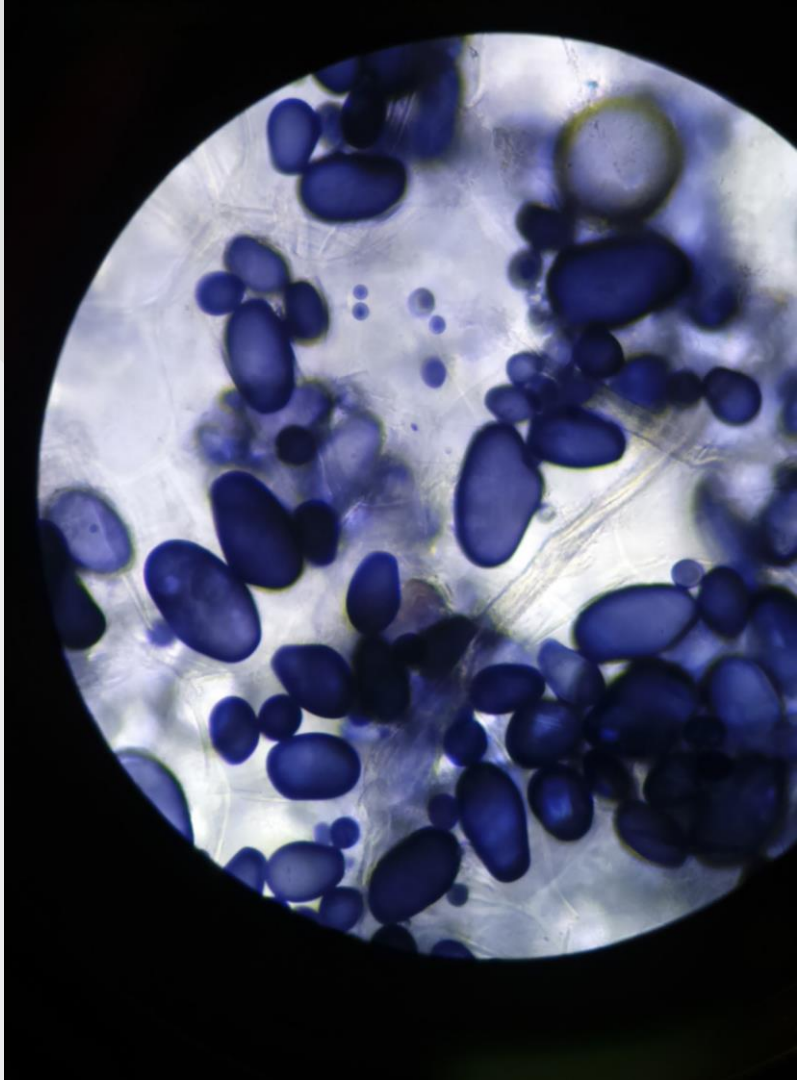
Chapter 1: Cell Biology

H2 Biology



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Introduction

Uni-cellular organisms are composed of a single cell, while **multi-cellular** organisms are composed of many cells.

E.g) Uni-cellular: *E. coli*, Amoeba
E.g.) Multi-cellular: Plants and Animals

In multi-cellular organisms…
Cells → Tissues → Organs → System → Organism

Multiple **cells** come together to form **tissues**. Multiple tissues come together to form **organs**. Multiple organs form an **organ system**. An **organism** comprises of an organ system.

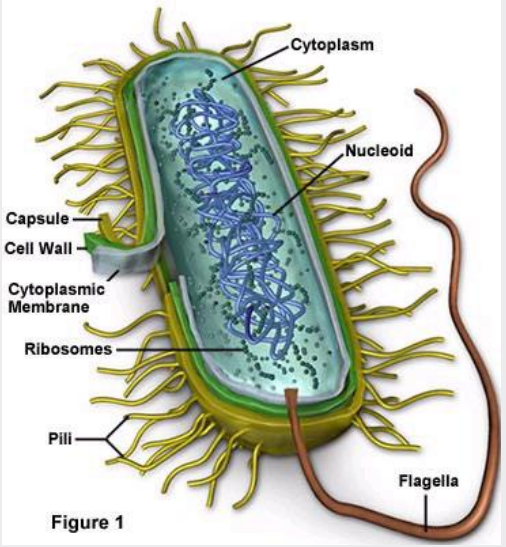
Introduction

Prokaryotic and Eukaryotic Cells

Organisms can be divided into 2 categories, namely, **prokaryotes** and **eukaryotes**.

