Nuclear filaments) for the first time
1882	Walther Flemming	Coined the word mitosis; chromosome behaviour
1883	Edouard Van Beneden	Cell division in round worm
1888	Theodor Boveri	Centrosome; Chromosome Theory

7.1.1 The Role of the Nucleus

As studied earlier, the nucleus is the organising centre of the cell. The information in the nucleus is contained within structures called **chromosomes**. These uniquely:

- Control activities of the cell.
- Genetic information copied from cell to cell while the cell divides.
- Hereditary characters are passed on to new individuals when gametic cells fuse together in sexual reproduction.

7.1.2 Chromosomes

At the time when a nucleus divides, the chromosomes become compact and multicoiled structure. Only in this condensed state do the chromosomes become clearly visible in cells. All other times, the chromosomes are very long, thin, uncoiled threads. In this condition they give the stained nucleus the granular appearance. The granules are called **chromatin**.

The four important features of the chromosome are:

- **The shape of the chromosome is specific:** The long, thin, lengthy structured chromosome contains a short, constricted region called **centromere**. A centromere may occur anywhere along the chromosome, but it is always in the same position on any given chromosome.
- **The number of chromosomes per species is fixed:** for example the mouse has 40 chromosomes, the onion has 16 and humans have 46.

- **Chromosomes occur in pairs:** The chromosomes of a cell occur in pairs, called **homologous pairs**. One of each pair come originally from each parent. Example, human has 46 chromosomes, 23 coming originally from each parent in the process of sexual reproduction.
- **Chromosomes are copied:** Between nuclear divisions, whilst the chromosomes are uncoiled and cannot be seen, each chromosome is copied. The two identical structures formed are called **chromatids**.

7.1.3 Nuclear Divisions

There are two types of nuclear division, as **mitosis** and **meiosis**. In mitosis, the daughter cells formed will have the same number of chromosomes as the parent cell, typically diploid (2n) state. Mitosis is the nuclear division that occurs when cells grow or when cells need to be replaced and when organism reproduces asexually.

In meiosis, the daughter cells contain half the number of chromosomes of the parent cell and is known as **haploid state (n)**.

Whichever division takes place, it is normally followed by division of the cytoplasm to form separate cells, called as **cytokinesis**.

7.2 Cell Cycle

Definition: A series of events leading to the formation of new cell is known as **cell cycle**. The phenomenonal changes leading to formation of new population take place in the cell cycle. It was discovered by **Prevost** and **Dumans** (1824). The series of events include several phases.

7.2.1 Duration of Cell Cycle

Different kinds of cells have varied duration for cell cycle phases. Eukaryotic cell divides every 24 hours. The cell cycle is divided into mitosis and interphase. In cell cycle 95% is spent for interphase whereas the mitosis and cytokinesis last only for an hour.

Table 7.2: Cell cycle of a proliferating human cell

Phase	Time duration (in hrs)
G_1	11
S	8
G_2	4
M	1

The different phases of cell cycle are as follows (Figure 7.1).

7.2.2 Interphase

Longest part of the cell cycle, but it is of extremely variable length. At first glance the nucleus appears to be resting but this is not the case at all. The chromosomes previously visible as thread like structure, have dispersed. Now they are actively involved in protein synthesis, at least for most of the interphase.

C-Value is the amount in picograms of DNA contained within a haploid nucleus.

7.2.3 G_1 Phase

The first gap phase – 2C amount of DNA in cells of G_1. The cells become metabolically active and grows by producing proteins, lipids, carbohydrates and cell organelles including mitochondria and endoplasmic reticulum. Many checkpoints control

