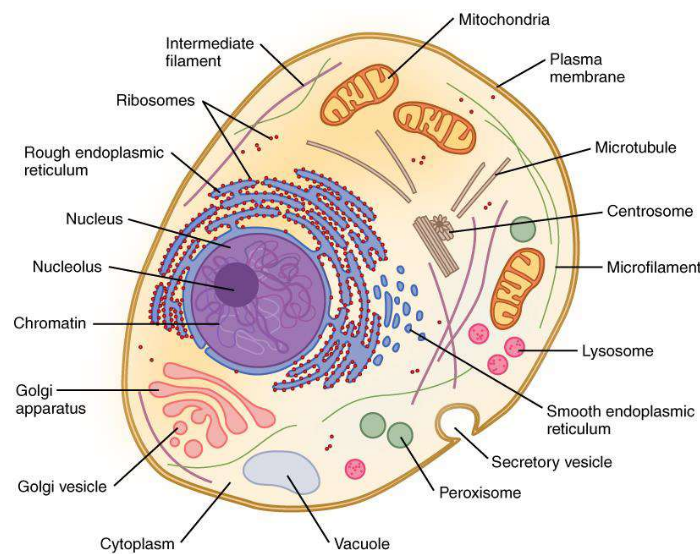
Cell & Its composition

Q.1 Define cell and its component?

Cell

- The call is defined as the basic **structural, functional, and biological unit** of all known living organisms. The cells are the autonomous, self-replicating the **smallest unit of life**.
- The term 'cell' came from a Latine word '**cella**' which means "**small room**".
- They are also called the "**building blocks of life**".
- **Cell biology, cellular biology, or cytology:** A branch of biology where we study cells.
- In 1665, English scientist and architect Robert Hooke first discovered the cell.

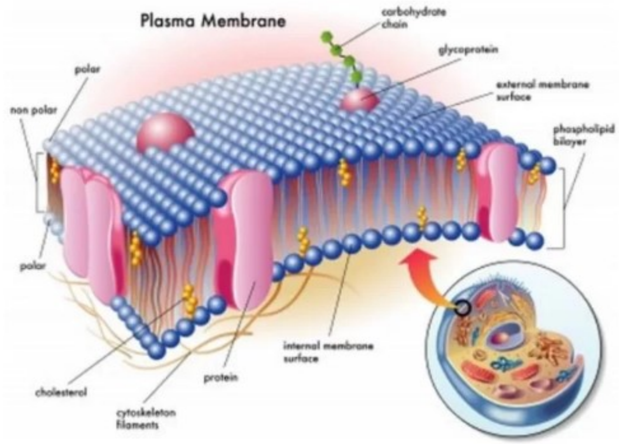
Cell Structure



1. Cell Membrane or plasma membrane

- The cytoplasm of a cell is surrounded by the cell membrane.
- The cell membrane is also known as the plasma membrane.
- In animal cells, the plasma membrane serves as an outer boundary, whereas in prokaryotes and plant a cell is covered by a **cell wall**.
- The thickness of a cell membrane is around 4 and 10 nanometers.

Structure and Chemical composition of Plasma Membrane



1. *Membrane Lipids:*

- *The cell membrane is composed of a lipid bilayer*
- *There are present two types of membrane lipids such as phospholipids and sterols (generally cholesterol).*
- *This membrane lipid contains both lipid-soluble and a water-soluble region, that is why they are called "amphiphilic".*
- *The head portion of Phospholipid is attached with two long hydrophobic fatty acid chains, this portion is insoluble in water and dissolves readily in organic solvents which gives it a lipid character.*
- *A phosphoryl group remains attached to another part of the head, this portion of the phospholipid dissolves in water.*

2. *Membrane Proteins*

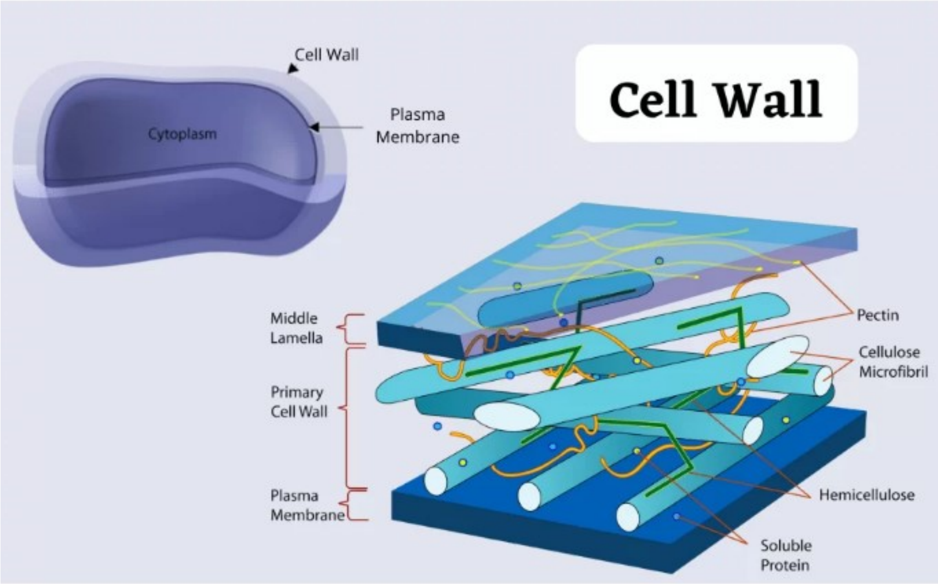
- *The cell membrane also contains two types of proteins such as extrinsic protein and the intrinsic protein.*
- *The extrinsic proteins remain loosely attached with the phosphoryl surface of the lipid bilayer by ionic bonds or calcium bridges.*
- *Whereas the intrinsic proteins remain embedded within the phospholipid bilayer.*
- *Intrinsic proteins are composed of 20- to 24-amino acids long sequences, which are extended through the internal regions of the cell membrane.*

Functions of Cell Membrane

- *During tissue formation and cell fusion, the cell membrane allows the interaction between cells.*
- *The cell membrane provides a shape to the cell and encloses the cell and its components from the external environment.*
- *It helps in the transport of essential compounds that are required for the survival of the cell.*

2. Cell Wall

- The cell membrane or plasma membrane is surrounded by a rigid and stiff structure which is called the cell wall. It provides structure and protection to the cell.



Structure and composition of Cell wall

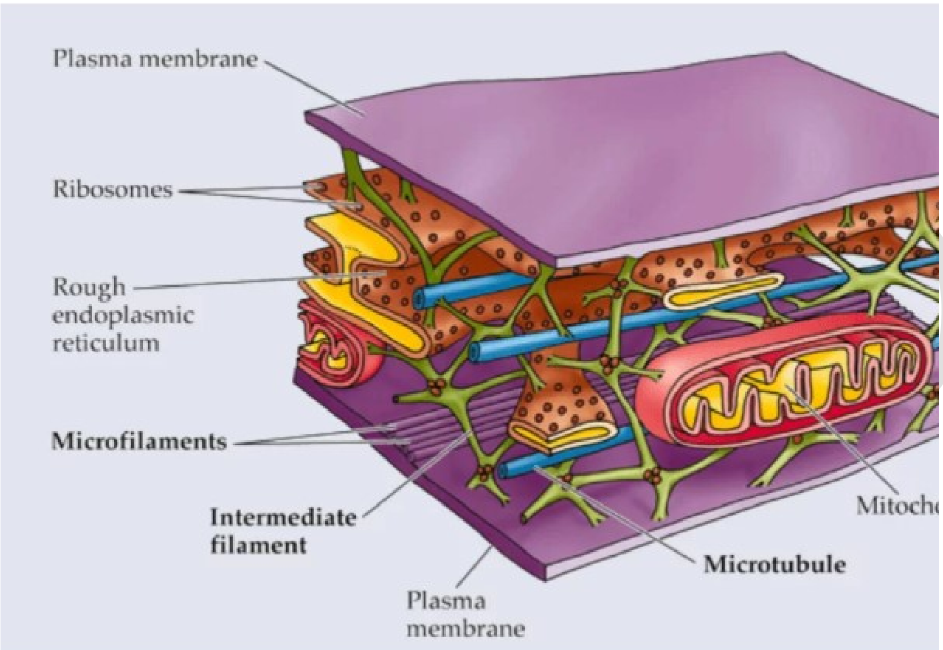
- The plant cell is composed of cellulose, hemicellulose, and proteins.
- The fungal cell wall is composed of chitin, glucans and proteins.
- The bacteria cell wall is composed of peptidoglycan.
- The cell wall has a multilayered structure, which consists of three-layer such as a middle lamina, a primary cell wall, and a secondary cell wall.
- The middle lamina is composed of polysaccharides which help in binding or in adhesion with neighbor cells.
- After the middle lamina, a cellulose layer is present which is called the Primary layer.
- The secondary layer of the cell wall is composed of cellulose and
- hemicellulose.

Functions of the Cell Wall

- It helps in the transportation of substances into the cell.
- Cell wall functions as a barrier between the interior cellular components and the external environment.
- The cell wall is maintaining the definite shape, strength, rigidity of the cell.
- It also protects the cell from mechanical stress and physical shocks.
- Cell walls control cell expansion during the intake of water and also prevent water loss from the cell.

3. Cytoskeleton

- It is a complex, dynamic network that interlinks protein filaments within the cytoplasm of all cells, such as bacteria and archaea.
- The cytoskeleton is extended from the cell membrane to the cell nucleus.



Structure and composition of Cytoskeleton

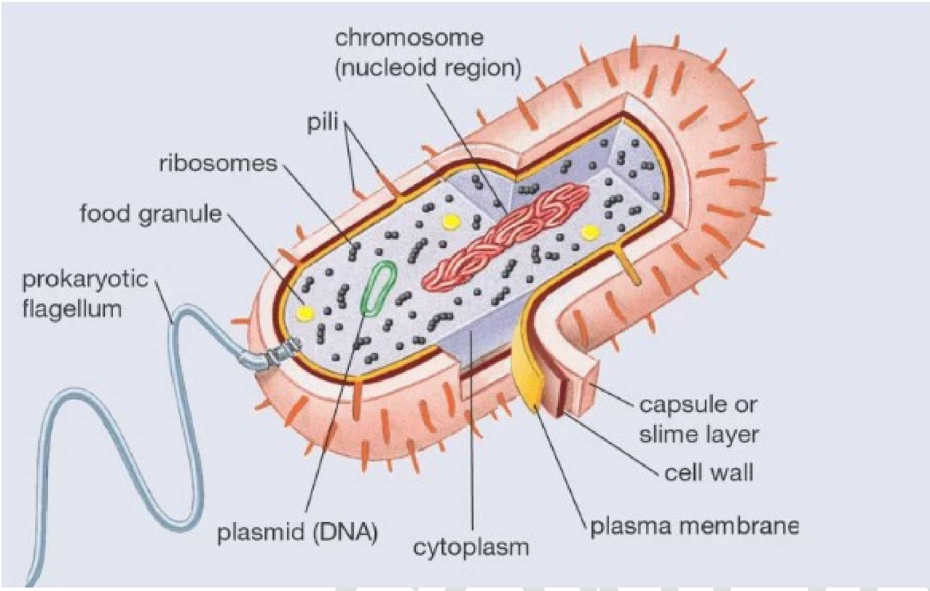
- In Eukaryotic cells, the Cytoskeleton is composed of microfilaments, microtubules, and intermediate filaments.
- The diameter of a microfilament is about 7 nm which is made up of many linked monomers of a protein known as actin. These actions are combined and formed a double helix structure.
- The Intermediate filaments are composed of multiple strands of fibrous proteins that are wound together. They have an average diameter of 8 to 10 nm.
- The Microtubules have a diameter of about 25 nm which is composed of tubulin proteins (tubulin protein consists of two subunits, α-tubulin, and β-tubulin). These proteins are arranged to form a hollow, straw-like tube.

