

STUDENTS' LEARNING OUTCOMES

After studying this chapter, the students will be able to:

- Describe that cells are the basic unit of life with respect to seven properties of life (movement, respiration, homeostasis, growth, reproduction, excretion, nutrition).
- State cell theory (including how to validate it and exceptions to it).
- Compare and contrast the workings of a light microscope and electron microscope with focus on resolution and magnification and live vs dead samples.
- Identify the ultrastructure of animal and plant cells.
- Describe the structure and functions of cell wall, cell membrane and subcellular organelles (endoplasmic reticulum, ribosomes Golgi apparatus, vesicles, lysosomes, peroxisome, vacuoles, mitochondria, plastids, centrioles, nucleus).
- Differentiate between prokaryotic and eukaryotic cells with diagrams.
- Explain the structure of the cell membrane and the techniques that can be used to study it.
- Define cell signalling.
- Discuss the pathway of a signal from outside the cell to the inside. (protein signal and steroid signal).
- Explain the 4 membrane transport mechanisms with diagrams (simple diffusion, facilitated diffusion, osmosis, active transport).
- Describe endocytosis and exocytosis with diagrams.
- Compare and contrast simple and facilitated diffusion.
- Define stem cells and advantages of using stem cells
- Categorize different types of stem cells.
- Evaluate the advantages and disadvantages of using Induced Pluripotent Stem Cells.

In this chapter "Cell and Subcellular Organelles," we will do a detailed study of cells, the fundamental units that compose all living things. Building on your previous knowledge from Grade IX, we will explore the cell theory and examine the structures of both animal and plant cells. You'll also discover the vital processes of cell signalling, and the revolutionary potential of stem cells. Additionally, we will investigate the mechanisms of membrane transport that are crucial for cellular function.

3.1- CELLS – THE BASIC UNIT OF LIFE

Cells are the basic unit of life, making up every living organism. In unicellular organisms like amoebas and bacteria, a single cell carries out all the functions necessary for life. Multicellular organisms, such as plants and animals, are composed of numerous specialized cells that work together to sustain life.

You know that all living organisms show the seven basic properties of life i.e., movement, respiration, homeostasis, growth, reproduction, excretion, and nutrition.

These properties actually define living organisms. Cells perform all the fundamental activities that characterize living organisms.

1. **Movement:** Cells can move. For example, sperm cells move with their flagella. White blood cells travel through the bloodstream to fight infections. Inside cells, organelles move to carry out vital functions.
2. **Nutrition:** Cells obtain nutrients from their environment to produce energy, build cellular structures, and drive biochemical reactions.
3. **Respiration:** Cells generate energy through respiration. This process breaks glucose to release ATP, the energy currency that powers cellular activities.
4. **Excretion:** Cells remove waste products through diffusion and active transport, preventing toxic buildup.
5. **Homeostasis:** Cells maintain a stable internal environment by regulating the movement of substances across their membranes.
6. **Growth:** Cells grow by taking in nutrients and converting them into cellular components.
7. **Reproduction:** Cells reproduce through mitosis and meiosis. Mitosis produces identical daughter cells for growth and repair, while meiosis creates gametes for sexual reproduction.

3.2- CELL THEORY

At the beginning of 17th century, many scientists began the use of microscopes to study very small objects. In 1665, English scientist **Robert Hooke** examined a thin slice of cork of oak tree under microscope. He observed that the cork was made of "many little boxes". Hooke also examined the pieces of stem and root of oak tree under microscope. He found that these were also made of similar little boxes. He concluded that the parts of plants were made of compartments. Hooke named these compartments as "**cellulae**".

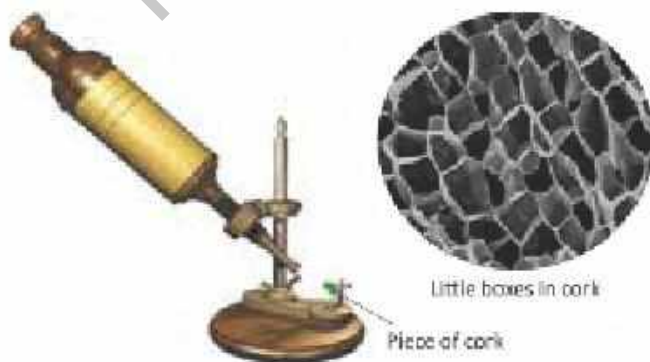


Figure 3.1: Robert Hooke's microscope and observation

In 1673, a Dutch scientist **Anton van Leeuwenhoek** made a better microscope and observed living cells in pond water. He called these cells as **animalcules**.

In 1809, the French biologist **Jean Baptiste de-Lamarck** also observed cells when he examined the parts of animals and plants under microscope. Later on, in 1831 the British botanist **Robert Brown** discovered nucleus in the cell.

After these studies, biologists began to organize information about cells. In 1838, the German botanist **Matthias Schleiden** observed many parts of plants under microscope. He concluded that all plants were composed of cells. The next year, the German zoologist **Theodor Schwann** concluded the same for animals. In 1885, the German physician **Rudolf Virchow** (1821–1902) observed that all cells come from other cells. In 1862, **Louis Pasteur** provided the experimental proof of this idea. These observations were combined to form a basic theory about cells. It is called cell theory. It has three essential points.

1. All living organisms are composed of one or more cells.
2. Cells are the basic units of structure and function in an organism.
3. Cells come only from the division of pre-existing cells.

Validation of Cell Theory

Cell theory can be validated through several observations and experiments. For example:

1. By using light microscopes and electron microscopes, scientists visualize cell structures and find tangible evidence that cells are indeed the structural units of all living organisms.
2. Through techniques like live-cell imaging and genetic studies, scientists can track how cells replicate and give rise to new cells. These techniques validate the principle that all cells originate from pre-existing cells.
3. Techniques like DNA sequencing reveal that cells share common genetic material and metabolic pathways, reinforcing the notion that the cell is the fundamental unit of life.
4. Experiments, such as cell culture studies and tissue engineering, validate cell theory by demonstrating cellular growth, differentiation, and reproduction.

Exceptions to Cell Theory

While cell theory is widely accepted, there are notable exceptions. For example:

1. Viruses challenge cell theory because they are not made of cells and cannot carry out life processes independently. They require a host cell to replicate and are considered by many scientists to be at the border of living and non-living entities. Similarly, prions and viroids show properties of living organism but are not composed of cells. They are made of only DNA, RNA or proteins.

2. Eukaryotic organelles mitochondria and chloroplasts have their own DNA and can replicate independently of the cell's nucleus. This suggests they may have originated from free-living prokaryotic cells.
3. Some organisms, such as certain fungi and algae, have structures where multiple nuclei coexist within a shared cytoplasmic mass. These structures blur the boundaries of individual cells as defined by traditional cell theory.
4. Muscle cells (myocytes) in vertebrates can fuse to form multinucleated fibres, challenging the concept of a single cell as the basic unit in complex tissues.