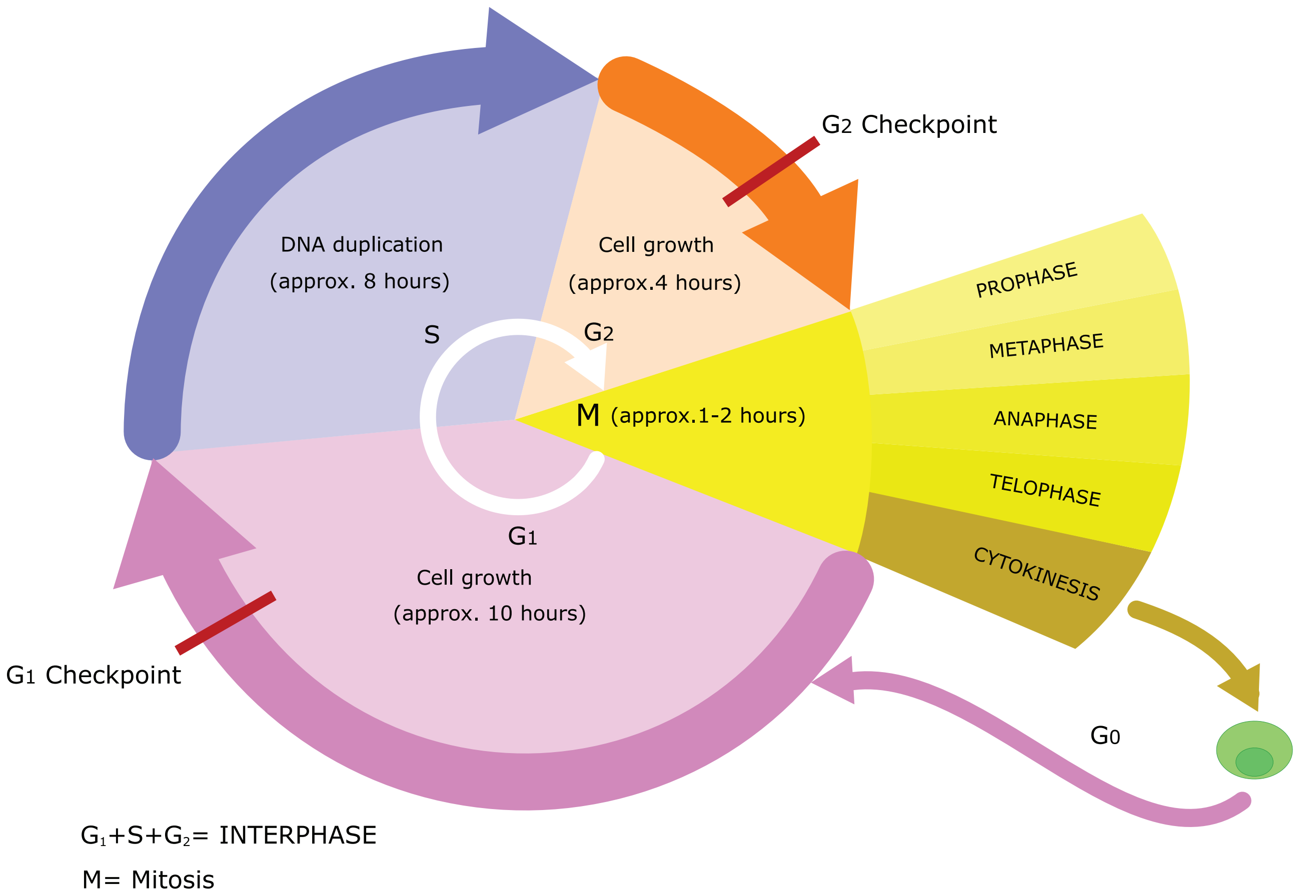


Figure 7.1: Cell cycle

the cell cycle. The checkpoint called the **restriction point** at the end of G_1, determines a cells fate whether it will continue in the cell cycle and divide or enter a stage called $\mathbf{G_0}$ as a quiescent stage and probably as specified cell or die. Cells are arrested in G_1 due to:

- Nutrient deprivation
- Lack of growth factors or density dependant inhibition
- Undergo metabolic changes and enter into G_0 state.

Biochemicals inside cells activates the cell division. The proteins called **kinases** and cyclins activate genes and their proteins to perform cell division. Cyclins act as major checkpoint which operates in G_1 to determine whether or not a cell divides.

DO YOU KNOW?

Dolly

Since the DNA of cells in G_0, do not replicate. The researcher are able to fuse the donor cells from a sheep's mammary glands into G_0 state by culturing in the nutrient free state. The G_0 donor nucleus synchronised with cytoplasm of the recipient egg, which developed into the clone Dolly.

7.2.4 G_0 Phase

Some cells exit G_1 and enters a quiescent stage called $\mathbf{G_0}$, where the cells remain metabolically active without proliferation. Cells can exist for long periods in G_0 phase. In G_0 cells cease growth with reduced rate of RNA and protein synthesis. The G_0 phase is not permanent. Mature neuron and skeletal muscle cell remain permanently in G_0. Many cells in animals remains in G_0 unless called on to proliferate by appropriate growth factors or other extracellular signals. G_0 cells are not dormant.

7.2.5 S phase – Synthesis phase – cells with intermediate amounts of DNA.

Growth of the cell continues as replication of DNA occur, protein molecules called **histones** are synthesised and attach to the DNA. The centrioles duplicate in the cytoplasm. DNA content increases from 2C to 4C.

7.2.6 G_2 – The second Gap phase – 4C amount of DNA in cells of G_2 and mitosis

Cell growth continues by protein and cell organelle synthesis, mitochondria and chloroplasts divide. DNA content remains as 4C. Tubulin is synthesised and microtubules are formed. Microtubles organise to form spindle fibre. The spindle begins to form and nuclear division follows.

One of the proteins synthesized only in the G_2 period is known as **Maturation Promoting Factor (MPF)**. It brings about condensation of interphase chromosomes into the mitotic form.

DNA damage checkpoints operates in G_1 S and G_2 phases of the cell cycle.

7.3 Cell Division

7.3.1 Amitosis (Direct Cell Division)

Amitosis is also called **direct** or **incipient cell division**. Here there is no spindle formation and chromatin material does not condense. It consist of two steps: (Figure 7.2).

❖ **Karyokinesis:**
- Involves division of nucleus.
- Nucleus develops a constriction at the center and becomes dumbell shaped.
- Constriction deepens and divides the nucleus into two.

❖ **Cytokinesis:**
- Involves division of cytoplasm.
- Plasma membrane develops a constriction along nuclear constriction.
- It deepens centripetally and finally divides the cell into two cells.

Example: Cells of mammalian cartilage, macronucleus of *Paramecium* and old degenerating cells of higher plants.