Functions of Cytoskeleton

- The cytoskeleton maintains the shape of the cell.
- It helps in cell locomotion.
- It organizes the structures and activities of the cell.

4. Capsule

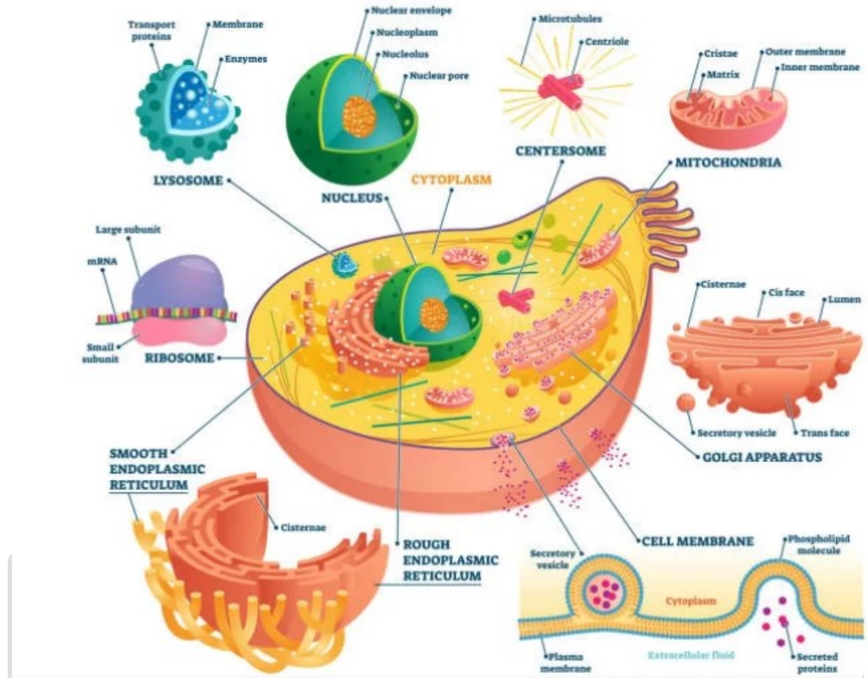
- The capsule is present at the outside of the cell membrane and cell wall in some bacteria.
- The capsule can be detected by staining them with India ink or methyl blue. The standard stains are not used to stain them because they cannot penetrate the capsule.



7. Cell Organelles

Cell organelles are referred to when those vital organelles are present within the cell and perform one or more vital functions.

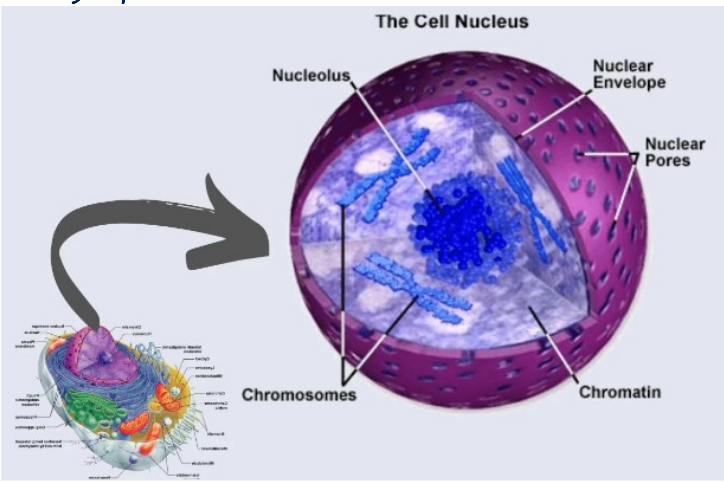
There are present several types of organelles such as nucleus, golgi apparatus, mitochondria, chloroplasts, peroxisomes and lysosomes, etc.



i). Cell nucleus:

- The nucleus stored the genetic information of the cell that is why it is called the information center of the cell. It is also called "brain of the cell", because it controls the functions of other organelles.
- In eukaryotic organisms the nucleus is surrounded by a nuclear membrane, and a nuclear envelope, which is separating it from the cell cytoplasm.
- It contains double-stranded, spiral-shaped deoxyribonucleic acid (DNA) molecules within its membrane. In Prokaryotic cells, the nucleus is absent

whereas the genetic material distributed in the cytoplasm.



Structure of Nucleus

- The nucleus has a diameter of 6 micrometres (6 x 10−6 metre), and contains about 1.8 metres of DNA.
- Nucleus has several important parts such as chromatin (Genetic material), nuclear envelope, nucleoplasm and nucleolus.
- The nuclear envelope is a lipid bilayer, which contains two layers such as outer and an inner phospholipid bilayer. This envelope separates the chromatin and nucleolus from cytoplasm. The nuclear envelope contains several pores which helps in import and export of proteins and RNA from cytoplasm.
- Chromatin is a dense, compact fibre which is formed by the combinations of both DNA and proteins.
- The nucleoplasm is referred to the portion which is located within the envelope.
- The nucleolus has four important components such as Fibrillar Centers, Granular Components, Dense Fibrillar Components, and Nucleolar vacuoles. It occupied the 25% volume of the nucleus. It performed the assembling of ribosomes and synthesis of rRNA.

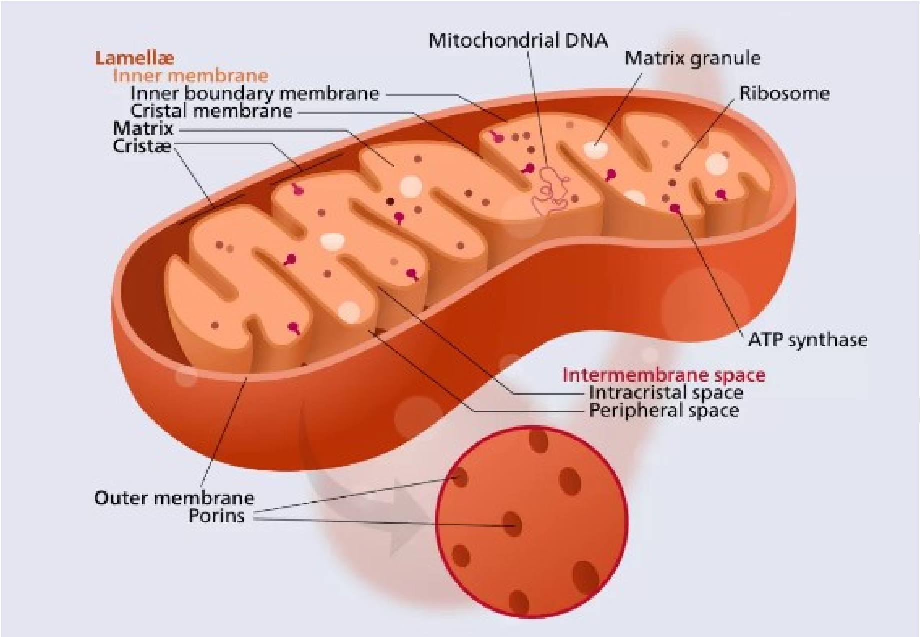
Functions

- Nucleus stored the genetic material and proteins(DNA or RNA).
- It controls the protein synthesis, cell division, growth, and differentiation.
- It produces messenger RNA (mRNA) for protein synthesis.

(ii). Mitochondria

- Mitochondria is referred to as **the powerhouse of a cell** because it
- generates energy for the cell.

- It is a self-replicating organelles which is found in both plant and animal cells in various numbers, shapes, and sizes.
- It produces ATP or energy by oxidative phosphorylation of end products which are arising from the cytoplasmic metabolism.



Structure of Mitochondria

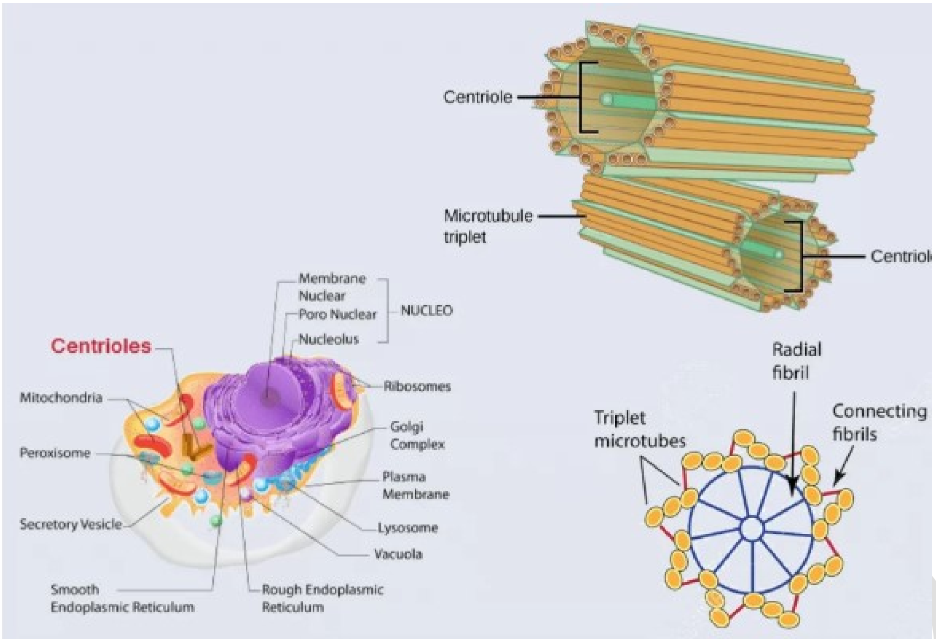
- Mitochondria has two distinct membranes such as inner layer and outer layer.
- The outer layer is smooth whereas the inner layer is folded and forms finger-like structures which are called cristae.
- The inner membrane enclosed space is called matrix, this space contains a fluid which is a mixture of metabolic products, enzymes, and ions.