3.3- MICROSCOPY

The discovery of cells and then the further studies of the internal structure of cells were dependent upon the use of microscope. Microscopy is the technique of using microscopes to observe and study objects that are too small to be seen with the naked eye. Microscopes use lenses and light or electron beams to magnify and illuminate specimens.

Light Microscopy

In light microscope, light is used to make the image of object. Light passes through object and then through two glass lenses. One lens produces an enlarged image of the object and the second lens magnifies the image more. After passing through object and lenses, the light forms enlarged clear image of object in viewer's eye.

Magnification and Resolution

These are two key characteristics of microscopes.

Magnification: This refers to a microscope's ability to enlarge the image of an object. Different lenses within a microscope offer varying levels of magnification. It is denoted by the symbol 'X', indicating how many times larger the image appears compared to the actual size. For example, a 10X lens can enlarge a 1 μm object to 10 μm . Total magnification in a microscope is determined by multiplying the magnification of all lenses.

Resolution: This refers to a microscope's ability to distinguish between two points that are close together on an object. The greater the resolution, the finer the detail that can be observed. The naked human eye has a resolution of about 0.1 mm. In contrast, a light microscope can resolve details down to approximately 250 nm (nanometres).

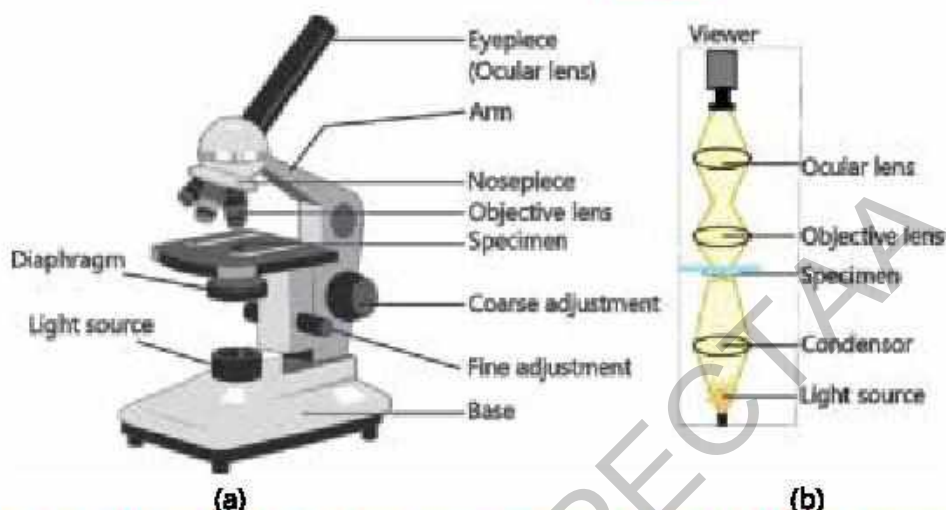


Figure 3.2: (a) Major parts of light microscope; (b) Working Principle of Light Microscope

The magnification of a light microscope is 1500X. It means it can magnify objects about 1500 times. Its resolving power is 0.2 micrometre (μm) and $1\mu\text{m} = 1/1000 \text{ mm}$. In other words, the light microscope cannot distinguish objects smaller than $0.2 \mu\text{m}$.

Light microscopes are advantageous for viewing living organisms, but since individual cells are generally transparent, their components are not distinguishable unless they are coloured with special stains (coloured chemicals). Staining, however, usually kills the cells.

Electron Microscopy

In electron microscope, a beam of electrons passes through the object. Magnetic lenses focus the electron beam on a screen or photographic film and make much enlarged image. Its resolving power is much greater than light microscope. It can clearly show objects as small as 0.2 nanometre (nm) and $1 \text{ nm} = 1/1000,000 \text{ mm}$. However, electron microscope cannot be used for viewing living material because of the methods needed to prepare the specimens. Biologists use two types of electron microscopes.

Transmission Electron Microscope (TEM) is used to view the internal structure of cell. TEM transmits a beam of electrons through a very thin specimen. It can magnify objects up to 250,000 times. **Scanning Electron Microscope (SEM)** is used to study the details of surfaces of cells or any other objects. The surfaces are coated with metal. When electron beam hits the metal, it is reflected and makes enlarged image. SEMs can magnify objects up to 100,000 times.

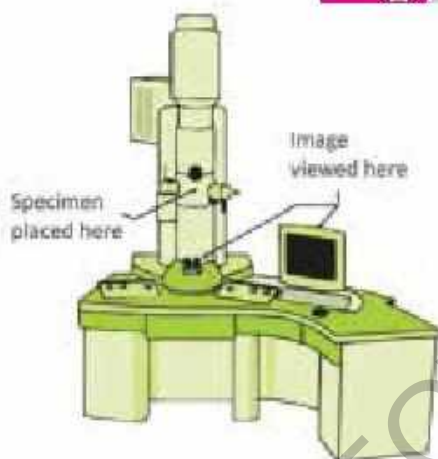


Figure 3.3: Electron microscope

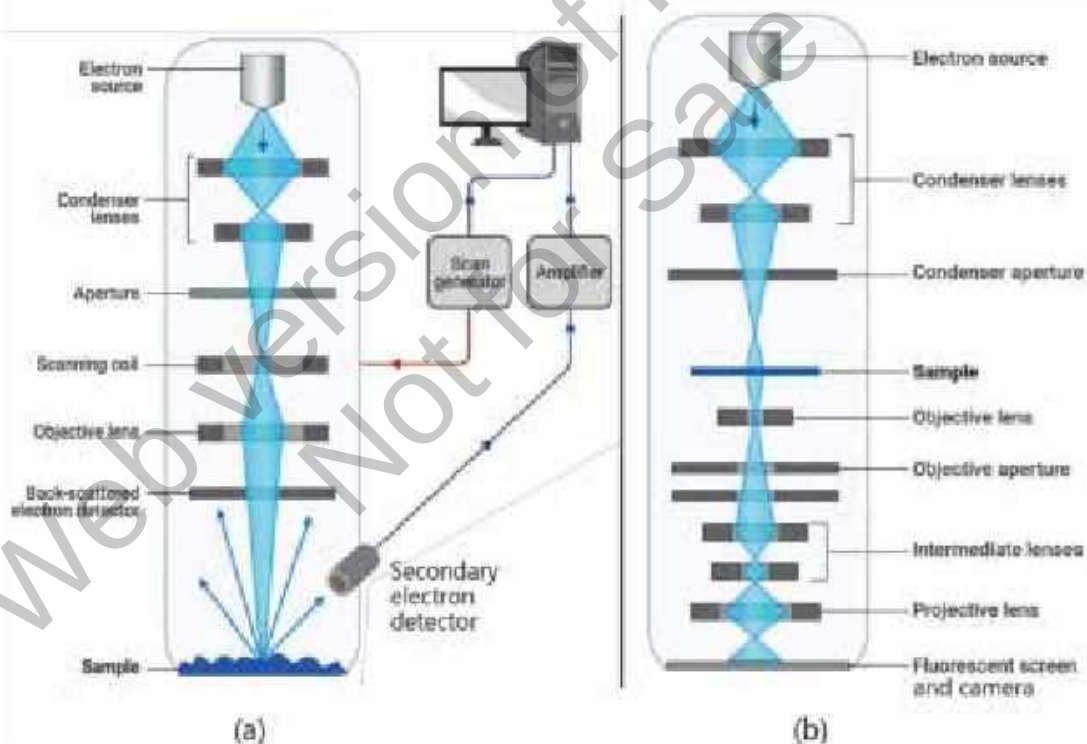


Figure 3.4: Working principle of; (a) Scanning electron microscope; (b) Transmission electron microscope