Prokaryotes

- A prokaryotic cell **lacks a true nucleus** and **lacks membrane-bound organelles**.
- Genetic material exists as a **circular DNA molecule** that lies freely in the cytoplasm in a region called the **nucleoid**.
- An example of a prokaryote is bacteria.



Prokaryotic Cell

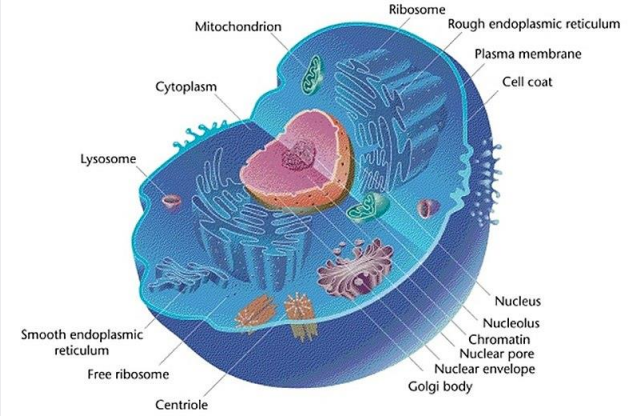
Introduction

Prokaryotic and Eukaryotic Cells

Organisms can be divided into 2 categories, namely, **prokaryotes** and **eukaryotes**.

Eukaryotes

- A **eukaryotic cell** has a **true, membrane-bound nucleus** and **membrane-bound organelles**.
- Genetic material exists as **DNA molecules** that are closely associated with **histone proteins** to form **chromatin**.
- Eukaryotic cells are generally larger than prokaryotic cells.
- Examples of eukaryotes: all plants, animals, fungi and protists.



Eukaryotic Cell

Introduction

Exam Tip:

Consolidate the content by doing a comparison between prokaryotic and eukaryotic cells!

Questions may test you on the **similarities and differences**.

Similarities		
	Differences	
Features	**Prokaryotic Cells**	**Eukaryotic Cells**
Nucleus		
Genetic Material		
Membrane-bound organelles		
Nuclear Division	Binary Fission	Meiosis or Mitosis
Ribosome	70S ribosome	80S ribosome

Introduction

Given the small size of cells, the microscope is used to measure the dimensions of a cell and its organelles.

It can also be used to observe organelles and physiological processes.

There are two types of microscopy, namely, **light microscopy** and **electron microscopy**.

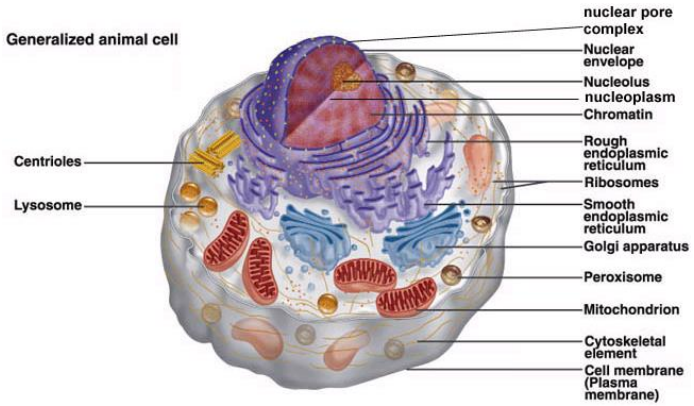
Cells and their molecules are often measured in **micrometers (µm) and nanometers (nm)**.