Functions of Mitochondria

- It produces energy in the form of ATP which is required for the proper functioning of cell organelles.
- It helps to detoxify the ammonia.
- Mitochondria produces different types of components of blood and segments of hormones.
- It assists the process of apoptosis.
- It also balanc the amount of Ca+ ions within the cell.

Centriole

- Centrioles are located near the nucleus but they appear only during cell division, they work in the process of mitosis and meiosis.
- Centrioles are cylindrical in shape and made up of a protein called tubulin. They mainly appear in most eukaryotic cells.



Structure of Centriole

- *Centriole consists of nine sets of microtubules, each in groups of three known as triplet microtubules.*
- *The Triplet microtubules consist of three concentric rings of microtubules which makes it very strong.*
- *A special protein is bound with each triplet which provides the shape of centriole.*
- *A amorphous material known as the pericentriolar material is surrounded by the triplet microtubules.*

Function of Centriole

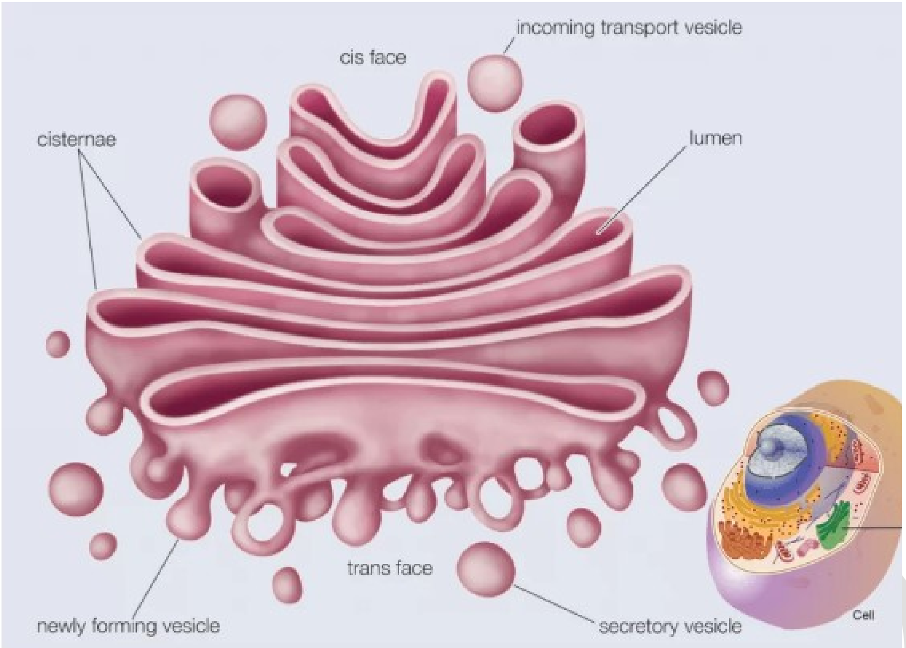
- *During the cell division centriole helps in the formation of spindle fibers.*
- *They help in the formations of cilia and flagella.*

Cytoplasm

- *The semifluid substance which is located between the nucleus and the cellular membrane is called cytoplasm.*
- *Different types of organelles are suspended within the cytoplasm such as ribosomes, mitochondria, golgi bodies, centriole, lysosomes and peroxisomes, etc.*

Golgi Apparatus/ Golgi Complex/ Golgi Body

- *Golgi Body mainly found in eukaryotic cells and they modify and transport molecules from endoplasmic reticulum to their destination.*
- *They are found in cytoplasm next to the endoplasmic reticulum and near the cell nucleus.*



Cell Structure and functions

Function of Golgi Complex

- It is also called "traffic police" because it directs proteins and lipids to their destination.
- It helps in sulfation of molecules.
- It helps in synthesis of cell membrane, lysosomes and other organelles.
- Helps in exocytosis of zymogen, mucus, lactoprotein, and parts of the thyroid hormone.

(ix). Lysozyme

- They are membrane bounded organelles and mainly found in cytoplasm of animal cells.
- These organelles degrade various macromolecules with the help of a hydrolytic enzyme.
- There are present two types of lysozyme such as primary and secondary lysozyme.
- The primary lysozyme has several hydrolytic enzymes such as lipases, amylases, proteases, and nucleases.
- Whereas the secondary lysosome is formed by the fusion of primary lysosomes containing engulfed molecules or organelles.

Function of Lysozyme

- They help in intracellular digestion of larger macromolecules, where the enzymes which are present in lysozyme degrade the larger macromolecules into smaller molecules.
- They also help in autolysis of unwanted organelles.
- They also help in secretion, plasma membrane repair, cell signaling, and energy metabolism.

(xiii). Peroxisomes

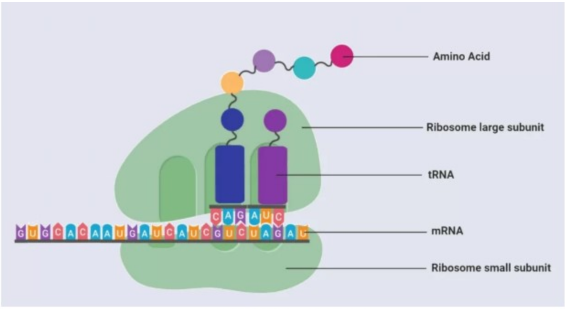
- It is a membrane-bounded organelle found in the cytoplasm of eukaryotic cells.
- They contain enzymes that help in the oxidation of molecules such as fatty acids and amino acids. As a result of the oxidation reaction they produce hydrogen peroxide, that is why they are named peroxisome.
- Hydrogen peroxide is toxic to cells that's why it contains another enzyme called catalase which converts the Hydrogen peroxide into water and oxygen and neutralizes the toxicity.

Function of Peroxisomes

- They help in oxidation of specific biomolecules.
- They help in biosynthesis of membrane lipids called plasmalogens.
- In plant cells during photorespiration they help in recycling of carbon from phosphoglycolate.

(xvi). Ribosomes

- These are present in all living cells as free particles or attached to the membranes of the endoplasmic reticulum (eukaryotic cells) and function as the site of protein synthesis.



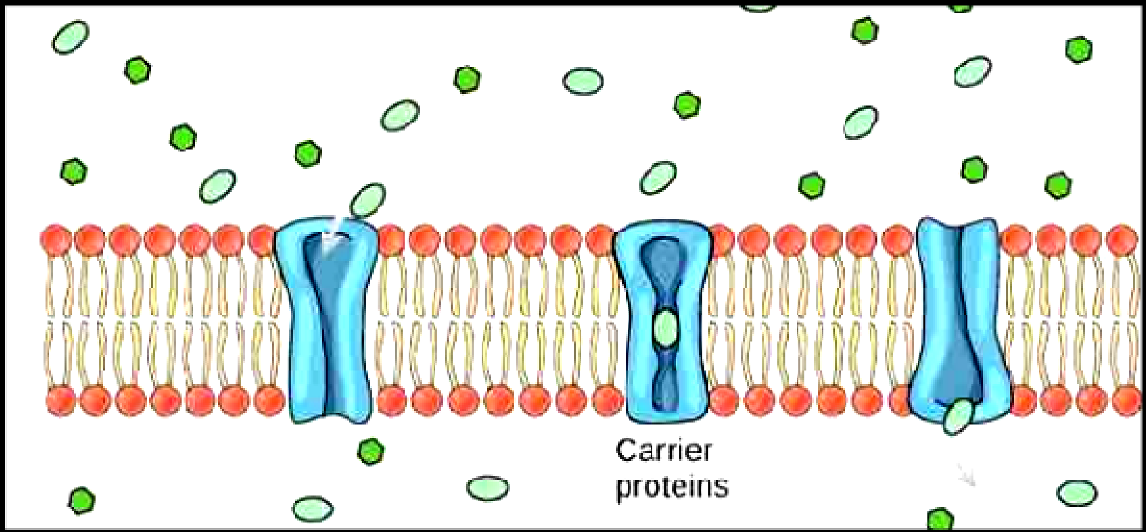
Structure of Ribosomes

- Ribosomes consist of ribosomal RNA and dozens of ribosomal proteins, these are arranged and formed two distinct subunits such as the small subunit and large subunit.
- The eukaryotic cell contains 80s ribosome with 40S smaller subunit and 60S larger subunit.
- The prokaryotic cell contains 70S ribosome where it has a 50S large subunit and 30s smaller subunits.

Function of Ribosomes

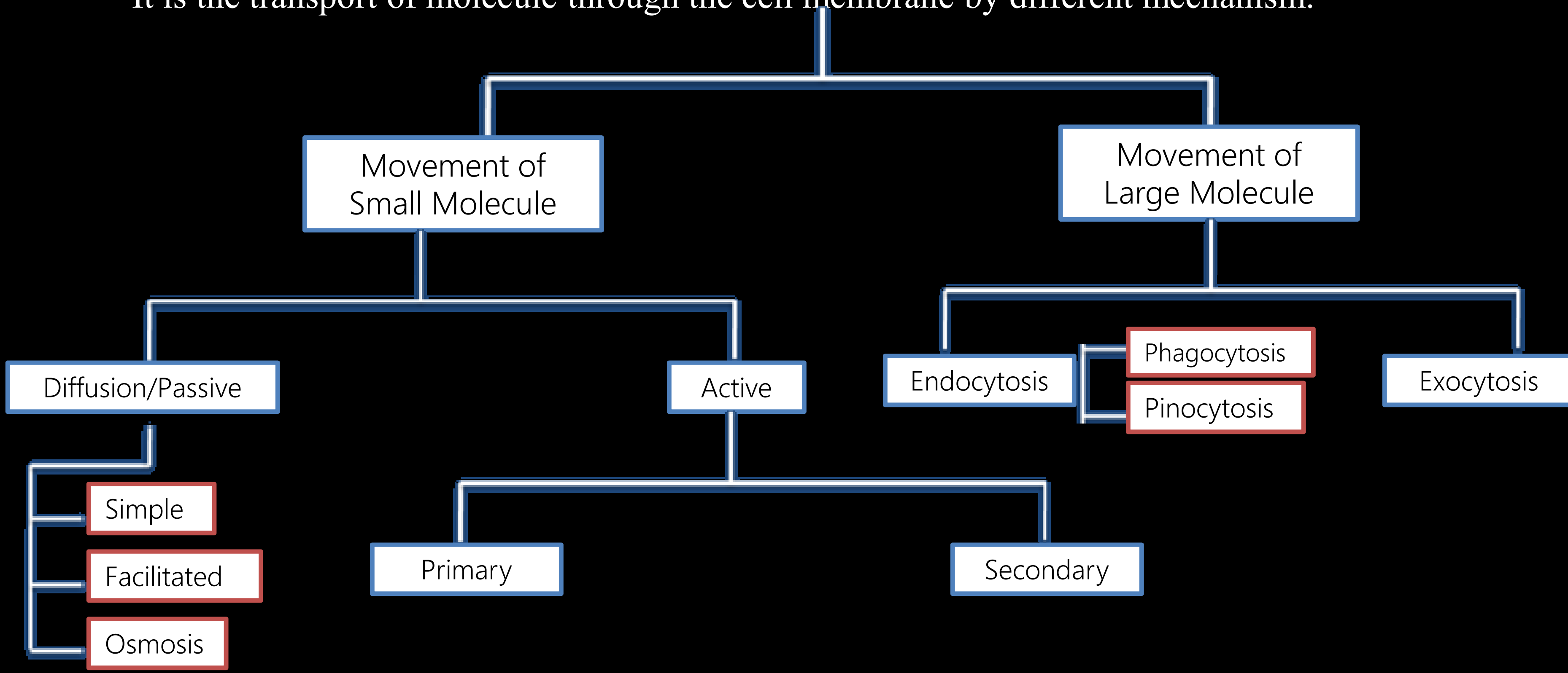
- Ribosomes help in protein synthesis.
- They involve protein folding.
- Ribosomes array the amino acids in the order designated by tRNA and assist in protein synthesis.