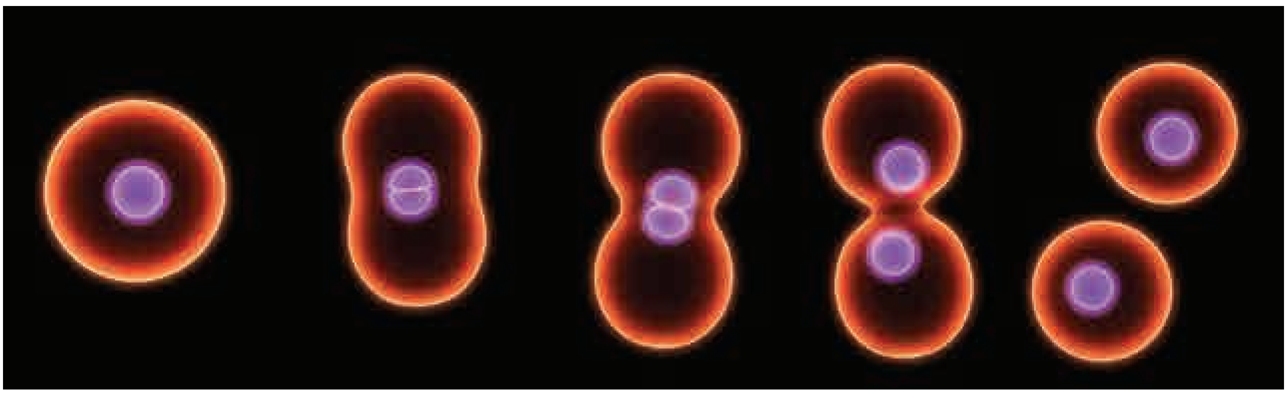


Figure 7.2: Amitosis

Drawbacks of Amitosis

- Causes unequal distribution of chromosomes.
- Can lead to abnormalities in metabolism and reproduction.

7.3.2 Mitosis

The most important part of cell division concerns events inside the nucleus. Mitosis occurs in shoot and root tips and other meristematic tissues of plants associated with growth. The number of chromosomes in the parent and the daughter (Progeny) cells remain the same so it is also called as **equational division**.

7.3.3 Closed and Open Mitosis

In closed mitosis, the nuclear envelope remains intact and chromosomes migrate to opposite poles of a spindle within the nucleus (Figure 7.3).

Example: Many single celled eukaryotes including yeast and slime molds.

In open mitosis, the nuclear envelope breaks down and then reforms around the 2 sets of separated chromosome.

Example: Most plants and animals

- Some animals are able to regenerate the whole parts of the body.

Mitosis is divided into four stages prophase, metaphase, anaphase and telophase (Figure 7.6).

Prophase

Prophase is the longest phase in mitosis. Chromosomes become visible as long thin thread like structure, condenses to form compact mitotic chromosomes. In plant cells initiation of spindle fibres takes place, nucleolus disappears. Nuclear envelope breaks down. Golgi apparatus and endoplasmic reticulum are not seen.

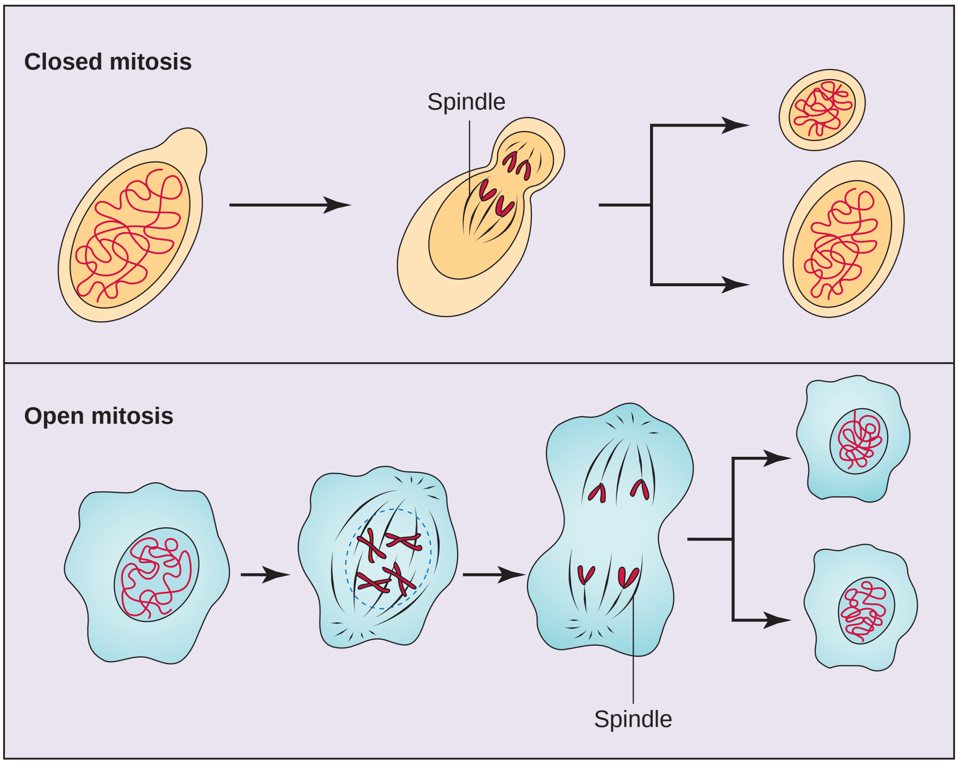


Figure 7.3: Closed and Open mitosis

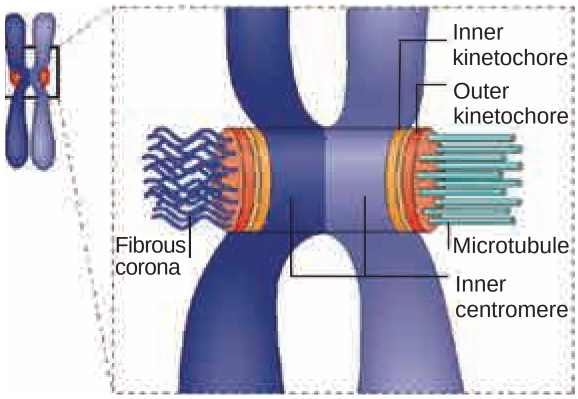


Figure 7.4: Centromere

In animal cell the centrioles extend a radial array of microtubules (Figure 7.4) towards the plasma membrane when they reach the poles of the cell. This arrangement of microtubules is called **an aster**. Plant cells do not form asters.