The conversions between the units of length are as follow:

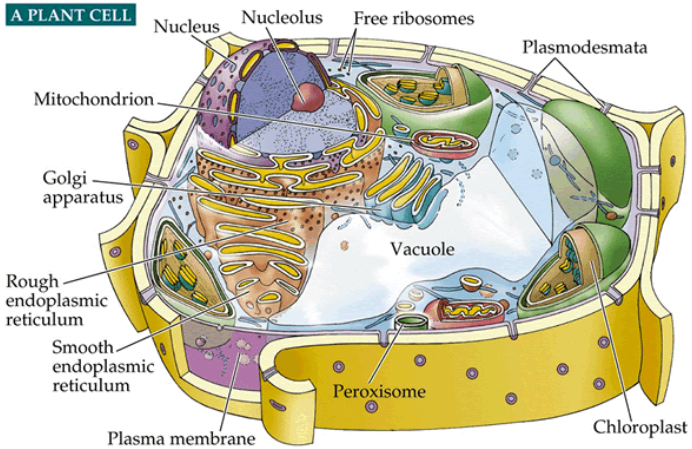
- 1 meter (m) = 1000 millimeters (mm)
- 1 mm (10^{-3} m) = 1000 micrometers (µm)
- 1 µm (10^{-6} m) = 1000 nanometers (nm)

Introduction

Animal Cells



Plant Cells



Lysosomes, **centrioles** and **flagella** are found in animal cells but not in plant cells.

Chloroplasts, a **large central vacuole**, **tonoplast**, **cell wall** and **plasmodesmata** are found in plant cells and not animal cells.

Cellular Structures and Functions

a) **Nucleus** – contains the **genetic material** of the organism in the form of **DNA**. Structurally, the nucleus comprises: **nuclear envelope** with **nuclear pores**, nucleoplasm, **chromatin** and **nucleolus.**

b) **Cytoplasm** – semi-fluid mixture of **cytosol** and **organelles**. The cytosol is the aqueous solution of ions and organic molecules/compounds, excluding organelles.

c) **Ribosomes** – non-membrane bound organelles that comprise of a **large subunit** and a **small subunit**. One subunit is made up of **rRNA** and **ribosomal proteins.** They are **70S ribosomes** in prokaryotes and **80S ribosomes** in eukaryotes.
   a) Ribosomes function as the main site of **protein synthesis**, where they translate **messenger RNA (mRNA)** into a **polypeptide chain**.

Cellular Structures and Functions

Endomembrane System

- **Endoplasmic Reticulum** – an interconnected network of tubules, vesicles and sacs.
  - **Rough Endoplasmic Reticulum (rER)** – consists of a three-dimensional network of interconnecting flattened membrane-bound sacs called cisternae. It looks rough because of the ribosomes attached to the cytoplasmic side of the ER membranes.
    - The rER functions in **folding polypeptides into their native three-dimensional conformations** (i.e., proteins), **transporting proteins** and **chemical modification** of proteins (e.g., **glycosylation**)
  - **Smooth Endoplasmic Reticulum (sER)** – consists of a three-dimensional network of interconnecting membrane-bound tubules called cisternae. It has a more tubular structure than the rER and has **no ribosomes** attached to the outer surface, hence giving it a smoother shape.
    - The sER functions in **synthesizing lipids**, **detoxification**, **calcium storage** and **carbohydrate metabolism**.

Cellular Structures and Functions

Endomembrane System

- **Golgi Apparatus (GA)** – consists of one or several stacks of flattened, curved membrane-bound sacs called cisternae.
  - New cisternae are constantly formed at the **cis** (receiving) **face** by fusing with transport vesicles from the rER and sER, while **Golgi vesicles** bud off from the **trans** (secreting) **face**.
  - The GA functions in **chemical modification of proteins and lipids** from the rER and sER (e.g., **glycosylation** and **phosphorylation**), **temporary storage and packaging of proteins** from the rER and **formation of lysosomes.**
  - In other words, the GA functions primarily for **chemically modifying**, **sorting**, and **packaging** cellular macromolecules for cell secretion or use within the cell.

Cellular Structures and Functions

Endomembrane System

- **Vesicles** – are tiny sacs bound by a single membrane, formed when a small piece/area of a membrane buds/pinches off while enclosing a substance. Vesicles are formed when they bud/pinch off from the rER, sER and GA. They function to **transport substances** from one membrane compartment to another. Vesicles play a key role in **endocytosis**.