TRANSPORT ACROSS CELL



Types of transport

It is the transport of molecule through the cell membrane by different mechanism.

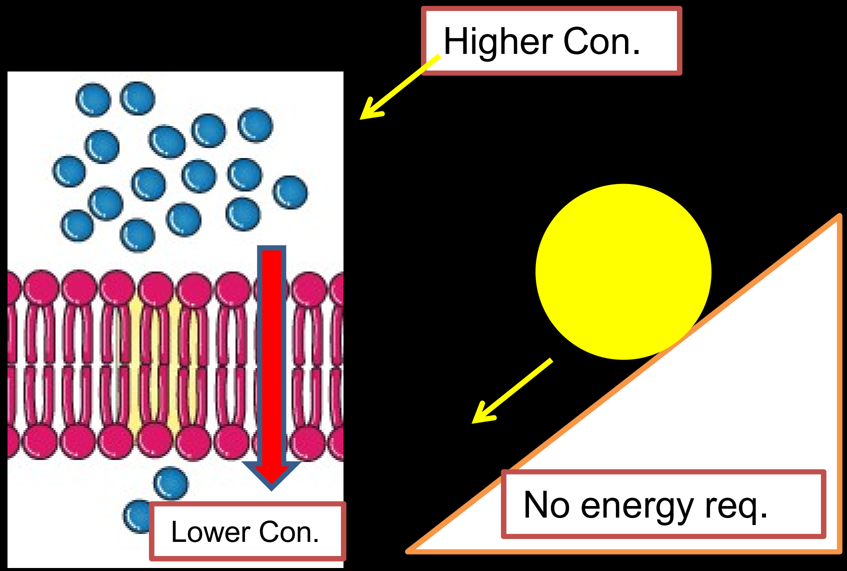


Movement of Small Molecule

(A) Diffusion/Passive : Simply transport of molecule from high concentration to low concentration.

Simple Diffusion:

1. The net movement of solutes from a region of high concentration to a region of low concentration.
2. No Energy requirement in the process.
3. Molecule remain in aq. phase/dissolve into lipid bilayer and transfer to opposite side of membrane.
4. Difference between concentration is known as ***Concentration gradient***.

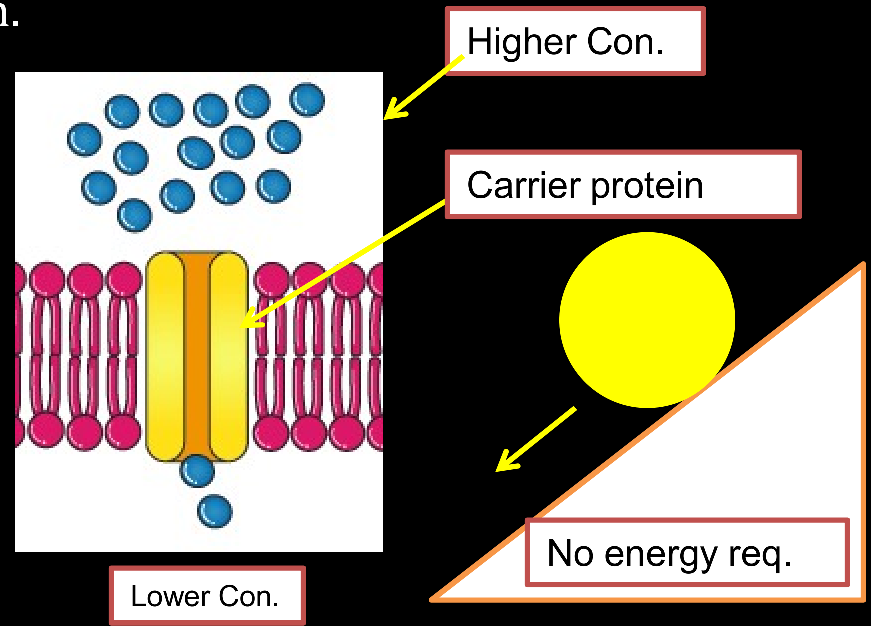


Movement of Small Molecule

(A) DIFFUSION/PASSIVE : Simply transport of molecule from high concentration to low concentration.

Facilitated diffusion:

1. Its also called Carrier mediated transport
2. No Energy requirement in the process.
3. Some lipid insoluble molecule vitamin, urea, glucose transfer through this process.
4. The receptor molecule/carrier changes its shape during the process.

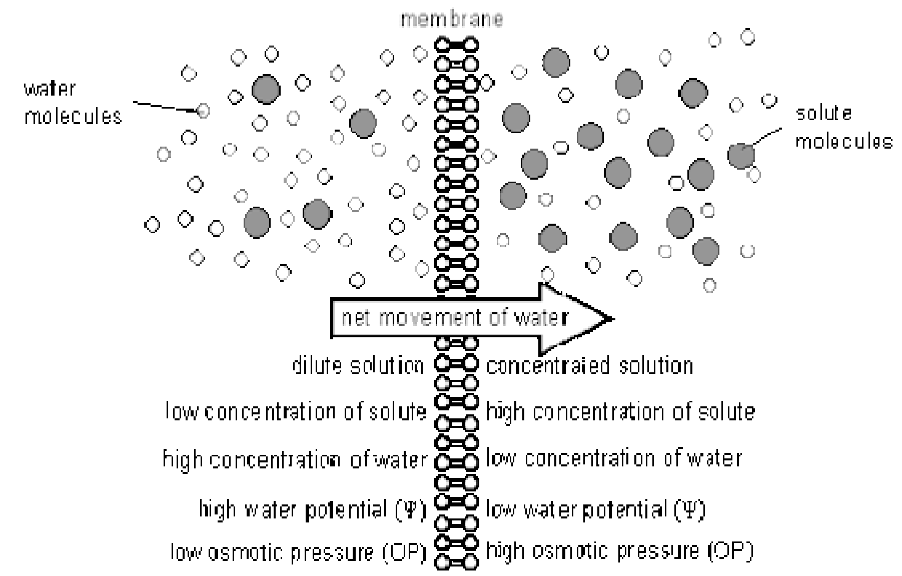


Movement of Small Molecule

(A) Diffusion/Passive : Simply transport of molecule from high concentration to low concentration.

Osmosis

1. Its movement of solvent molecule through semi permeable membrane from higher con. of solvent to lower con.
2. HYDROSTATIC PRESURE: Pressure exerted by liquid on SPM.
3. OSMOTIC PRESSURE: Pressure exerted by solute molecule on SPM through which it can not pass.



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Osmosis

Higher con of solvent/water to lower con.

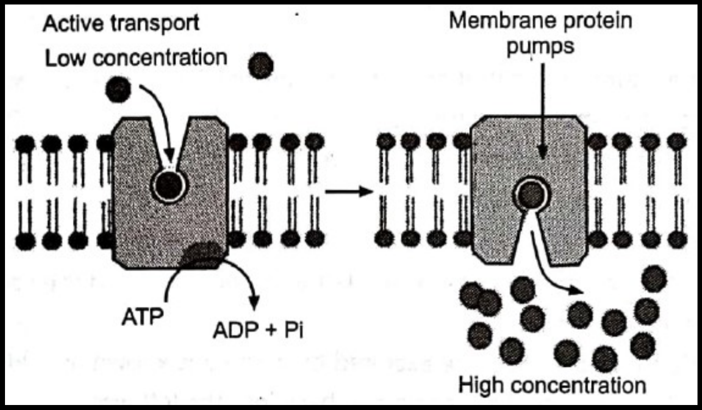
Lower con. Of solute to higher con. of solute

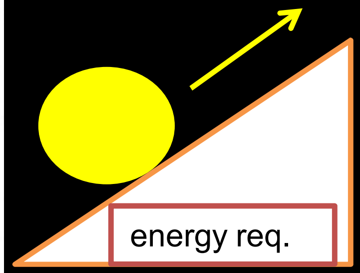
Movement of Small Molecule

(B) ACTIVE TRANSPORT : Simply transport of molecule from low concentration to high concentration which requires energy from hydrolysis of ATP.

Primary Active transport:

1. Energy is derived from hydrolysis of ATP which changes the shape of carrier protein.
2. Carrier protein pumps a substance across plasma membrane against concentration gradient.





Movement of Small Molecule

(B) ACTIVE TRANSPORT : Simply transport of molecule from low concentration to high concentration which requires energy from hydrolysis of ATP.

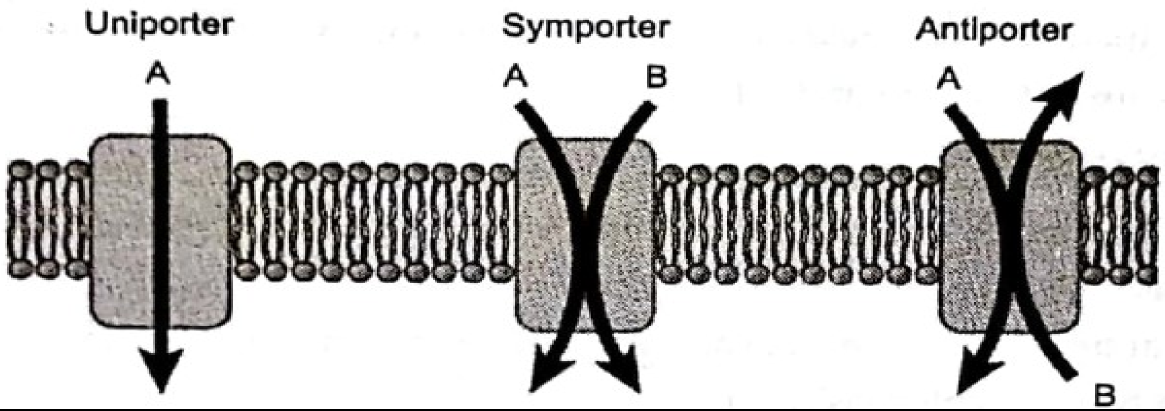
Secondary Active transport:

1. It also uses energy to transport molecules across a membrane.
2. However, in contrast to primary active transport, there is no direct coupling of ATP
3. Instead, the electrochemical potential difference created by pumping ions out of the cell.
4. The main forms of active transport are Uniport, Antiport and Symport.