Metaphase

Chromosomes (two sister chromatids) are attached to the spindle fibres by kinetochore of the centromere. The spindle fibres is made up of tubulin. The alignment of chromosome into compact group at the equator of the cell is known as **metaphase plate**. This is the stage where the chromosome morphology can be easily studied.

Kinetochore is a DNA–Protein complex present in the centromere DNA where the microtubules are attached. It is a trilaminar disc like plate.

The spindle assembly checkpoint which decides the cell to enter anaphase.

Anaphase

Each chromosome split simultaneously and two daughter chromatids begins to migrate towards two opposite poles of a cell. Each centromere splits longitudinally into two, freeing the two sister chromatids from each other. Shortening of spindle fibre and longitudinal splitting of centromere creates a pull which divides chromosome into two halves. Each half receive two chromatids (that is sister chromatids are separated). When the sister chromatids separate the actual partitioning of the replicated genome is complete.

A ubiquitine ligase is activated called as the **anaphase-promoting complex cyclosome** (**APC/C**) leads to degradation of

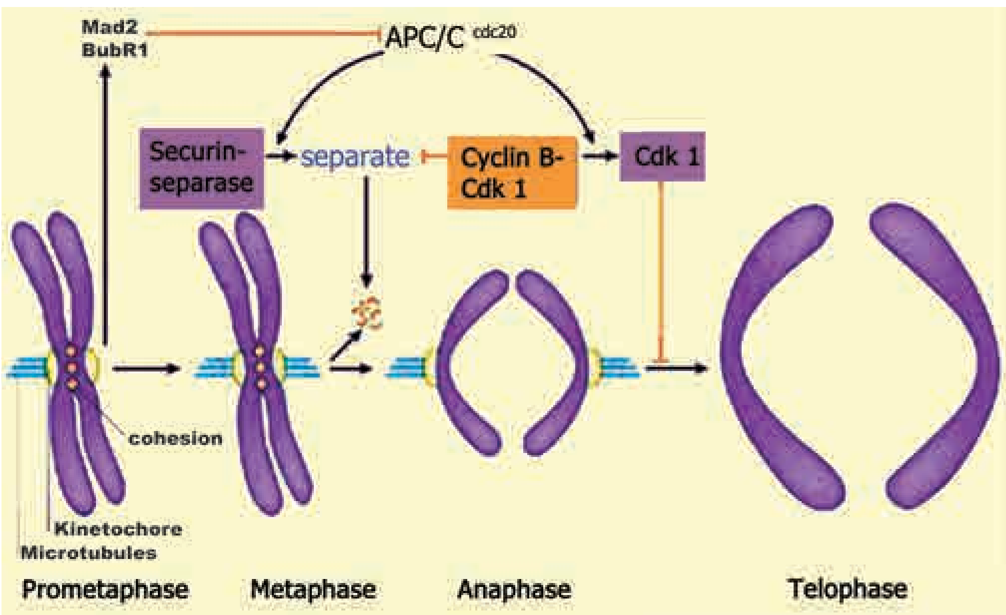


Figure 7.5: Anaphase promoting complex cyclosome

the key regulatory proteins at the transition of metaphase to anaphase. APC is a cluster of proteins that induces the breaking down of cohesion proteins which leads to the separation of chromatids during mitosis (Figure 7.5).

Telophase

Two sets of daughter chromosomes reach opposite poles of the cell, mitotic spindle disappears. Division of genetic material is completed after this karyokinesis, cytokinesis (division of cytoplasm) is completed, nucleolus and nuclear membranes reforms. Nuclear membranes form around each set of sister chromatids now called **chromosomes**, each has its own centromere. Now the chromosomes decondense. In plants, phragmoplast are formed between the daughter cells. Cell plate is formed between the two daughter cells, reconstruction of cell wall takes place. Finally the cells are separated by the distribution of organelles, macromolecules into two newly formed daughter cells.

A Culture of animal cells in which the cell cycles were asynchronous was incubated with 3H-Thymidine for 10 minutes. Autoradiography showed that 50% of the cells were labelled. If the cell cycle time (generation time) was 16 hrs how long was the S period?

Length of the S period = Fraction of cells in DNA replication × generation time

Length of the S period = 0.5 × 16 hours = 8 hours

Activity

Squash preparation of onion root tip to visualize and study various stages of mitosis.