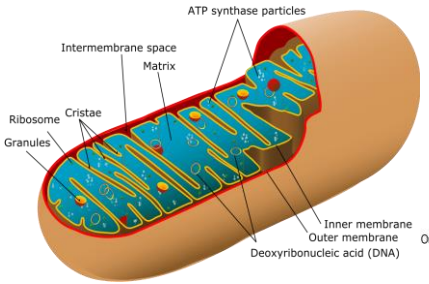
- **Lysosomes** – are small, spherical vesicles containing **hydrolytic enzymes** found in eukaryotic cells. These enzymes include proteases, nucleases, lipases and acid phosphatases. The internal environment of the lysosome is often acidic, providing the optimal pH for the enzymes to function. (*Recall: Lysosomes are absent in plant cells*)
    - Lysosomes function in **digestion of food/foreign particles** during the process of **phagocytosis**, the **removal of unwanted or damaged organelles** in the process of **autophagy**.

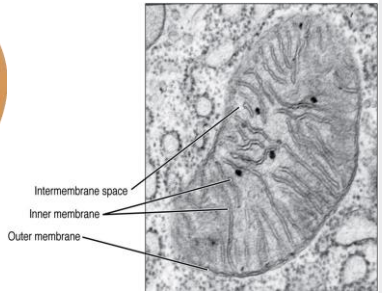
Cellular Structures and Functions

- **Mitochondria** – are cylindrical/rod-shaped organelles, bound by a double-membrane where the **inner membrane is extensively folded to form cristae**. This extensive folding **increases the surface area** of the inner membrane, allowing for many proteins and enzymes to be embedded, such as: **electron carriers** and stalked particles containing **ATP synthase**. The inner and outer membranes are separated by an intermembrane space, and the semi-fluid mitochondrial matrix contains **circular DNA**, **70S ribosomes**, **Krebs cycle enzymes**, **glycogen granules**.
    - The primary role of the mitochondrion is to function as the **site of cellular respiration**, where **glucose is metabolized** to **synthesize adenosine triphosphate (ATP)**. ATP is the main **energy** source of cellular processes.
- **Chloroplasts** – are cylindrical organelles bound by a double-membrane, where the **inner membrane gives rise to thylakoids and lamellae**. Thylakoids are stacked to form **grana** (consisting of multiple **granum**), and extensive folding of thylakoids **increases the surface area** for proteins and enzymes to be embedded, such as: **electron carriers** and stalked particles containing **ATP synthase**. The interior of the chloroplast is filled with a gel-like matrix called the **stroma**, which contains circular **DNA**, **70S ribosomes**, **Calvin cycle enzymes**, and **starch grains**.
    - The primary tole of the chloroplast is to function as the site of **photosynthesis**, where light energy trapped by pigments is used to synthesize organic compounds such as sugars from carbon dioxide and water.