Movement of Small Molecule

Secondary Active transport:

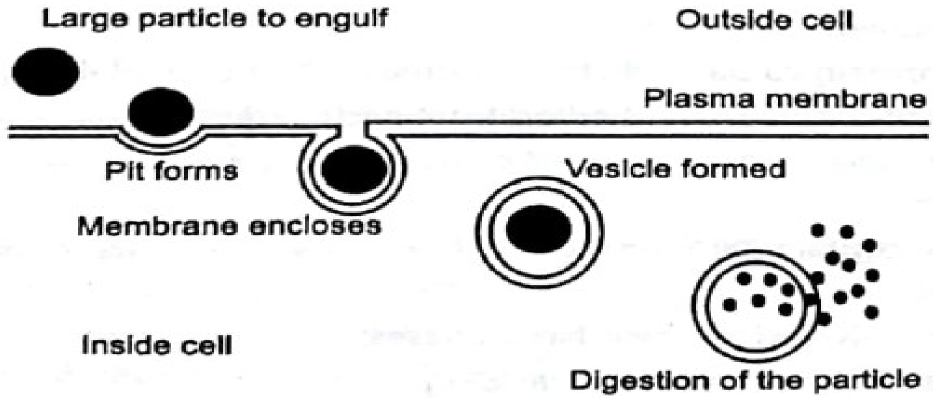
- A symport is an active transport protein that transports two different molecules across the cell membrane at the same time.
- The material transferred along with some ions is called as symport or co-transport.
- An anti-port is an active transport protein that transports two molecules in opposite directions against their concentration gradients.
- An uni-port is an active transport protein that transports single molecule across the cell membrane.



Movement of large Molecule

Endocytosis

- It is a transport mechanism that involves engulfing extracellular materials within a segment of the cell membrane to form a vesicle called as corpuscular or vesicular transport.
- For example, Macromolecular nutrients like fats and starches, oil soluble vitamins A, D, E, K and drugs such as insulin.
- Endocytosis includes two types of processes:
  - (a) **Phagocytosis:** It is a form of endocytosis in which the cell engulfs large solid particles, such as worn out cells, whole bacteria or viruses.
  - (b) **Pinocytosis:** It is a form of endocytosis in which tiny droplets of extracellular fluid are taken up.



Movement of large Molecule

Exocytosis

It is the process by which the cells direct the contents of secretory vesicles out of the cell membrane is known as exocytosis

Types of Exocytosis

- Constitutive exocytosis
- Regulated exocytosis

1. **Constitutive exocytosis:** Secretory materials are continuously released without requirement of any specific kind of signal.
2. **Regulated exocytosis :** Regulated exocytosis requires an external signal, a specific sorting signal on the vesicles for release of components.

Examples : secretion of neurotransmitter, hormones and many other molecules.

CELL CYCLE AND CELL DIVISION

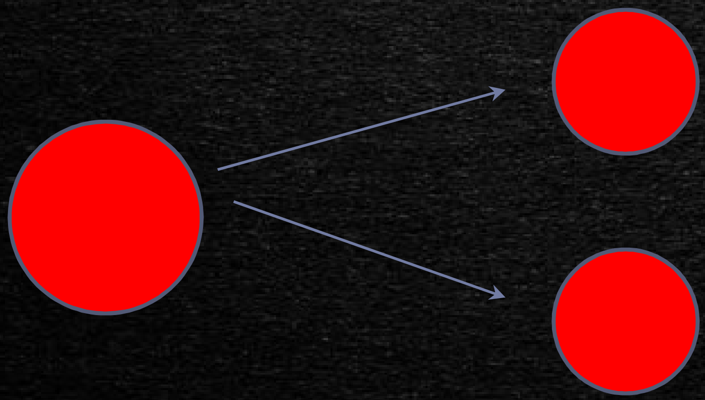
Reeteesh Malvi

CONTENT

1. Introduction to cell division
2. Importance of cell division
3. Types of cell division
4. Cell cycle

INTRODUCTION TO CELL DIVISION

1. It is a process in which one cell divide to produce two daughter cells.
2. These cell divides once in approximately every 24 hours.
3. Duration of cell cycle can vary with organism and cell type.



Importance of cell division

- Cell division is fundamental to all living organisms and required for growth and development.
- To facilitate exchange of material.
- Cell division is necessary to create genetic diversity

Types of cell division

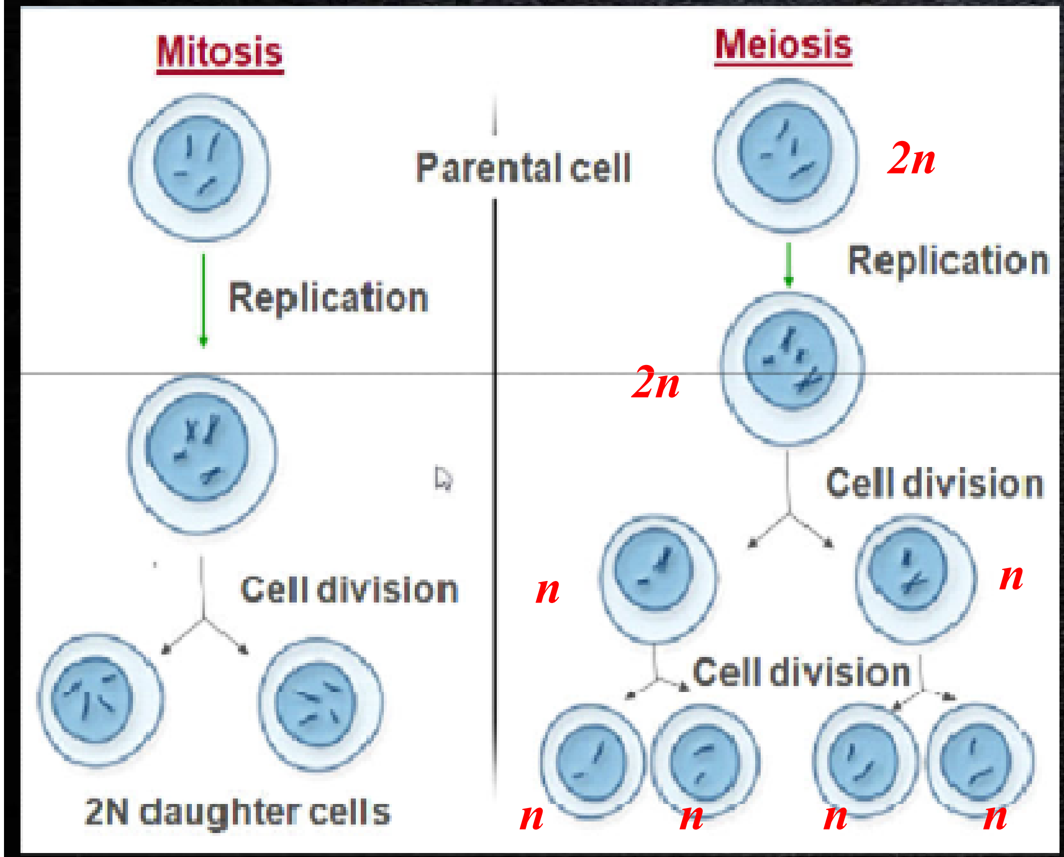
The cell division is of two types on the basis of number of genomes present in the daughter cells in comparison to the dividing parent cell — **mitosis and meiosis.**

Mitosis : समसूत्री विभाजन (Equall in number)

Meiosis : अर्धसूत्रण (Reduction in number)