Difference Between Electron Microscope and Light Microscope

Light Microscope	Electron Microscope
Uses light (approx. 400-700 nm) as an illuminating source	Uses electron beams (approx. 1 nm) as an illuminating source
Lower magnification (usually 500X to 1500X) than an electron microscope	Higher magnification (direct magnification is 16000X and photographic magnification is 1000000X)
Low resolution (may be 0.2 μm)	High resolution (may be 0.2 nm)
Both live and dead specimens can be seen	Only dead and the dried specimen can be seen
Specimen preparation takes about a few minutes or an hour	Specimen preparation takes several days
The image is seen through the ocular lens. No screen needed	The image is received on a zinc sulphate fluorescent screen

3.4- STRUCTURE OF CELL

You know that there are two basic types of cells i.e., prokaryotic and eukaryotic. All bacteria are prokaryotes. Yeast and Euglena are examples of unicellular eukaryotes. Plants and animals are examples of multicellular eukaryotes. Eukaryotic cells are more complex than the prokaryotic cells. In the following paragraphs we will study the structures present in cells and their functions.

Cell Wall

Cell wall is more or less solid layer surrounding a cell. It is found in bacteria, fungi, plants, and algae. When a cell wall is removed using cell wall degrading enzymes, the remaining components of the cell are called a **protoplast**.

The **primary wall** is the actual cell wall of cell. It is composed of polysaccharides i.e. cellulose, hemicellulose and pectin. The cellulose microfibrils are aligned at all angles and are held together by

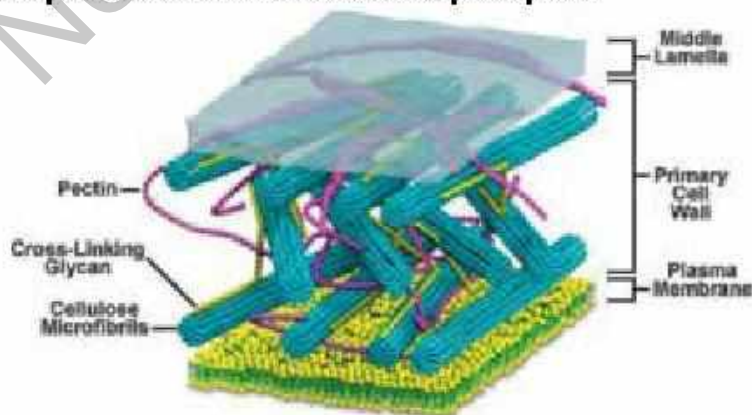
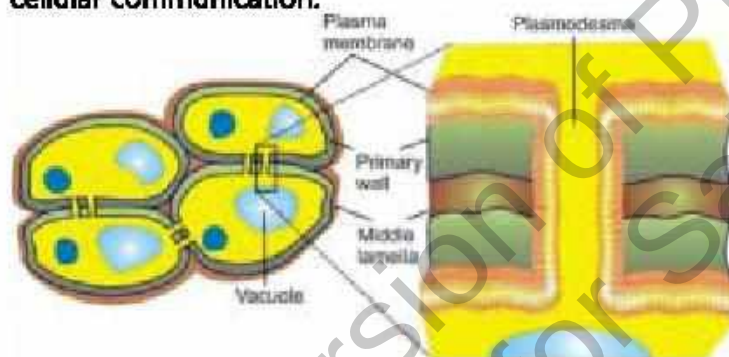


Figure 3.5: The composition of primary cell wall

hydrogen bonds. Many proteins are also present in primary walls. The **middle lamella** is a gelatinous layer that separates and holds the primary walls of the neighbouring cells. It is laid first, formed from the cell plate during cytokinesis, and the primary cell wall is then expanded inside the middle lamella. It contains magnesium and calcium pectates (salts of pectic acid). In some plant cells, after maturation, a **secondary wall** is made between protoplast and primary wall. Secondary cell walls contain lignin, cellulose and hemicellulose. Due to the presence of lignin, secondary wall is more rigid than the primary wall.

Plasmodesmata (singular, plasmodesma): These are small channels that directly connect the cytoplasm of neighbouring plant cells to each other. Plasmodesmata penetrate both the primary and secondary cell walls. They allow certain molecules to pass directly from one cell to another. So, they are important in cellular communication.



Plasmodesmata have caused debate among scientists regarding cell theory. Some scientists suggest that the cells of higher plants are not really cells since they are not physically separated or independent from one another.

Figure 3.8: The cell walls of two neighbouring cells showing a plasmodesma

The group of algae called diatoms synthesize their cell walls from silicic acid. The acid is polymerized inside cells, then the wall is extruded to protect the cell. The synthesis of Silica cell walls requires less energy. That is why there are higher growth rates in diatoms.



Plasmodesmata are formed during cell division when parts of the endoplasmic reticulum of the parent cell get trapped in the new cell wall.

Cell walls have a number of functions: They provide rigidity to the cell for structural and mechanical support; maintain cell shape and the direction of cell growth and ultimately the architecture of the plant. The cell wall also prevents expansion when water enters the cell. Cell walls protect against pathogens and the environment and are a store of carbohydrates for the plant.

The cell wall of **algae** contains cellulose and a variety of glycoproteins.

The cell wall of **fungi** is composed of chitin, the same carbohydrate that gives strength to the exoskeletons of insects.

The cell wall of **prokaryotes** (bacteria and cyanobacteria) is composed of peptidoglycan, that is a single large polymer of amino acids and sugar.

The cell wall of **archaeobacteria** is composed of different polysaccharides and proteins, with no peptidoglycan.

Plasma Membrane

All prokaryotic and eukaryotic cells have a plasma membrane that encloses their contents and serves as a semi-porous barrier to the outside environment.

Structure of plasma membrane

The fluid mosaic model is a widely accepted concept that describes the dynamic nature of plasma membrane. It was proposed by two American biologists S.J. Singer and Garth Nicolson in 1972. According to the fluid mosaic model, the basic foundation of plasma membrane is a **lipid bilayer**. This bilayer is made of phospholipids. A collection of proteins float within the lipid bilayer.