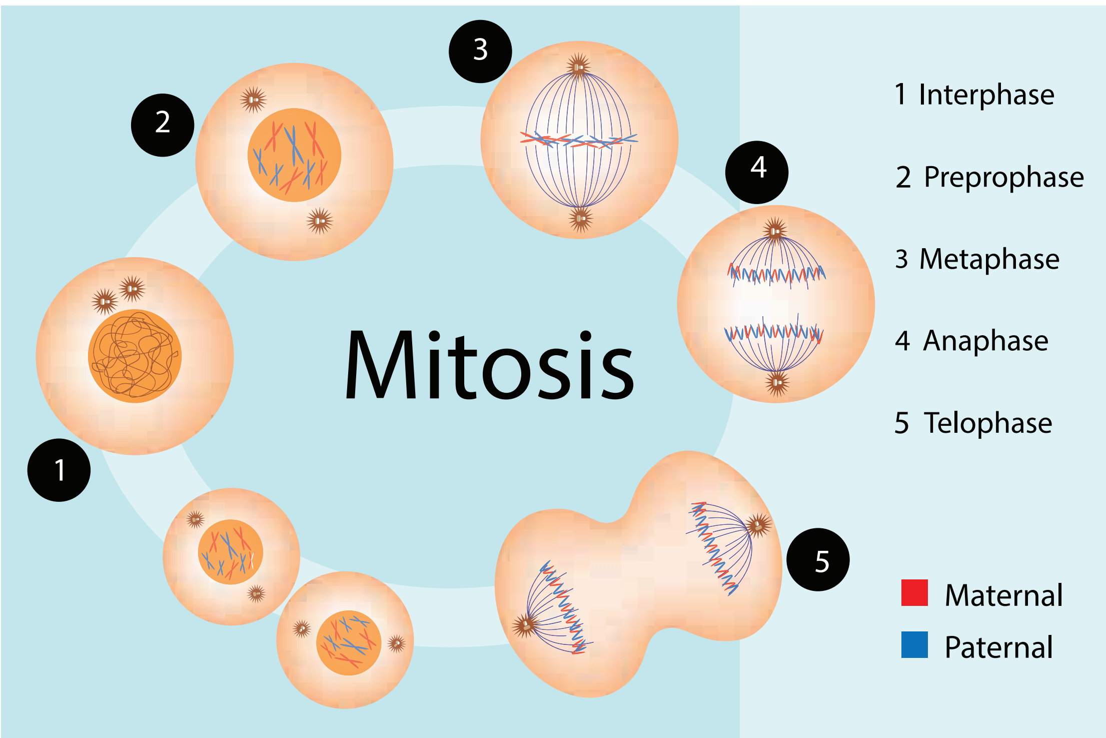


Figure 7.6: Mitosis

7.3.4 Cytokinesis

Cytokinesis in Animal Cells

It is a contractile process. The contractile mechanism contained in contractile ring located inside the plasma membrane. The ring consists of a bundle of microfilaments assembled from **actin** and **myosin**. This fibril helps for the generation of a contractile force. This force draws the contractile ring inward forming a cleavage furrow in the cell surface dividing the cell into two.

Check your grasp!

What effect does mitosis have on transcription?

During mitosis transcription stops.

Cytokinesis in Plant Cell

Division of the cytoplasm often starts during telophase. In plants, cytokinesis cell plate grows from centre towards lateral walls - centrifugal manner of cell plate formation.

Phragmoplast contains microtubules, actin filaments and vesicles from golgi apparatus and ER. The golgi vesicles contains carbohydrates such as pectin, hemicellulose which move along the microtubule of the pharagmoplast to the equator fuse, forming a new plasma membrane and the materials which are placed their becomes new cell wall. The first stage of cell wall construction is a line dividing the newly forming cells called a **cell plate**. The cell plate eventually stretches right across the cell forming the middle lamella. Cellulose builds up on each side of the middle lamella to form the cell walls of two new plant cells.

DO YOU KNOW?

Skin cells and the cells lining your gut are constantly dying and are being replaced by identical cells.

7.3.5 Significance of Mitosis

Exact copy of the parent cell is produced by mitosis (genetically identical).

1. **Genetic stability** – daughter cells are genetically identical to parent cells.
2. **Growth** – as multicellular organisms grow, the number of cells making up their tissue increases. The new cells must be identical to the existing ones.
3. **Repair of tissues** - damaged cells must be replaced by identical new cells by mitosis.
4. **Asexual reproduction** – asexual reproduction results in offspring that are identical to the parent. Example Yeast and Amoeba.
5. In flowering plants, structure such as bulbs, corms, tubers, rhizomes and runners are produced by mitotic division. When they separate from the parent, they form a new individual.

   The production of large numbers of offsprings in a short period of time, is possible only by mitosis. In genetic engineering and biotechnology, tissues are grown by mitosis (i.e. in tissue culture).
6. **Regeneration** – Arms of star fish

7.3.6 Meiosis

In Greek *meioum* means to reduce. Meiosis is unique because of synapsis, homologous recombination and reduction division. Meiosis takes place in the reproductive organs. It results in the formation of gametes with half the normal chromosome number.

Haploid sperms are made in testes; haploid eggs are made in ovaries of animals.

In flowering plants meiosis occurs during microsporogenesis in anthers and megasporogenesis in ovule. In contrast to mitosis, meiosis produces cells that are not genetically identical. So meiosis has a key role in producing new genetic types which results in genetic variation.

Stages in Meiosis

Meiosis can be studied under two divisions i.e., meiosis I and meiosis II. As with mitosis, the cell is said to be in interphase when it is not dividing.

Prophase I is the longest and most complex stage in meiosis. Pairing of homologous chromosomes (bivalents).

Meiosis I-Reduction Division

Prophase I – Prophase I is of longer duration and it is divided into 5 substages – Leptotene, Zygotene, Pachytene, Diplotene and Diakinesis (Figure 7.7).

Leptotene – Chromosomes are visible under light microscope. Condensation of chromosomes takes place. Paired sister chromatids begin to condense.

Zygotene – Pairing of homologous chromosomes takes place and it is known as **synapsis**. Chromosome synapsis is made by the formation of synaptonemal complex. The complex formed by the homologous chromosomes are called as **bivalent (tetrads)**.