Miosis : constriction of pupil size

Mitosis and Meiosis



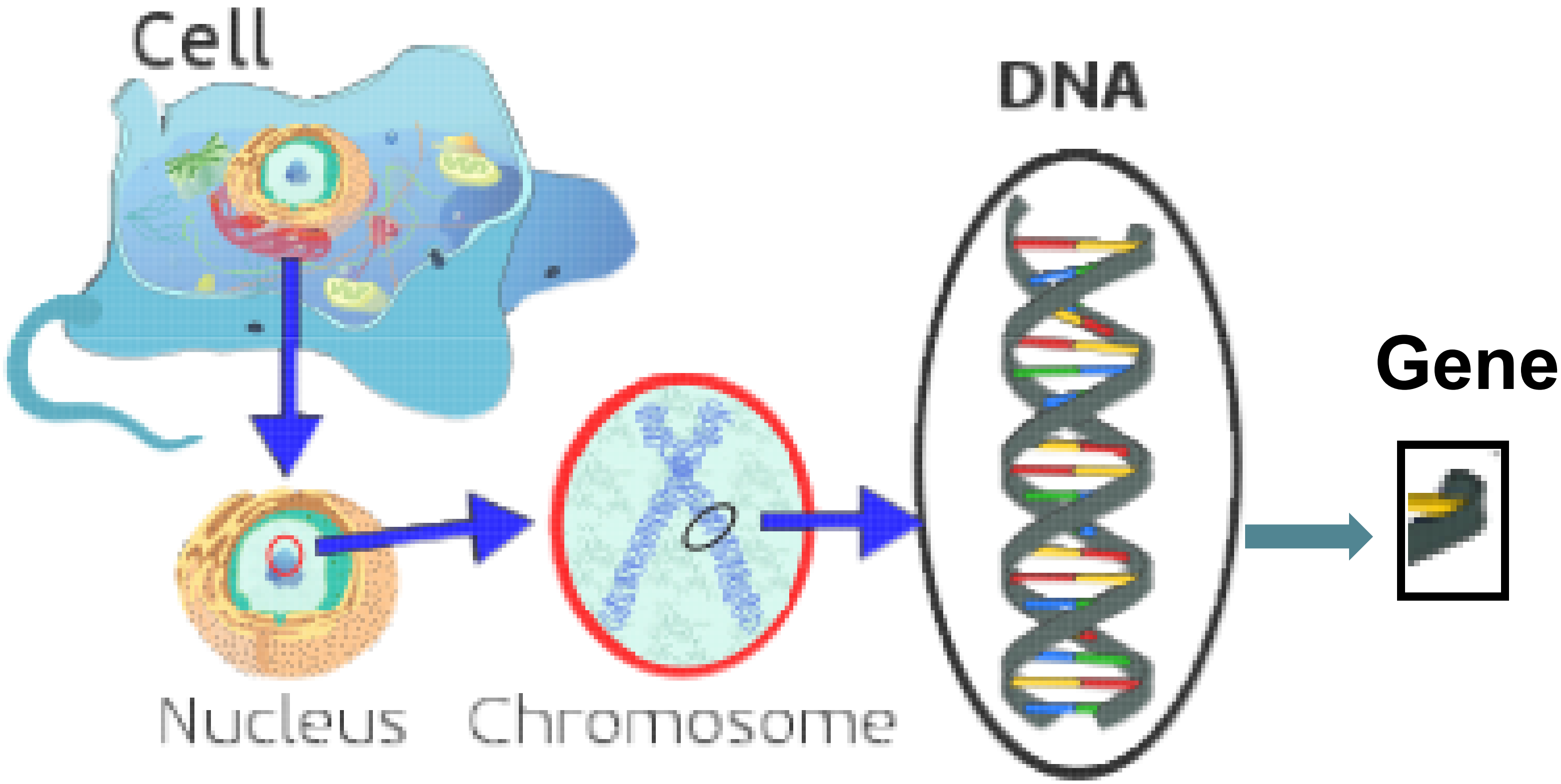
Mitosis

1. ***The term mitosis was coined by W. Flemming in 1882.***
2. ***The multiplication*** of a body cell into two daughter cells of equal size and containing the same number of chromosomes as in the parent cell is called mitosis or **somatic division**

Meiosis

1. ***The term meiosis was first coined by J. B. Farmer (1905) with J. E.* Moore.**
2. **Meiosis occurs only in gonads (in germ mother cells) during the formation of** gametes like sperm and ovum.
3. Meiosis is a process by means of which double number or 2N or diploid chromosomes is reduced to its half number or N or haploid. It is also called **reduction process.**

Relation between Chromosome, DNA and Gene



Other terminologies

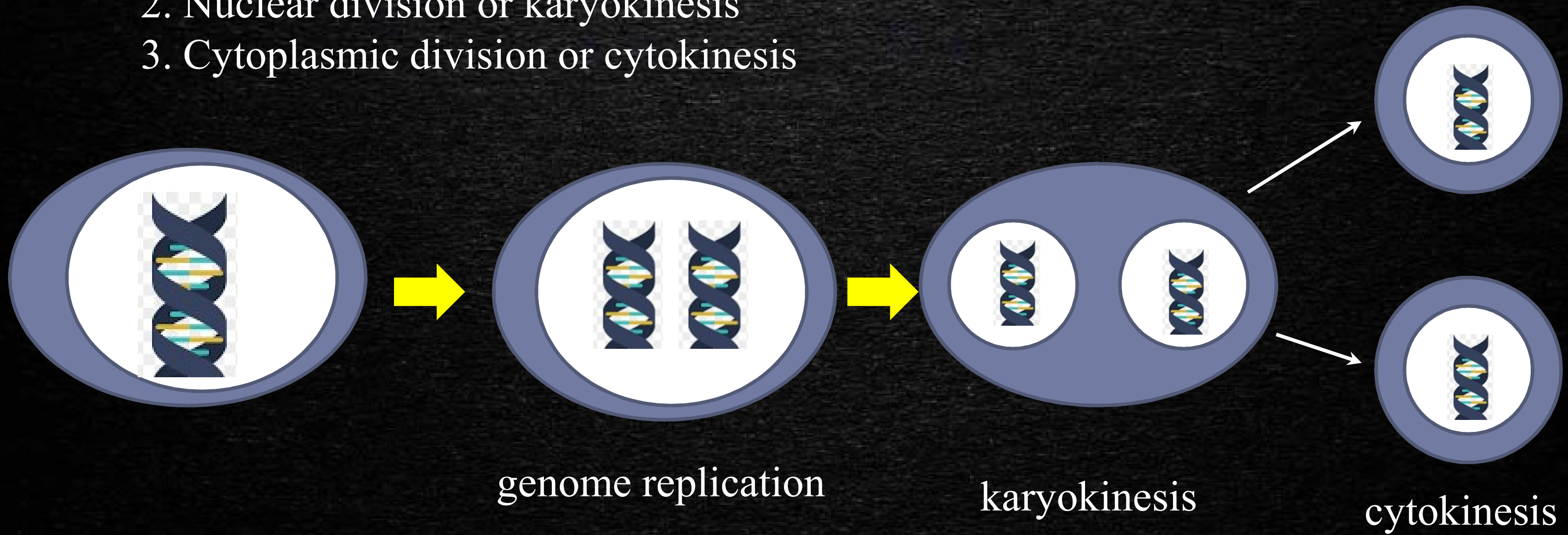
1. **Haploid** : **A cell that contains a single set of chromosomes**. *(n)*
2. **Diploid** : **A cell that contain two copies of each chromosome. *(2n)***
3. **Homologous** : A **homologous chromosome** pertains to one of a pair of chromosomes with the same gene sequence, loci, chromosomal length, and centromere
4. **Karyokinesis :** **During cell division, the process of partition of a cell's nucleus into the daughter cells**.
5. **Cytokinesis :** **C**ytokinesis is **the physical process of cell division**
6. **Cross over :** the exchange of genes between homologous chromosomes.

Cell Cycle and Cell Division

The **cell cycle: It** is a repeating series of events that include growth, DNA synthesis, and cell division.

The cell division is a continuous and dynamic process and it involves the following three stages:

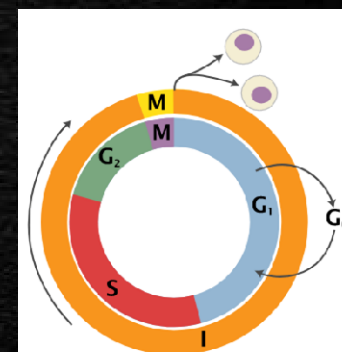
1. DNA or genome replication
2. Nuclear division or karyokinesis
3. Cytoplasmic division or cytokinesis



Cell Cycle and Phases

Cell Cycle

- Interphase
  - G-1 — **Gap I**
  - S — **S Phase or Synthesis**
  - G-2 — **G_2 Phase or Gap 2**
- M-Phase
  - Mitosis
  - Meiosis
    - Meiosis-I
    - Meiosis-II



Interphase

Interphase is the time lapse between two successive M phases of cell division.

Interphase is further divided into three phases: G_1, S, G_2

1. **G_1 Phase or Gap 1:** G1 phase is very significant phase of cell cycle as the cell grows and accumulates the building blocks of chromosomal DNA and the associated proteins as well as sufficient energy reserves to complete the task of replicating each chromosome.
2. **S Phase or Synthesis:**
    1. DNA replication takes place.
    2. The DNA content of the cell doubles and centriole duplicates.
    3. It is important to note that the chromosome number remains the same

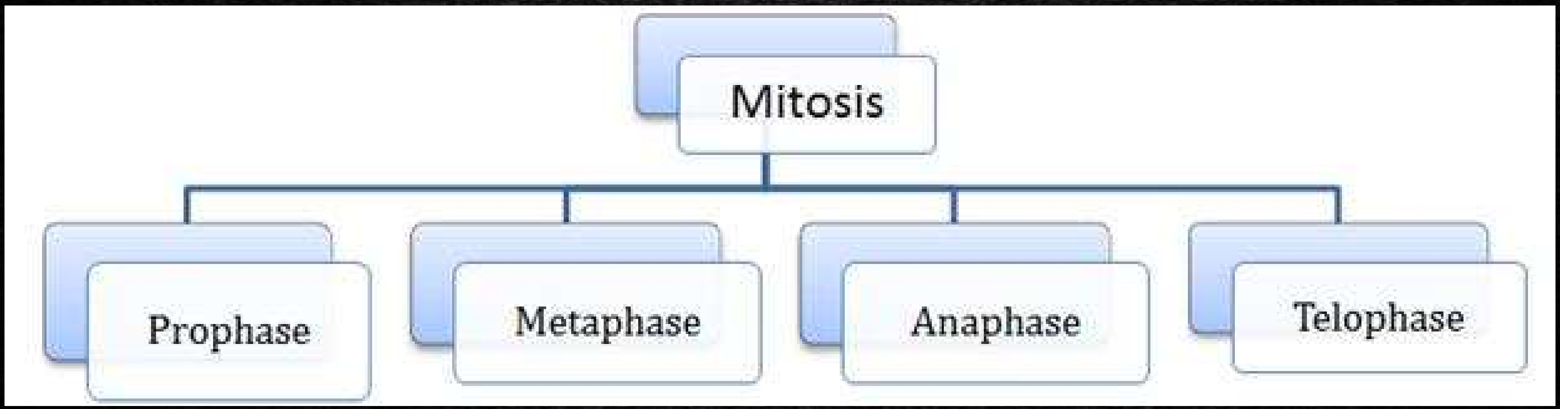
3. G_2 Phase or Gap 2:

- Cell continues to grow and prepare for mitosis.
- Protein synthesis takes place.
- In an adult human being, there are many cells, which do not divide, e.g. heart cells divide occasionally only to replace injured and dead cells.
- These cells enter an inactive phase called **G_0 or quiescent stage** of the cell cycle.

In adult animals, some cells do not divide or may divide occasionally. These cells do not divide further and exits the G1 phase to enter an inactive stage called **Quiescent Stage** (G0) of cell cycle.

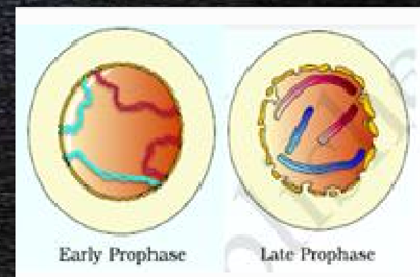
M Phase: The number of chromosomes in the parent and daughter cells remains the same so it is also known as **equational division.**

Karyokinesis, i.e. nuclear division is followed by **cytokinesis**, i.e. division of the cytoplasm to give rise to two daughter cells



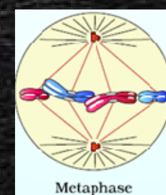
Prophase

Nuclear membrane disappears, spindle fibers form, and DNA condenses into chromosomes (sister chromatids).



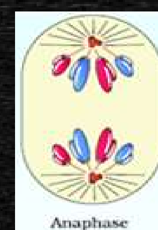
Metaphase

The sister chromatids align along the equator of the cell by attaching their centromeres to the spindle fibers.