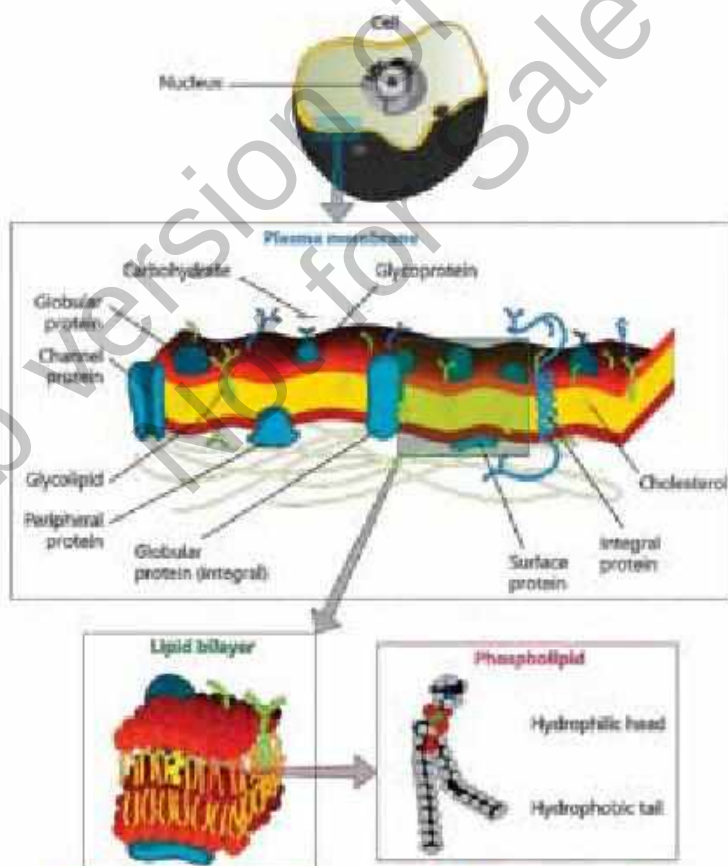


Figure 3.7: Structural components of plasma membrane

The phospholipids have a phosphate group at one end of each molecule. Phospholipids are characteristically **hydrophilic** ("water-loving") at their phosphate ends and **hydrophobic** ("water-fearing") along their tail regions containing C-H chains. In the lipid bilayer of plasma membrane, the hydrophobic lipid tails are oriented inwards and the hydrophilic phosphate groups are aligned outwards, either toward the cytoplasm of the cell or the extracellular environment.

The interior of lipid bilayer sheet is hydrophobic. It repels water-soluble molecules that attempt to pass through it. If a cell was fully encased in pure lipid bilayer, it would be completely impermeable to water-soluble molecules e.g., sugars, polar amino acids etc. That is why, in addition to phospholipids molecules, the membranes also contain proteins that provide passageways across the membrane.

In eukaryotes, plasma membranes have cholesterol molecules, wedged into the phospholipid bilayer. They keep the fluidity of membrane at low temperatures. Many proteins float within the phospholipid bilayer of plasma membrane. Some other proteins simply adhere to the surfaces of the bilayer. The positioning of proteins is related to the organization of cytoskeleton. Plasma membrane proteins function in several different ways.

- Many proteins play role in the selective transport of certain substances across the phospholipid bilayer, either acting as channels or active transport molecules.
- Some proteins help in attachment of plasma membrane to cytoskeleton and external fibres.
- Some proteins, on the exterior surface, attach with sugars and make identification marks.
- Other proteins function as receptors, which bind messenger molecules (e.g. hormones) and transmit signals to the interior of cell.
- Some proteins also exhibit enzymatic activity, catalysing various reactions related to the plasma membrane.

The ability to distinguish among different cells is crucial to life. It allows cells in an embryo to sort themselves into tissues and organs. It also helps cells of the immune system to recognize and reject foreign cells, e.g., infectious bacteria.

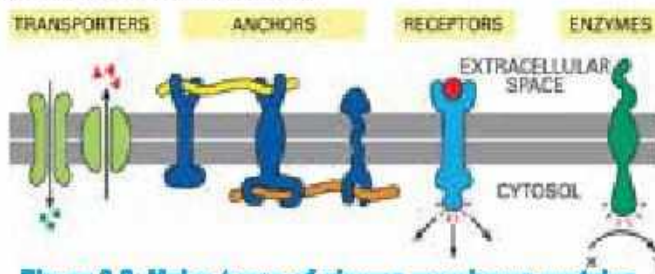


Figure 3.8: Major types of plasma membrane proteins

The outside surface of plasma membrane has chains of sugars bonded to proteins and lipids. A protein with attached sugar is called a **glycoprotein**, whereas a lipid with attached sugar is called a **glycolipid**. The glycoproteins and

glycolipids vary from species to species, from individual to individual in the same species, and even from one cell type to another in the same individual. The glycolipids and glycoproteins (collectively called **glycocalyx**) function as cell identification marks that are recognized by other cells.

Functions of plasma membrane

Plasma membranes serve as semi-porous barriers to the outside environment. The membrane acts as a boundary, holding the cell constituents together. The plasma membrane is permeable to specific molecules, however, and allows nutrients and other essential elements to enter the cell and waste materials to leave the cell. Small molecules, such as oxygen, carbon dioxide, and water, are able to pass freely across the membrane, but the passage of larger molecules, such as amino acids and sugars, is carefully regulated. Eukaryotic cells also have membranes around some of their interior organelles. Like the exterior plasma membrane, these membranes also regulate the flow of materials into and out of organelles.

Techniques to study the structure of plasma membrane

1. Transmission Electron Microscopy can reveal detailed structures of the lipid bilayer and associated proteins.
2. Scanning Electron Microscopy is useful for examining the surface topology of cells and membranes.
3. Confocal Microscopy uses laser scanning and fluorescence to create sharp, detailed images of the cell membrane.
4. Total Internal Reflection Fluorescence Microscopy is used for high-resolution images of the membrane and its interactions with the cytoskeleton and other cellular components.
5. Atomic Force Microscopy provides topographical images of cell membrane at high resolution.
6. X-ray Crystallography is used to determine the atomic structure of membrane proteins.

Membrane	Percent by weight		
	Protein	Lipid	Carbohydrate
Human red blood cell	49	43	8
Mitochondria (outer membrane)	52	48	0
Mitochondria (inner membrane)	76	24	0
Bacteria	75	25	0

7. Lipidomics involves the comprehensive analysis of lipids in the cell membrane using techniques like mass spectrometry.
8. Fluorescence Recovery After Photobleaching is used to study the mobility and dynamics of membrane proteins and lipids. It involves bleaching a fluorescently labelled region of the membrane with a laser and observing the recovery of fluorescence as unbleached molecules move into the area.