Pachytene – At this stage bivalent chromosomes are clearly visible as tetrads. Bivalent of meiosis I consists of 4 chromatids and 2 centromeres. Synapsis is completed and recombination nodules appear at a site where crossing over takes place between non-sister chromatids of homologous chromosome. Recombination of homologous chromosomes is completed by the end of the stage but the chromosomes are linked at the sites of crossing over. This is mediated by the enzyme recombinase.

Diplotene – Synaptonemal complex disassembled and dissolves. The homologous chromosomes remain attached at one or more points where crossing over has taken place. These points of attachment where 'X' shaped structures occur at the sites of crossing over is called **Chiasmata**. Chiasmata are chromatin structures at sites where recombination has been taken place. They are specialised chromosomal structures that hold the homologous chromosomes together. Sister chromatids remain closely associated whereas the homologous chromosomes tend to separate from each other but are held together by chiasmata. This substage may last for days or years depending on the sex and organism. The chromosomes are very actively transcribed in females as the egg stores up materials for use during embryonic development. In animals, the chromosomes have prominent loops called **lampbrush chromosome**.

Diakinesis – Terminalisation of chiasmata. Spindle fibres assemble. Nuclear envelope breaks down. Homologous chromosomes become short and condensed. Nucleolus disappears.

Metaphase I

Spindle fibres are attached to the centromeres of the two homologous chromosomes. Bivalent (pairs of homologous chromosomes) aligned at the

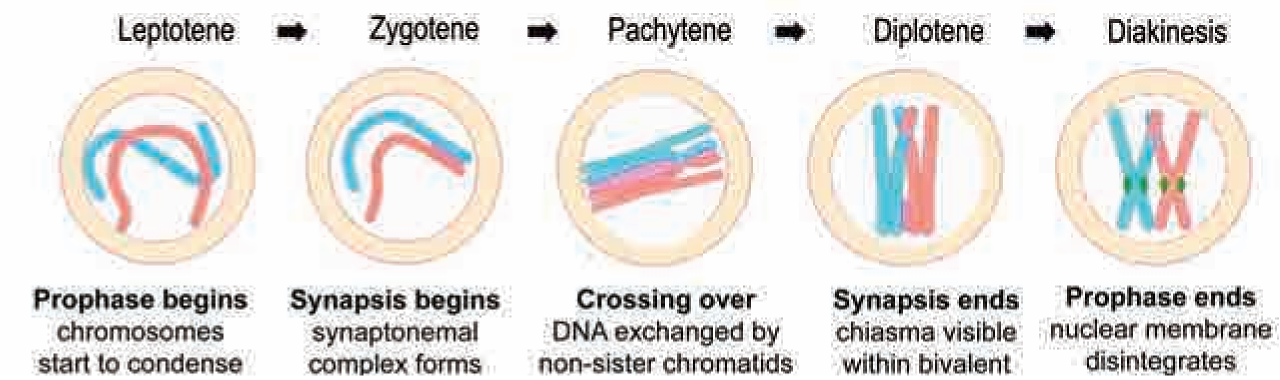


Figure 7.7: Prophase I

equator of the cell known as **metaphase plate**. Each bivalent consists of two centromeres and four chromatids.

The random distribution of homologous chromosomes in a cell in Metaphase I is called **independent assortment**.

Anaphase I

Homologous chromosomes are separated from each other. Shortening of spindle fibers takes place. Each homologous chromosomes with its two chromatids and undivided centromere move towards the opposite poles of the cells. The actual reduction in the number of chromosomes takes place at this stage. Homologous chromosomes which move to the opposite poles are either paternal or maternal in origin. Sister chromatids remain attached with their centromeres.

Telophase I

Haploid set of chromosomes are present at each pole. The formation of two daughter cells, each with haploid number of chromosomes. Nuclei are reassembled. Nuclear envelope forms around the chromosome and the chromosomes becomes uncoiled. Nucleolus reappears.

In plants, after karyokinesis cytokinesis takes place by which two daughter cells are formed by the cell plate between 2 groups of chromosomes known as **dyad of cells (haploid)**.

The stage between the two meiotic divisions is called **interkinesis** which is short-lived.

Meiosis II – Equational division.

This division is otherwise called **mitotic meiosis**. Since it includes all the stages of mitotic divisions.

Prophase II

The chromosome with 2 chromatids becomes short, condensed, thick and becomes visible. New spindle develops at right angles to the cell axis. Nuclear membrane and nucleolus disappear.

Metaphase II

Chromosome arranged at the equatorial plane of the spindle. Microtubules of spindle gets attached to the centromere of sister chromatids.

Anaphase II

Sister chromatids separate. The daughter chromosomes move to the opposite poles due to shortening of microtubules. Centromere of each chromosome split, allowing to move towards opposite poles of the cells holding the sister chromatids.