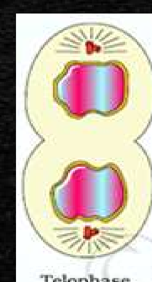
Anaphase

Sister chromatids are separated at the centromere and are pulled towards opposite poles of the cell by the mitotic spindle.



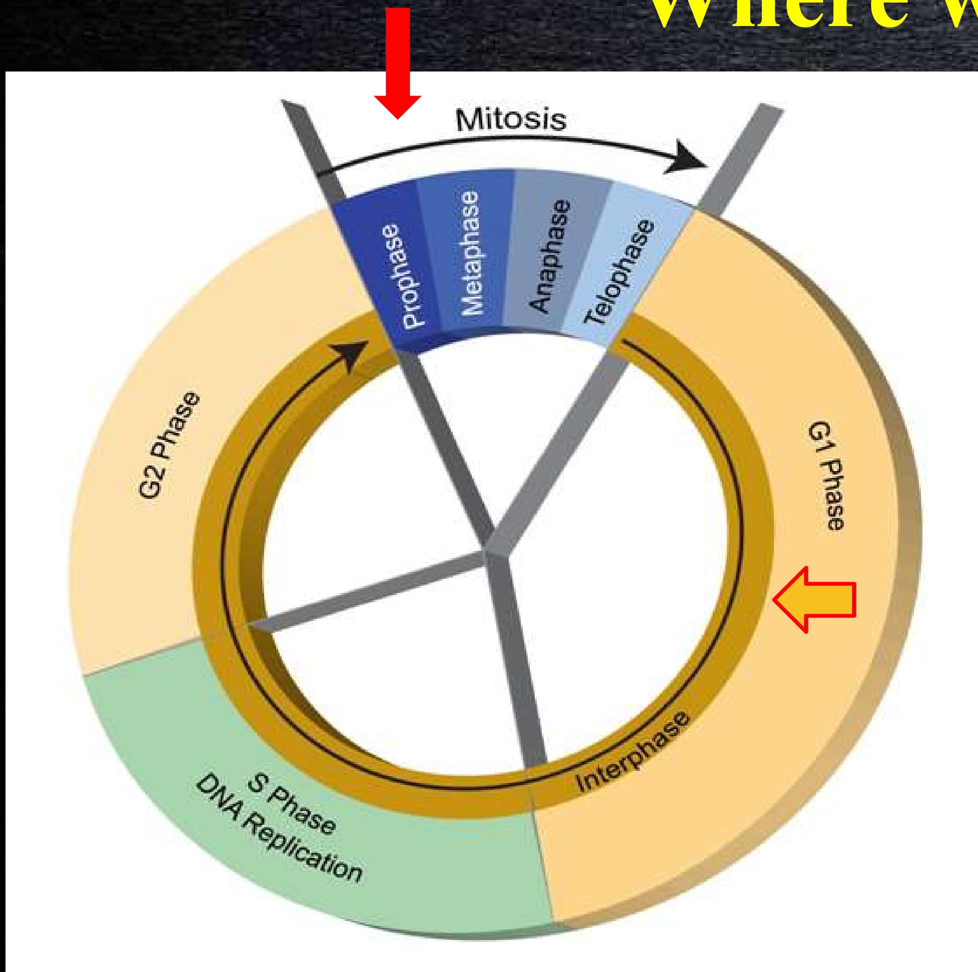
Telophase

Chromosomes arrive at opposite poles and unwind into thin strands of DNA, the spindle fibers disappear, and the nuclear membrane reappears.



Meiosis

Where we are ?



1. Interphase
   1. G-1 Phase
   2. S-Phase
   3. G-2 Phase

2. M.Phasse
   - Mitosis :
     Somatic cells
2. M.Phasse
   - **Meiosis**:
     Reproductive cells

Meiosis

The cell division that reduces the number of chromosome into half and results in the production of haploid daughter cells

Meiosis-I

1. Prophase-I
   - Leptotene
   - Zygotene
   - Panchytene
   - Diplotene
   - Diakinesis
2. Metaphase-I
3. Anaphase-I
4. Telophase-I

Meiosis-II

1. Prophase-II
2. Metaphase-II
3. Anaphase-II
4. Telophase-II

Meiosis I

1. Prophase-I **(LeZy Pach Dip n Dia**.)

Leptotene: Chromosome becomes distinct and visible under microscope.

Zygotene : Chromosomes start pairing together (**synapsis**)

Pachytene : Crossing over between non-sister chromatids of homologous chromosome occurs for exchange of genetic materials.

Diplotene : Dissolution of synaptonemal complex and tendency to separation of bivalent except at the site of crossing over. This forms an X like structure called ***chiasmata.***

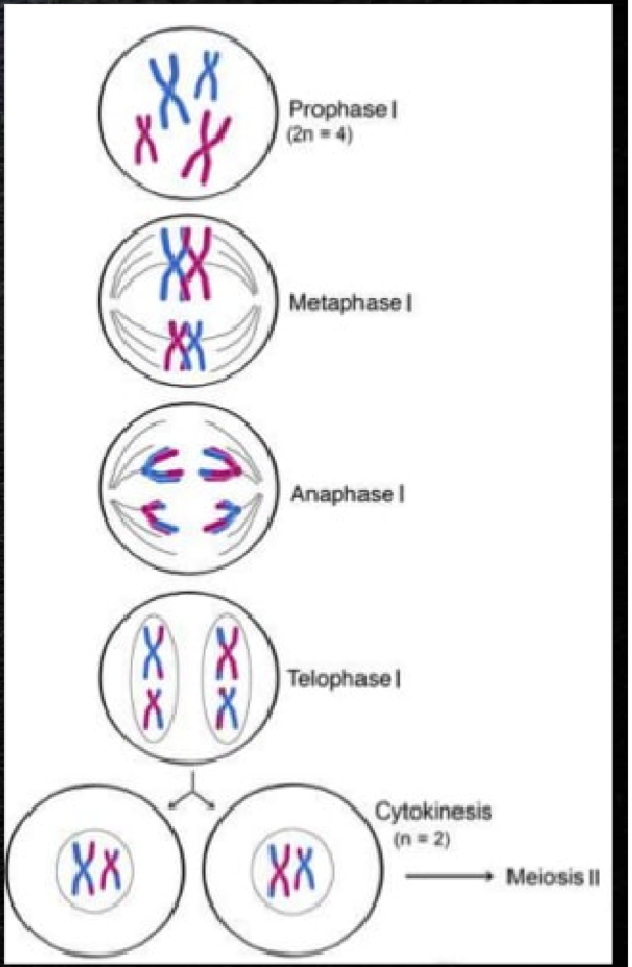
Diakenesis : Terminalisation of chiasmata. The nuclear membrane breaks and nucleolus disappear.

2. **Metaphase-I -** The bivalent chromosome align at equatorial plate and microtubules from the opposite poles of the spindle get attached to the pair of homologous chromosomes.

3. **Anaphase I** – homologous chromosome separate but sister chromatids remain attached at centromere.

4. **Telophase I** : Nuclear membrane and nucleolus reappears and cytokinesis follows. This is called as diad of the cells.

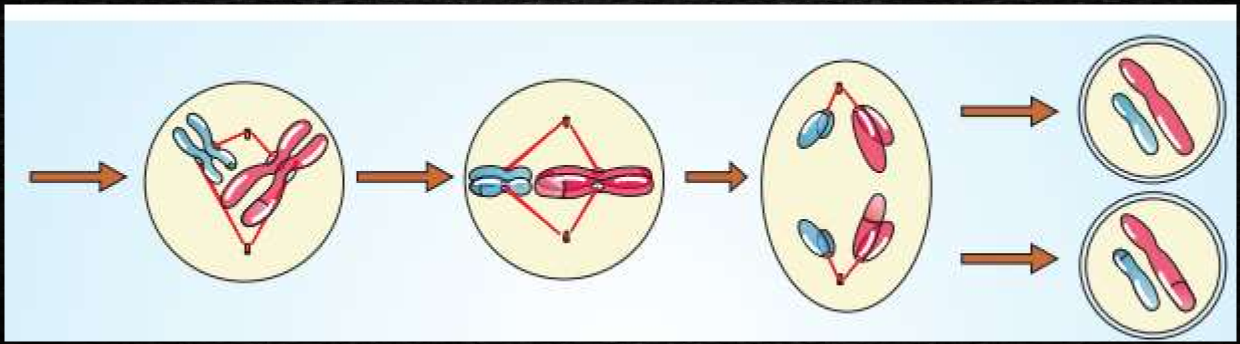
Cytokinesis-I



Meiosis II

It is initiated immediately after cytokinesis.

1. Prophase II, nuclear membrane disappears and chromosome becomes compact.
2. Metaphase II stage, the chromosomes align at equator and microtubules attach with kinetochores of sister chromatids.
3. Anaphase II start with splitting of centromere of each chromosome to move towards opposite poles followed by cytokinesis.



Difference between Mitosis and meiosis

Mitosis	Meiosis
1. Takes place in the somatic cells. 2. It is a single division which produces two cells. 3. Haploid and diploid both kind of cells may undergo mitosis. 4. Crossing over absent. 5. Pairing of chromosome does not occur.	1. Takes place in reproductive cells. 2. It is a double division which produces four cells. 3. Only diploid cells undergo meiosis cell division. 4. Crossing over takes place. 5. Pairing of homologous chromosome occurs.

CELL JUNCTIONS

Cell junctions are specialized structures that connect adjacent cells or link cells to the extracellular matrix, facilitating communication, adhesion, and maintaining the structural integrity of tissues. They are especially important in epithelial tissues. There are three main types of cell junctions:

1. Tight Junctions (Occluding Junctions)

- **Function**: Tight junctions seal neighboring cells together in an epithelial sheet, preventing the passage of molecules and ions between cells (paracellular pathway). They help maintain the polarity of cells by restricting the movement of membrane proteins between the apical and basolateral surfaces.
- **Location**: Found predominantly in epithelial tissues, such as the intestinal lining or the blood-brain barrier.
- **Proteins Involved**: Claudins, occludins, and junctional adhesion molecules (JAMs).

2. Adherens Junctions (Anchoring Junctions)

- **Function**: These junctions connect the actin cytoskeleton of one cell to the actin cytoskeleton of another. They play a role in maintaining tissue integrity and allowing mechanical coupling between cells.
- **Location**: Common in epithelial and endothelial tissues.
- **Proteins Involved**: Cadherins (transmembrane proteins), catenins (link cadherins to actin filaments).

3. Desmosomes (Anchoring Junctions)

- **Function**: Desmosomes provide strong adhesion between adjacent cells by linking intermediate filaments (like keratin) of the cytoskeleton. They help resist mechanical stress in tissues that experience significant stretching.
- **Location**: Prominent in tissues such as the skin, heart, and other epithelia.
- **Proteins Involved**: Desmogleins, desmocollins (cadherin family), and plakoglobin.