Cytoplasm and Organelles

You know that a cell consists of three major components i.e., plasma membrane, cytoplasm and nucleus. The cytoplasm is a semi-viscous and semi-transparent substance. In eukaryotic cells, it is present between the plasma membrane and nuclear envelope. In prokaryotic cells, it covers all the space beneath plasma membrane. It consists of an aqueous ground substance, known as **cytosol**, which contains a variety of organelles and other inclusions. Cytosol contains water in which many organic (proteins, carbohydrates, lipids) and inorganic salts are completely or partially dissolved. The cytoplasm of the cell provides space for the proper functioning of the organelles and also acts as the site for various biochemical (metabolic) reactions for example Glycolysis (breakdown of glucose during aerobic respiration).

The cytoplasm contains discrete structures which are specific for various cellular functions and are called **cell organelles**. The organelles are generally enclosed by membrane except few such as ribosome. The following paragraphs describe the structures and functions of important organelles.

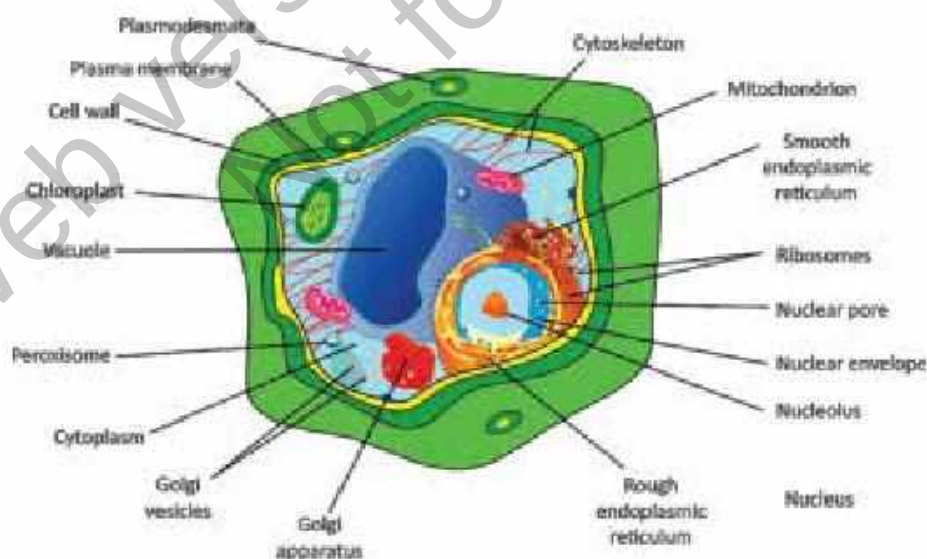


Figure 3.9: The Ultra-structure of a Plant cell

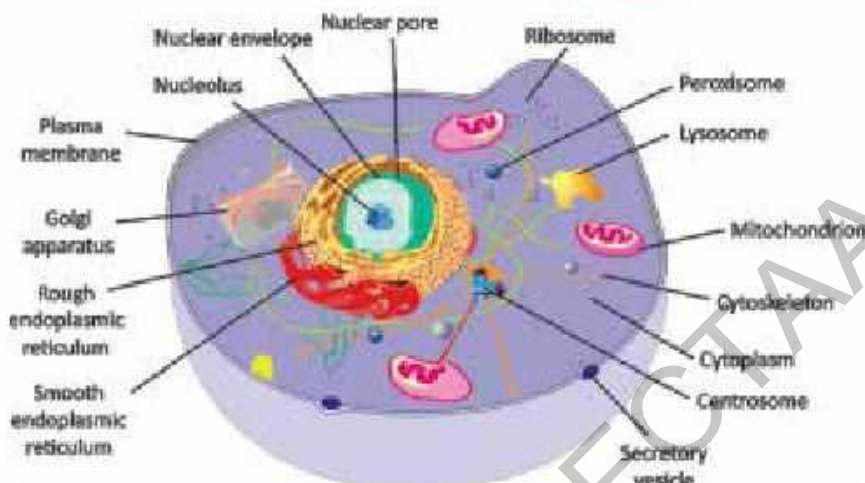


Figure 3.10: The Ultra-structure of an Animal cell

1- Nucleus

A prominent nucleus is present in all eukaryotic cells (at centre in animal cells while pushed to side in plant cells). The spherical nucleus typically occupies about 10 percent of a eukaryotic cell's volume. It serves as information processing and administrative centre of the cell. It performs two major functions: it stores the cell's hereditary material (DNA) and coordinates the cell's activities e.g., growth, protein synthesis and cell division.

The semifluid matrix found inside the nucleus is called **nucleoplasm**. Within the nucleoplasm, most of the nuclear material consists of chromatin that organizes to form chromosomes during cell division. The nucleus also contains one or more nucleoli, which synthesize ribosomes.

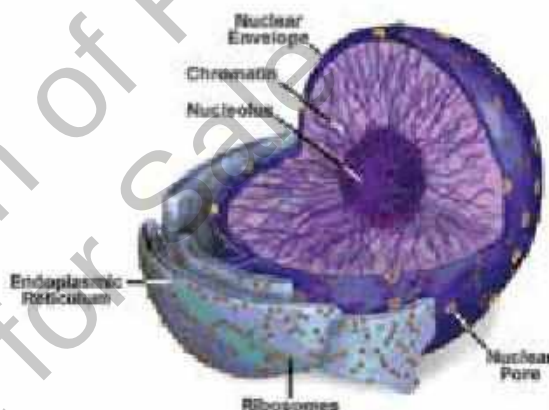


Figure 3.11: The structure of nucleus

Building blocks of DNA and RNA and ATPs are allowed to enter into the nucleus. Ribosomal subunits which are built in nucleoli are the examples of materials that are allowed to leave the nucleus and enter the cytoplasm.

The Nuclear Envelope and Nuclear Pores

The nuclear envelope is a double-layered membrane that encloses the contents of the nucleus during most of the cell's lifecycle. The space between the

double layers is called the perinuclear space and is connected with the rough endoplasmic reticulum. During cell division, the nuclear envelope disintegrates, but reforms in the daughter cells. On the inner side of nuclear envelope, there is a protein lining, called **nuclear lamina**. It binds to chromatin to give it structural support.