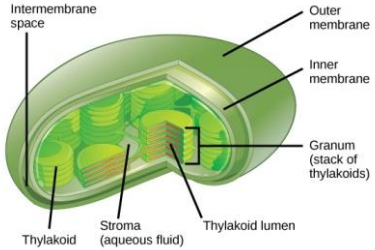
Cellular Structures and Functions

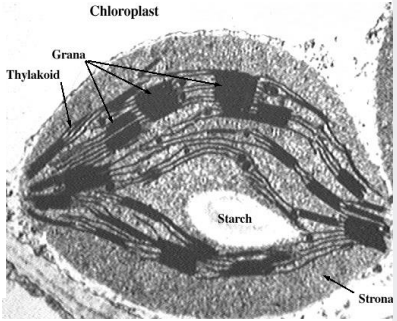
Mitochondria





Chloroplasts





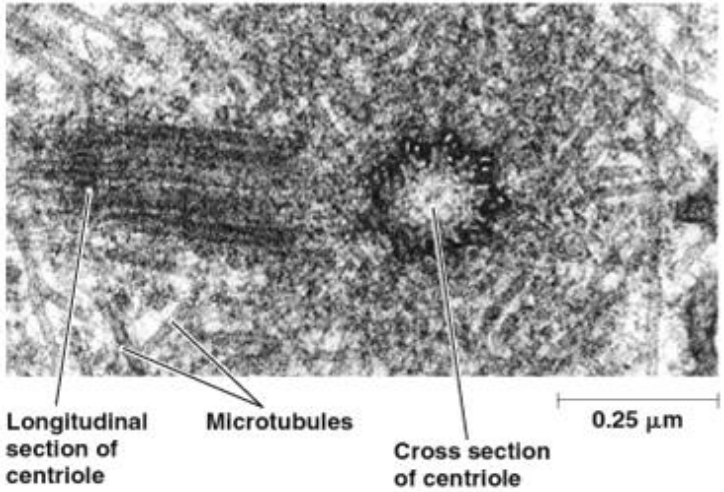
Cellular Structures and Functions

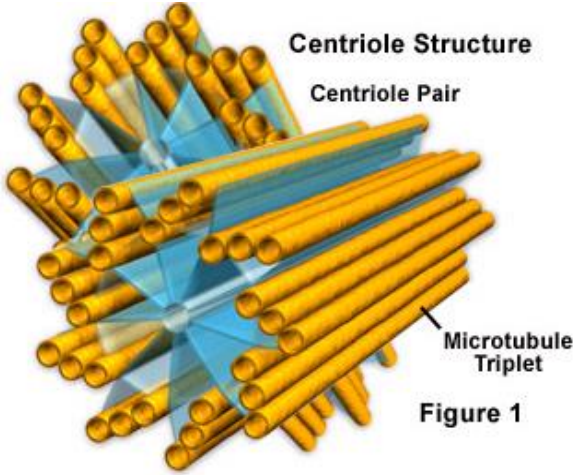
What do you think are the similarities between mitochondria and chloroplasts?

1. Both are bounded by a double _____.
2. Both contain _____ and _____ embedded in the inner membrane.
3. They contain ___ ribosomes.
4. They contain single, ____ DNA.
5. They can divide by the process of _____.

Cellular Structures and Functions

- **Centrioles** – are **pairs of rod-like structures**, positioned at **right angles** to each other. They are composed of **nine sets of triplet microtubules** arranged in a ring. Centrioles function during animal **cell division** where they **replicate and migrate to opposite poles** of the cell to **organize microtubules into spindle fibers**. This helps to **align** the chromosomes during metaphase and **pull** the chromosomes apart during anaphase.



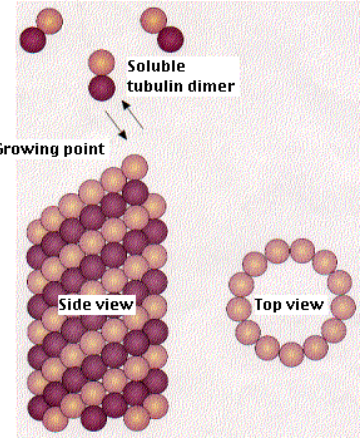


Cellular Structures and Functions

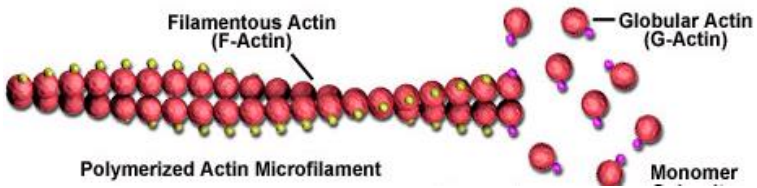
- **Cytoskeleton** – a network of fibers extending throughout the cytoplasm that organizes the structures and activities within the cell. The 3 main types of fiber that make up the cytoskeleton are: **microtubules**, **microfilaments** and **intermediate filaments**.
    - **Microtubules** – are the thickest class of cytoskeletal fibers that are made up of a helically arranged globular protein (**tubulin**). They are able to **resist compression**, have a **certain degree of stiffness** and can **lengthen or shorten** by **polymerization** and **depolymerization** of tubulin.
        - They function in the **movement of chromosomes** during cell division. They also function in the **movement of organelles** within the cell, whereby **motor proteins** carry organelles along microtubules to their destination (E.g., Vesicle movement). Finally, microtubules provide **mechanical support and maintains the shape of the cell**.
    - **Microfilaments** – are the thinnest class of the cytoskeletal fibers, made up of solid rods of globular protein called actin.
        - They are involved in **cleavage furrow formation** during cell division, play a role in **cell motility** and helps to **maintain and change cell shape**.