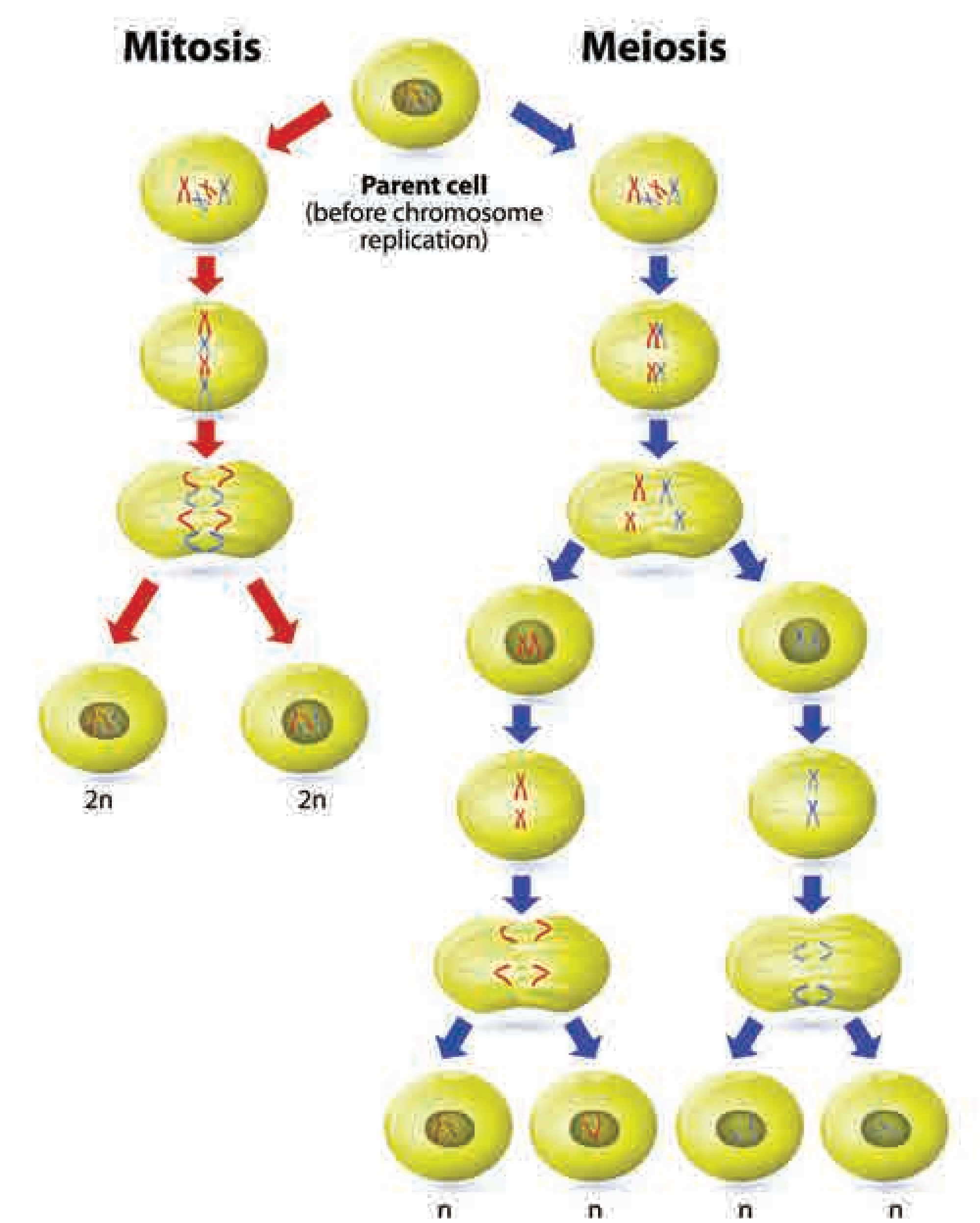


Figure 7.8: Meiosis

Telophase II

Four groups of chromosomes are organised into four haploid nuclei. The spindle disappears. Nuclear envelope, nucleolus reappear.

After karyokinesis, cytokinesis follows and four haploid daughter cells are formed, called **tetrads**.

7.3.7 Significance of Meiosis

- This maintains a definite constant number of chromosomes in organisms.
- Crossing over takes place and exchange of genetic material leads to variations among species. These variations are the raw materials to evolution. Meiosis leads to genetic variability by partitioning different combinations of genes into gametes through independent assortment.
- Adaptation of organisms to various environmental stress.

7.4 Difference Between Mitosis and Meiosis

Table 7.3: Difference between mitosis in Plants and Animals

Plants	Animals
Centrioles are absent	Centrioles are present
Asters are not formed	Asters are formed
Cell division involves formation of a cell plate	Cell division involves furrowing and cleavage of cytoplasm
Occurs mainly at meristem	Occurs in tissues throughout the body

Table 7.4: Difference Between Mitosis and Meiosis (Figure 7.8)

Mitosis	Meiosis
One division	Two divisions
Number of chromosomes remains the same	Number of chromosomes is halved
Homologous chromosomes line up separately on the metaphase plate	Homologous chromosomes line up in pairs at the metaphase plate
Homologous chromosome do not pair up	Homologous chromosome pairup to form bivalent
Chiasmata do not form and crossing over never occurs	Chiasmata form and crossingover occurs
Daughter cells are genetically identical	Daughter cells are genetically different from the parent cells
Two daughter cells are formed	Four daughter cells are formed

7.5 Mitogen

The factors which promote cell cycle proliferation is called **mitogen**. Plant mitogens include gibberellin, ethylene, Indole acetic acid, kinetin. These increase mitotic rate.

Mitotic Poisons (Mitotic Inhibitors)

Certain chemical components act as inhibitors of the mitotic cell division and they are called **mitotic poisons**.

Endomitosis

The replication of chromosomes in the absence of nuclear division and cytoplasmic division resulting in numerous copies within each cell is called **endomitosis**. Chromonema do not separate to form chromosomes, but remain closely associated with each other. Nuclear membrane does not rupture. So no spindle formation. It occurs notably in the salivary glands of *Drosophila* and other flies. Cells in these tissues contain giant chromosomes (polyteny), each consisting of over thousands of intimately associated, or synapsed, chromatids. Example: Polytene chromosome.