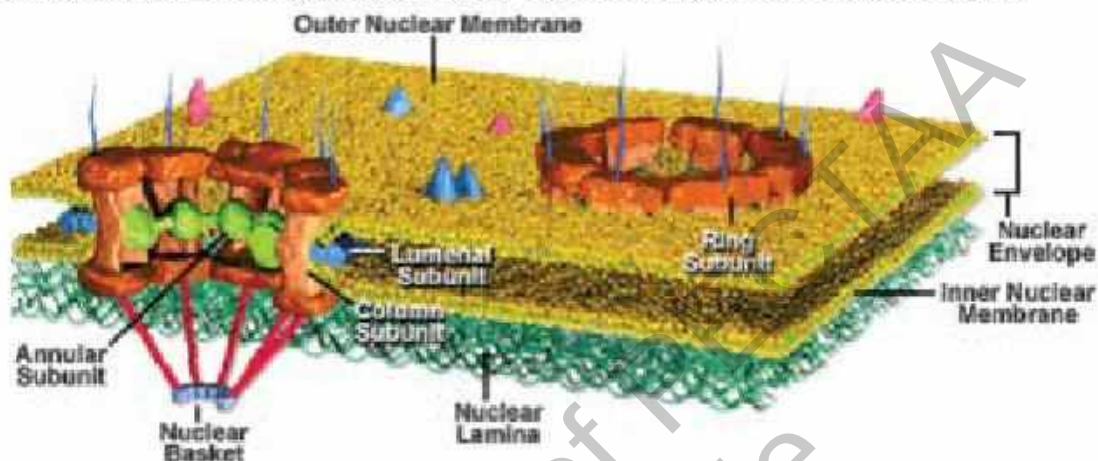


Figure 3.12: The structure of nuclear envelope and nuclear pore complex

The nuclear envelope has tiny holes known as **nuclear pores**. These pores regulate the passage of molecules between nucleus and cytoplasm. Nuclear pores are permeable to small molecules. Some larger proteins, e.g., histones, are also allowed to enter into nucleus. A nuclear pore is made of an elaborate structure called the nuclear pore complex. It is composed of several subunits. These are; **annular subunit** (surrounding the inside of the pore), **column subunit** (making the wall of the complex), **ring subunit** (attached to the outer side of the column subunit), and **luminal subunit** (anchoring the pore complex into the nuclear envelope). Tiny fibrils usually extend from the complex and make a basket-like structure on the nuclear side of the complex.

Nucleolus

The nucleolus is a prominent darkly stained structure in the nucleoplasm. There may be one or two nucleoli in a nucleus. Nucleoli manufacture the subunits that combine to form ribosomes. Nucleoli are formed at certain sites in chromosome, called Nucleolus Organizer Regions (NORs). The DNA found at NORs encodes the ribosomal RNA (rRNA).

The nucleolus consists of granular and fibrillar components, and DNA. The granules consist of ribosomal subunits that have already been formed. The fibrils are composed of the raw materials of ribosome subunits i.e., rRNA molecules and associated proteins.

Chromatin and Chromosomes

Nucleus contains string-like fibres, collectively called chromatin. It is composed of DNA and proteins. The structure of chromatin reveals that it is made of a series of bead-like structures, called nucleosomes. In a nucleosome, DNA strand wraps around groups of small proteins called histones.

During interphase (when the cell is carrying out its normal functions), the chromatin is dispersed throughout the nucleus in the form of a tangle of fibres. When the cell begins to divide, all chromatin strands are compressed into specialized structures, the chromosomes. A chromosome is made of arms, called chromatids, and a central point, called centromere.

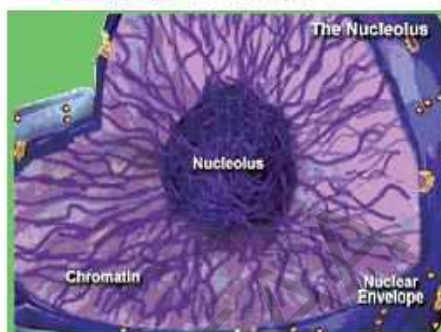


Figure 3.13: The nucleolus within a nucleus

Inside the nucleus of every human cell, there is a 6 feet long DNA. It is subdivided into 46 individual molecules (each 1.5 inches long), one for each chromosome.

There are two types of chromatin. **Euchromatin** is the genetically active chromatin involved in transcribing RNA to produce proteins. The other kind of chromatin is termed **heterochromatin**. Its DNA is genetically inactive.

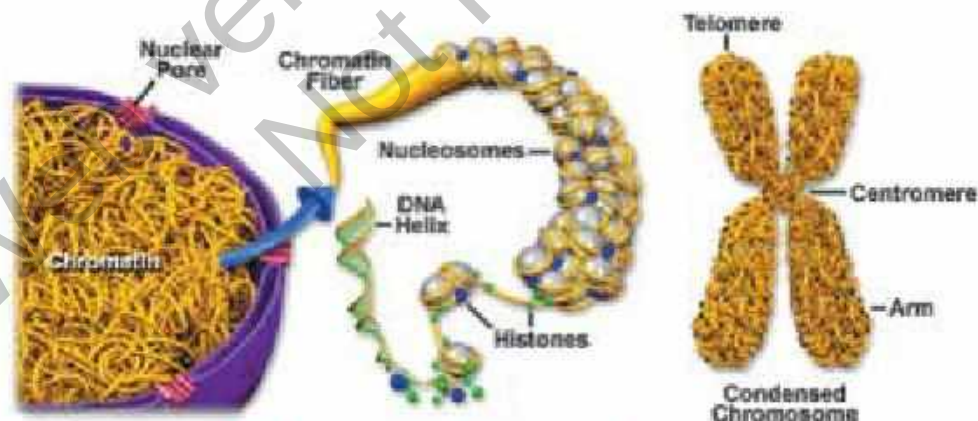


Figure 3.14: Condensation of chromatin to form a chromosome

The number of chromosomes within the nuclei of an organism's cells is species-specific. Human diploid cells (those that are not gametes) have 46 chromosomes. The chromosome number may be as low as 2, as in some ants and

roundworms, or more may be than a thousand, as in the Indian fern (*Ophloglossum reticulatum*), which has 1,260 chromosomes. It means that the number of chromosomes in a species does not correlate to the complexity of the organism.

2- Endoplasmic Reticulum (ER)

It is a network of flattened sacs and branching tubules that extends throughout the cytoplasm in plant and animal cells. These sacs and tubules are called cisternae (singular *cisterna*).

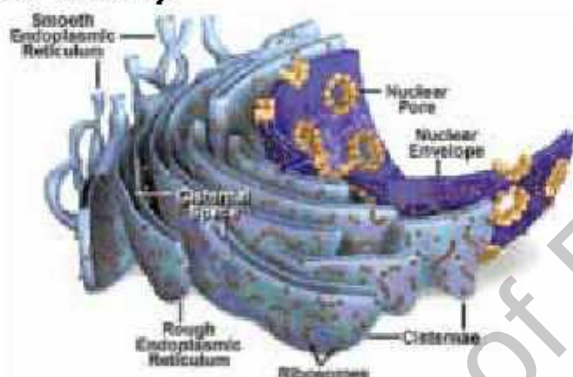


Figure 3.15: Endoplasmic reticulum

Due to their physical membranous connection, the lumen of the endoplasmic reticulum and the space between the layers of the nuclear envelope comprise a single compartment. This close association enables the endoplasmic reticulum and the nucleus to share information in a very efficient manner.