Cellular Structures and Functions

Microtubules



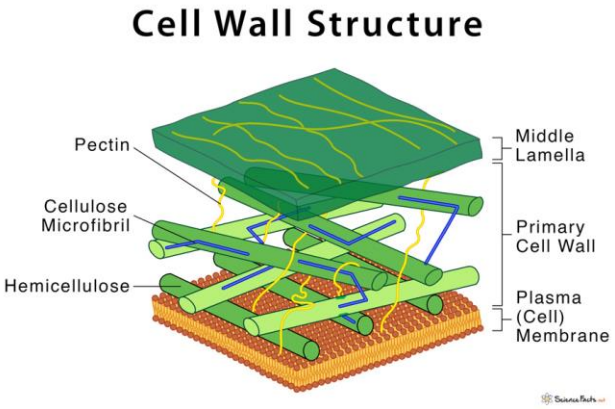
Microfilaments



A+B=C

Cellular Structures and Functions

- **Plant Cell Wall** – is a structure that comprises cellulose microfibrils that run through a matrix of complex polysaccharides, pectins and hemicellulose.
    - The cell wall's primary function is to **provide mechanical strength and support** for the individual plant cells, and hence the plant as a whole. It **maintains the shape of plant cells** due to its **high tensile strength**. Furthermore, the cell wall is **highly rigid** and **resistant to expansion**. This causes the development of **turgidity** when water enters the cell via osmosis.



Cell Membrane

- **Cell membranes** refer to the membranes outlining the surface of all living cells and membrane-bound organelles in eukaryotic cells. Some examples of such organelles are the endoplasmic reticulum, Golgi apparatus, nucleus, mitochondria and chloroplasts.

- The main components of a cell membrane are **phospholipids, proteins, glycoproteins, glycolipids and cholesterol.** Different membranes have different compositions of lipids and proteins, depending on the membrane's function.

- The **fluid mosaic model** is used to describe the cell membrane.

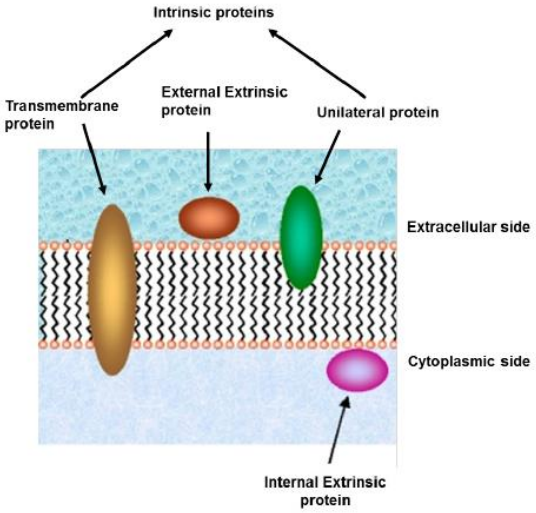
- **Fluid** refers to how the **phospholipids and proteins** comprising the membrane can **move freely** (laterally) within the bilayer.

- **Mosaic** refers to how **protein molecules are embedded and scattered** among the phospholipids. Some proteins are for example, channel proteins, receptors, enzymes and glycoproteins.