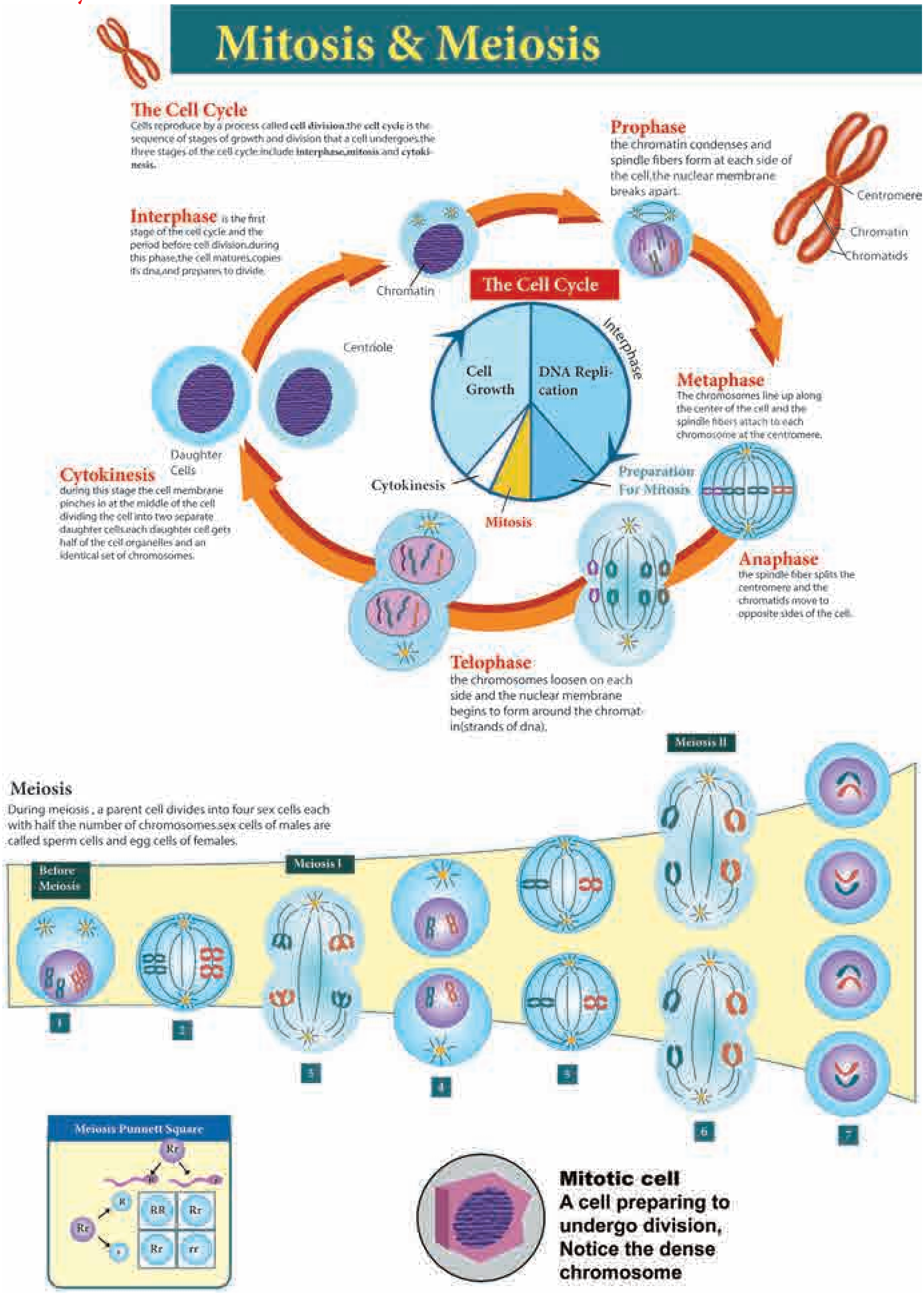
Anastral

This is present only in plant cells. No asters or centrioles are formed only spindle fibres are formed during cell division.

Amphiastral

Aster and centrioles are formed at each pole of the spindle during cell division. This is found in animal cells.

Summary


Mitosis & Meiosis
The Cell Cycle
Cells reproduce by a process called cell division.the cell cycle is the sequence of stages of growth and division that a cell undergoes.the three stages of the cell cycle include interphase,mitosis and cytokinesis.
Interphase is the first stage of the cell cycle.and the period before cell division.during this phase,the cell matures,copies its dna,and prepares to divide.
Prophase
the chromatin condenses and spindle fibers form at each side of the cell.the nuclear membrane breaks apart.
Centromere
Chromatin
Chromatids
Chromatin
Centriole
The Cell Cycle
Interphase
Cell Growth
DNA Replication
Cytokinesis
Mitosis
Preparation For Mitosis
Metaphase
The chromosomes line up along the center of the cell and the spindle fibers attach to each chromosome at the centromere.
Daughter Cells
Cytokinesis
during this stage the cell membrane pinches in at the middle of the cell dividing the cell into two separate daughter cells.each daughter cell gets half of the cell organelles and an identical set of chromosomes.
Anaphase
the spindle fiber splits the centromere and the chromatids move to opposite sides of the cell.
Telophase
the chromosomes loosen on each side and the nuclear membrane begins to form around the chromatin(strands of dna).
Meiosis
During meiosis , a parent cell divides into four sex cells each with half the number of chromosomes.sex cells of males are called sperm cells and egg cells of females.
Before Meiosis
Meiosis I
Meiosis II
1
2
3
4
5
6
7
Meiosis Punnett Square
Rr
RR
Rr
Rr
rr
Mitotic cell
A cell preparing to undergo division,
Notice the dense chromosome