All cisternae are interconnected so that the ER has only one large and highly convoluted lumen, called cisternal space. It takes up more than 10 percent of the total volume of a cell. The cisternae are also connected to the double-layered nuclear envelope. So, the ER provides a pipeline between nucleus and cytoplasm. The ER manufactures, processes, and transports a wide variety of biochemical compounds for use inside and outside of the cell. There are two kinds of endoplasmic reticulum: rough and smooth.

The surface of **rough endoplasmic reticulum (RER)** is covered with ribosomes, giving it a bumpy appearance when viewed through the microscope. This type of endoplasmic reticulum is involved mainly in the production and processing of proteins. During processing of proteins, RER adds other chemicals (e.g. sugars) to proteins. Then RER transports the processed proteins to areas of the cell where they are needed, or sends them to Golgi apparatus for further processing and modification.



Figure 3.17: A fluorescence image of an endothelial cell showing ER (green)

Smooth endoplasmic reticulum is much more extensive in the cells which do lot of lipid and carbohydrate metabolism (brain and muscle) or detoxification (liver).

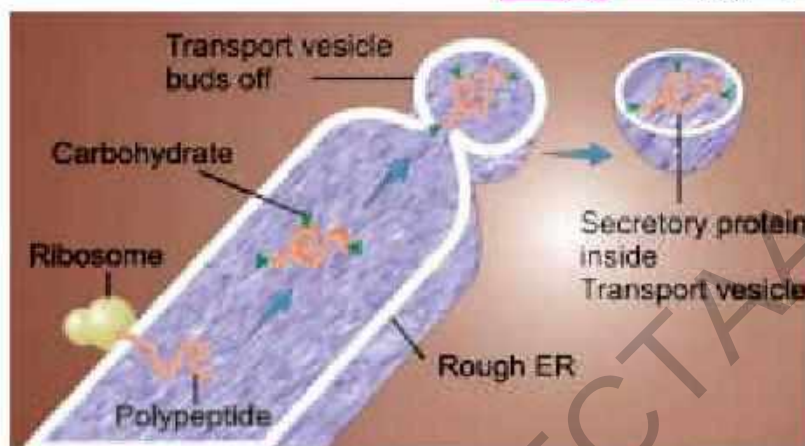


Figure 3.16: The functioning of rough endoplasmic reticulum

The surface of **smooth endoplasmic reticulum (SER)** lacks ribosomes. So, it appears more even under the microscope. In most cells, it is much less extensive than the rough endoplasmic reticulum. Smooth endoplasmic reticulum is chiefly involved in the production of lipids, building blocks for carbohydrate metabolism, and the detoxification of drugs and poisons. Smooth endoplasmic reticulum also plays a role in various cellular activities by storing calcium and doing calcium metabolism. In muscle cells, smooth endoplasmic reticulum releases calcium to trigger muscle contractions.

3- Ribosomes

All living cells contain ribosomes that are tiny granular structures composed of approximately 60 percent ribosomal RNA (rRNA) and 40 percent protein. Ribosomes are not bound by a membrane and are much smaller than other organelles. In eukaryotic cells, ribosomes are mainly found attached to rough endoplasmic reticulum and some are scattered freely. In prokaryotic cells, all ribosomes are freely scattered in cytoplasm. Ribosomes serve as the protein production machinery for the cell. They are most abundant in cells that are active in protein synthesis, such as pancreas and brain cells. A typical cell contains several thousand ribosomes but some cell types may have a few million ribosomes.

Eukaryote ribosomes are produced and assembled in the nucleolus. Ribosomal proteins enter the nucleolus and combine with rRNA strands to create the two ribosomal subunits (one small and one large). The ribosome subunits leave the nucleus through the nuclear pores. In the cytoplasm, both subunits combine for the purpose of protein synthesis. When protein synthesis is not being done, the two subunits get separated.

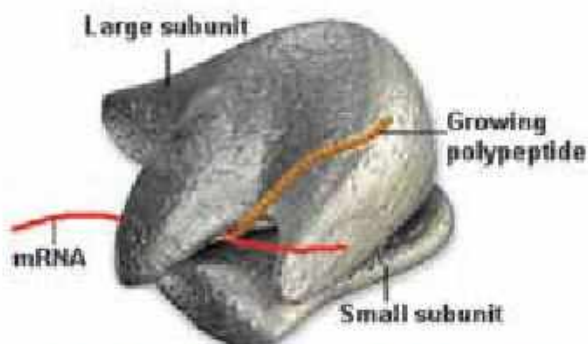


Figure 3.18: Ribosome translating the mRNA

In addition to the most familiar cellular locations of ribosomes, they can also be found inside mitochondria and the chloroplasts of plants. These ribosomes notably differ in size and makeup than the ribosomes found in cytoplasm, and are more like those present in prokaryotes.

Protein synthesis requires the assistance of two other kinds of RNA molecules in addition to rRNA. Messenger RNA (mRNA) provides the instructions, which it has taken from the DNA. Transfer RNA (tRNA) brings amino acids to the ribosome. Once the chain of amino acids has been synthesized, the ribosome releases it.

The proteins that are synthesized by free ribosomes are for the cell's own internal use. While the proteins produced by the ribosomes bound to RER are transported outside of the cell.

The subunits of a ribosome are described by their **Svedberg (S) values**, which are based upon their rate of sedimentation in a centrifuge. The complete ribosome in a eukaryotic cell has a Svedberg value of 80S. The smaller subunit has value of 40S while the larger subunit has 60S. Prokaryotic cells, on the other hand, contain 70S ribosomes, each of which consists of a 30S and a 50S subunit.

The Svedberg values are not additive i.e. the values of the two subunits of a ribosome do not add up to the Svedberg value of the complete ribosome. This is because the rate of sedimentation of a molecule depends upon its size and shape, rather than simply its molecular weight.

4- Mitochondria

Mitochondria (sing., *mitochondrion*) are rod-shaped organelles that are considered the power generators of the cell. A mitochondrion is bounded by two membranes. There is a narrow intermembrane space between the two membranes. Beneath the inner membrane, there is a larger internal matrix. The outer membrane is smooth and acts like a sieve, filtering out molecules

Scientists hypothesize about the origin of mitochondria. According to them, millions of years ago small, free-living prokaryotes were engulfed, but not consumed, by larger prokaryotes. The two organisms developed a symbiotic relationship over time, the larger organism providing the smaller with ample nutrients and the smaller organism providing ATP molecules to the larger one.

that are too big. The inner membrane is highly convoluted and forms many infoldings called cristae which increase the surface area.

The inner surface of the cristae has knob-like extensions into the matrix, known as F-1 particles. These particles are actually the enzymes called ATP-synthase. Other complexes are also found in inner mitochondrial membrane, which serve as electron carriers in electron transport chain. Mitochondria are different from most other organelles. A mitochondrion has its own circular DNA (similar to the DNA of prokaryotes), all kinds of RNA and 70S ribosomes. A mitochondrion can replicate independently of the cell.