Cell Membrane

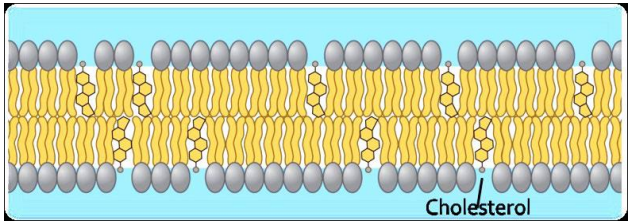
- **Phospholipids** – amphipathic, consisting of a **hydrophilic phosphate group** and 2 **hydrophobic fatty acid tails**.

- **Membrane proteins** can be divided into **extrinsic** or **intrinsic** proteins. Extrinsic proteins are further divided into either **internal** or **external**, while intrinsic proteins are divided into **unilateral** or **transmembrane**.



Cell Membrane

- There are a variety of membrane proteins each with their own functions such as:
    - **Transport proteins:** e.g.. **Channel proteins** and **carrier proteins**.
    - **Enzymes**
    - **Receptor proteins** for **signal transduction**
- **Glycoproteins and glycolipids** refer to proteins and lipids with addition of **short carbohydrate chains**. They primarily function for **cell-cell recognition**, **cell-cell adhesion** and can also serve as **receptor sites**.
- **Cholesterol** is a class of sterols found in the membranes of animal cells. It is interspersed across the bilayer and prevents the close packing of phospholipids. It functions to **regulate fluidity of the cell membrane**, **maintains mechanical stability** and **prevents leakage of small polar molecules**.



Cell Membrane

- **Membrane fluidity** is affected by various factors such as **temperature**, **lipid composition** and **presence of cholesterol.** Membrane fluidity is important for allowing interactions between membrane proteins, growth and healing of the cell membrane, cell elongation and division and formation of vesicles.

- The main functions of cell membranes are:

  - Providing a **boundary** that separates cell contents from the external environment.

  - **Compartmentalization** to **prevent indiscriminate mixing of cellular contents** and **specialization of cell function**.

  - **Partially/Selectively Permeable Barrier.**

  - **Signal transduction** due to **presence of receptor proteins**.

  - **Intercellular communication**

Transport

- **Transport** of substances across membranes is an important process that occurs in cells.

- This allows the cell to:
  - Obtain nutrients
  - Maintain optimal pH
  - Secrete products
  - Excrete metabolic waste
  - Generate an ionic gradient

- The mode of transport depends on the properties of the molecule, which can be divided into two main categories:

- **Hydrophobic molecules** – are **non-polar molecules** and do not favor interaction with water molecules. For instance, **small hydrophobic non-polar molecules** such as oxygen can dissolve in the hydrophobic fatty acid tails of the phospholipid bilayer, hence passing through the membrane,

- **Hydrophilic molecules** – can be **polar molecules or charged ions**. **Small polar substances** such as water molecules can pass through the gaps between phospholipids. **Large polar substances** such as glucose require help from transport proteins as they cannot pass through the membrane easily. **Charged ions** also require help from transport proteins.

Transport

- There are 3 main modes of transport.
  - **Passive Transport** – the **movement of substances down a concentration gradient without the use of ATP**.
    - **Diffusion** – the **net movement of molecules down a concentration gradient until a dynamic equilibrium is reached**.
    - **Facilitated Diffusion** – the **net movement of molecules down a concentration gradient** with the help of specific **transport proteins** until a **dynamic equilibrium is reached**.
    - **Osmosis** – the **net movement of water molecules down a water potential gradient** until **dynamic equilibrium** is reached.
  - **Active Transport** – the **movement of substances against a concentration gradient**, using **energy in the form of ATP**.

Transport

- There are 3 main modes of transport.
  - **Bulk Transport**
    - **Endocytosis** – the process of **intake of substances by invagination of the cell surface membrane** or **extension of pseudopodia**. A small area of **cell surface membrane hence pinches/buds off to form a vesicle containing the substance**.
      - **Phagocytosis** – the **uptake of large, solid materials**. A specific process whereby phagocytes recognize the molecules before engulfing them. E.g., White blood cells phagocytosing pathogens.
      - **Pinocytosis** – the **uptake of droplets of extracellular fluids via tiny vesicles**.
    - **Exocytosis** – the transport of materials **out of the cell**, via a vesicle.

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