4. Gap Junctions (Communicating Junctions)

- **Function**: These junctions allow the direct passage of small molecules and ions between neighboring cells. They enable communication and coordination of cellular activities, such as in heart muscle cells during contraction.
- **Location**: Found in a variety of tissues, including cardiac muscle, neurons, and epithelia.
- **Proteins Involved**: Connexins, which form connexons (channels that bridge the gap between cells).

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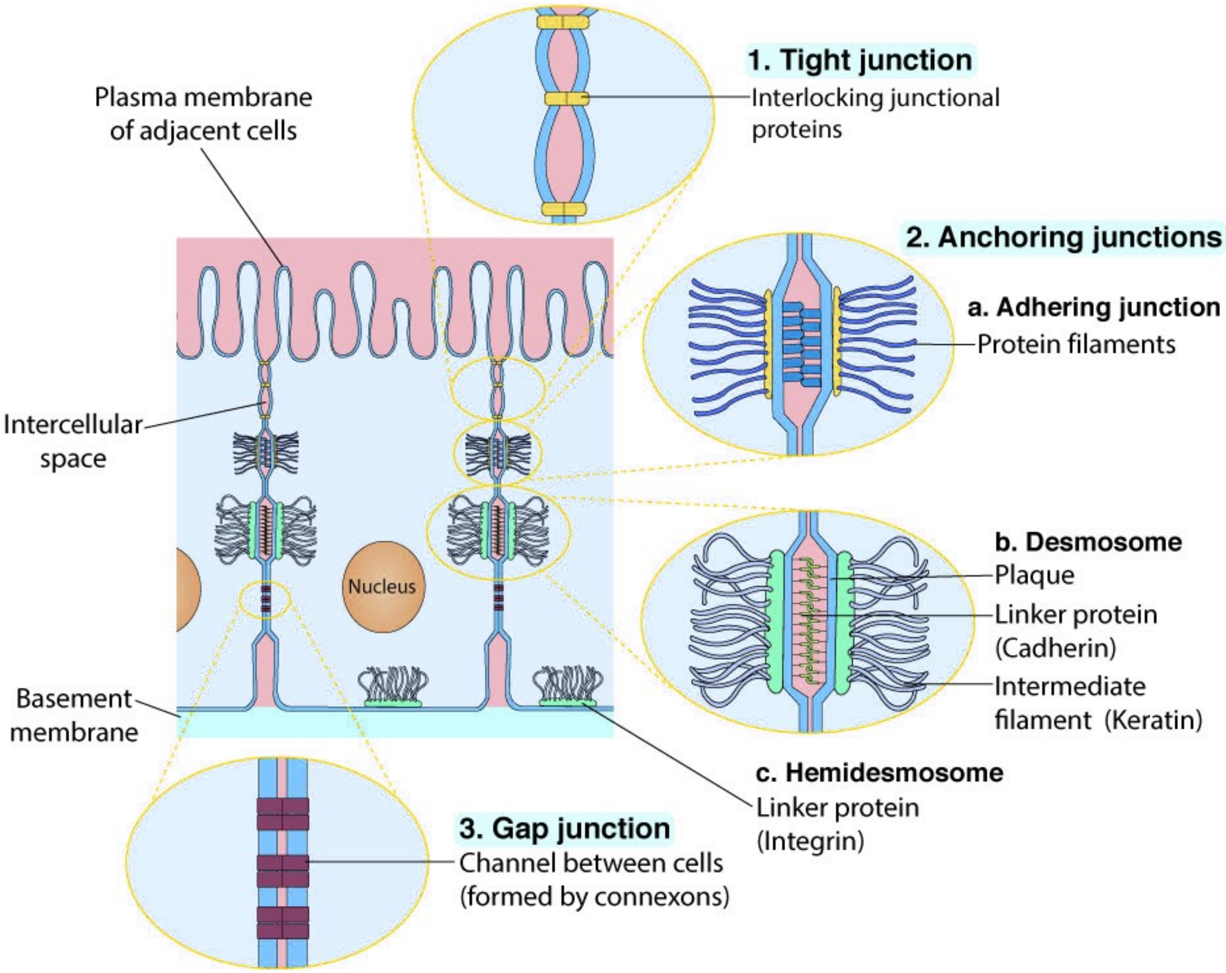
TYPES OF CELL JUCTIONS

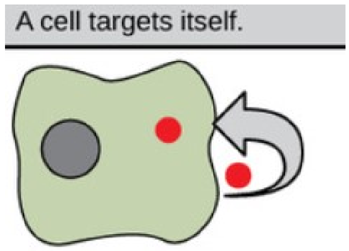


General principles of cell communication

Cell communication is essential for coordinating activities within multicellular organisms, ensuring that cells respond to internal and external stimuli appropriately. It involves sending, receiving, and processing signals. The general principles of cell communication can be summarized as follows:

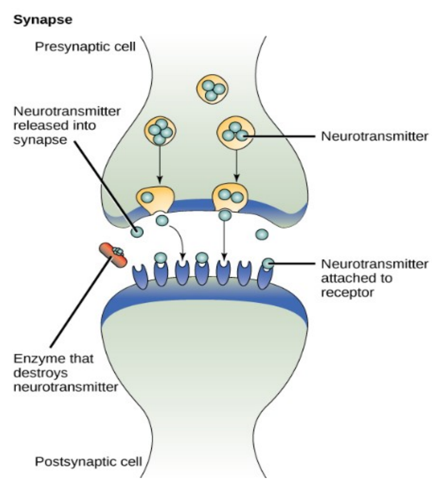
1. Types of Signaling

- **Autocrine Signaling**: Autocrine signals are produced by signaling cells that can also bind to the ligand that is released. This means the signaling cell and the target cell can be the same or a similar cell (the prefix auto- means self, a reminder that the signaling cell sends a signal to itself).

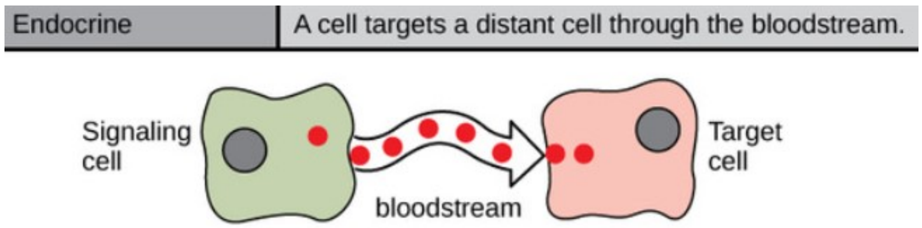


  Example : Early development of an organism. Autocrine signaling also regulates pain sensation and inflammatory responses.

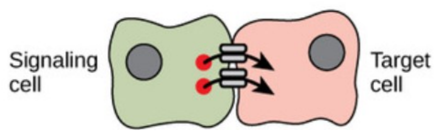
- **Paracrine Signaling**: Signals that act locally between cells that are close together are called paracrine signals. Paracrine signals move by diffusion through the extracellular matrix. These types of signals usually elicit quick responses that last only a short amount of time.
  Example : Transfer of signals across synapses between nerve cells.



- **Endocrine Signaling**: Hormones are released into the bloodstream and travel long distances to target cells throughout the body. This type of signaling is important for regulating processes like metabolism, growth, and reproduction.



- **Juxtacrine (Contact-Dependent) Signaling**: Cells communicate directly through physical contact, often through gap junctions or other membrane-bound proteins. This is important in immune responses and during development.



- **Synaptic Signaling**: Specialized communication between neurons or between neurons and muscle cells via neurotransmitters released at synapses.

2. Signal Molecules

Signal molecules can vary widely in size, structure, and function, and they fall into different categories:

- **Hydrophilic Molecules**: These include peptides, proteins, or small molecules (like neurotransmitters) that cannot cross the plasma membrane. They bind to cell-surface receptors.
- **Hydrophobic Molecules**: These include steroid hormones (like cortisol, estrogen) and thyroid hormones that can diffuse across the plasma membrane and bind to intracellular receptors.
- **Gases**: Small molecules like nitric oxide (NO) can diffuse across membranes and regulate functions like blood vessel dilation.

3. Receptors

Receptors are proteins that bind signaling molecules and initiate the cellular response. There are two major types:

- **Cell-Surface Receptors**: These receptors bind to hydrophilic signal molecules that cannot enter the cell. Major classes include:
    - **G-Protein-Coupled Receptors (GPCRs)**: Activate intracellular G-proteins, triggering a cascade of events.
    - **Receptor Tyrosine Kinases (RTKs)**: Trigger phosphorylation cascades that lead to changes in gene expression or cellular function.
    - **Ion Channel Receptors**: Respond to ligand binding by opening or closing ion channels, affecting membrane potential and cellular activity.
- **Intracellular Receptors**: These receptors are located in the cytoplasm or nucleus. They bind to hydrophobic molecules like steroid hormones and often act as transcription factors to regulate gene expression.

4. Signal Transduction Pathways

After the receptor is activated, the signal is relayed through a series of steps, often involving:

- **Second Messengers**: Small molecules like cyclic AMP (cAMP), inositol triphosphate (IP3), or calcium ions (Ca^{2+}) that amplify and propagate the signal within the cell.
- **Phosphorylation Cascades**: Kinases add phosphate groups to proteins, activating or deactivating them. This is a common way to transmit signals.
- **Protein-Protein Interactions**: Specific proteins interact to propagate the signal to the next step in the pathway.

5. Cellular Responses

The final outcome of signal transduction can vary depending on the cell type and the signal received. Common responses include:

- **Gene Expression**: Changes in transcription factors can turn specific genes on or off, altering protein synthesis.
- **Metabolic Changes**: Signals can activate or inhibit enzymes, affecting cellular metabolism.
- **Cell Growth and Division**: Many pathways control whether a cell will proliferate, differentiate, or enter apoptosis (programmed cell death).

- **Changes in Cell Shape or Movement**: Signals can influence the cytoskeleton, leading to changes in cell motility, adhesion, or morphology.

6. Signal Termination

Signal transduction pathways are tightly regulated, and mechanisms are in place to terminate the signal once the desired response is achieved. This may involve:

- **Degradation of Signal Molecules**: Enzymes break down the signaling molecules, reducing their concentration.
- **Receptor Inactivation**: Receptors can be internalized, degraded, or inactivated.
- **Dephosphorylation**: Phosphatases remove phosphate groups, turning off the signal.

7. Signal Amplification

A small number of signaling molecules can trigger a large-scale response due to amplification at multiple steps of the signal transduction pathway. For example, one activated receptor can activate multiple G-proteins, which in turn activate many downstream molecules.