Mitochondria are the sites of cellular respiration. They generate adenosine triphosphate (ATP) from oxygen and nutrients. ATP is the chemical energy "currency" of the cell that powers the cell's metabolic activities. Enzymes in the matrix catalyse some of the steps of cellular respiration like Krebs cycle. Other proteins that function electron transport chain are found on the inner membrane.

The number of mitochondria present in a cell depends upon the metabolic requirements of that cell, and may range from one to thousands. Mitochondria are found in nearly all eukaryotes, including plants, animals, fungi, and protists, and are large enough to be observed with a light microscope.

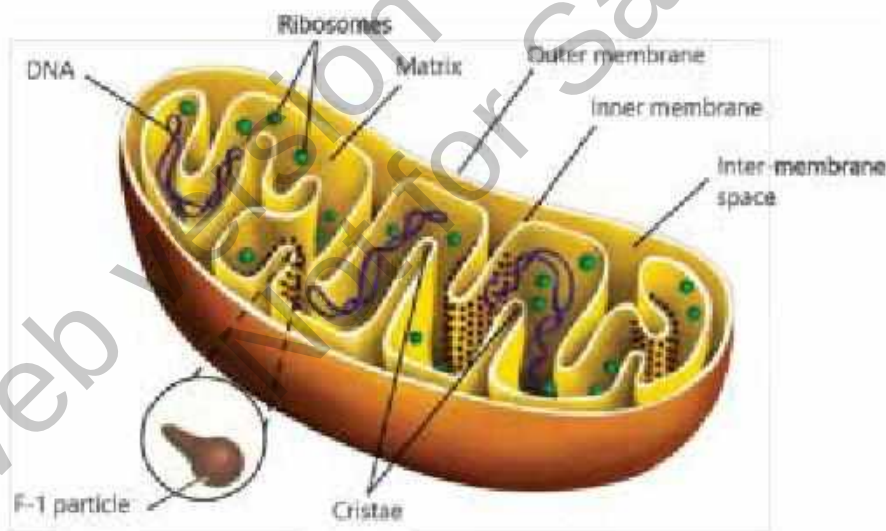


Figure 3.19: Structure of a mitochondrion

5- Chloroplasts

One of the most important characteristics of plants is their ability to conduct photosynthesis

Recalling:

Cells of plants and many protists have three types of plastids i.e., chloroplasts, chromoplasts and leucoplasts. The colourless leucoplasts are involved in the storage and yellow-to-red coloured chromoplasts give colours to plant parts.

i.e., to make their own food by converting light energy into chemical energy. This process occurs in almost all plant species and is carried out in specialized organelles known as chloroplasts. All of the green structures in plants, including stems and un-ripened fruit, contain chloroplasts, but the majority of photosynthetic activity in most plants occurs in the leaves. On the average, the chloroplast density on the surface of a leaf is about one-half million per square millimetre. Chloroplasts contain the pigments chlorophyll "a" and chlorophyll "b", which are able to absorb the light energy needed for photosynthesis to occur.

The ellipsoid-shaped chloroplast is enclosed by two membranes and the area between the two membranes is called the intermembrane space. A semi-fluid called stroma is present inside the inner membrane. It contains dissolved enzymes and comprises most of the chloroplast's volume. The outer membrane is much more permeable than the inner layer.

The inner membranes lie in close association with one another and fuse along their peripheries. In this way, two adjacent membranes form a disk-shaped compartment called **thylakoid**. Many thylakoids form stacks called **grana** (singular *granum*). The **lamellae** are the non-green compartments that connect two grana. Each granum may contain a few to several thylakoids, and a chloroplast may contain a hundred or more grana. Like the mitochondrion, the chloroplast is different from most other organelles because it has its own DNA and reproduces independently of the cell in which it is found.

Mitochondria are similar to chloroplasts. Both organelles convert energy for the cell. Mitochondria perform aerobic respiration. They generate chemical energy in the form of ATP by metabolizing sugars, fats and other chemical fuels with the assistance of oxygen. Chloroplasts perform photosynthesis. They convert energy from the sun into the biosynthesis of organic nutrients using carbon dioxide and water. Like mitochondria, chloroplasts also contain their own DNA and are able to grow and reproduce independently of the cell.

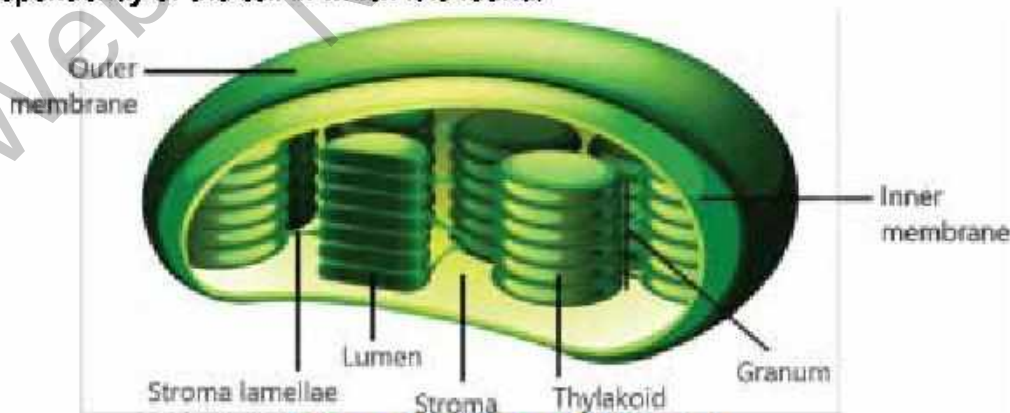


Figure 3.20: Structure of chloroplast

Light is absorbed by chlorophyll molecules embedded in the thylakoid disks. When these chlorophyll molecules absorb light, they emit electrons and thus ATPs are formed. Using these ATPs, in the stroma, low-energy carbon dioxide is transformed into a high-energy compound like glucose.

6- Golgi Apparatus

Golgi apparatus consists of five to eight cup-shaped, membrane-covered sacs called cisternae that are stacked over each other. It is found in the cells of plant, animal and unicellular eukaryotes. In some unicellular flagellates, the Golgi apparatus may consist of 60 cisternae. Similarly, the number of Golgi apparatuses in a cell varies according to its function. Animal cells generally contain between ten and twenty Golgi stacks in their Golgi apparatus. This complex is usually located close to the nucleus.

Each Golgi stack has two distinct faces. The 'cis' face is found near the endoplasmic reticulum. The 'trans' face is positioned near the plasma membrane.

The Golgi apparatus is the distribution and shipping department for the cell's chemical products. It modifies proteins and lipids that have been built in the endoplasmic reticulum and prepares them for export outside the cell or for transport to other locations in the cell.

Small vesicles that contain proteins, carbohydrates, phospholipids and other molecules, bud off from the ER. These vesicles move through the cytoplasm until they reach the 'cis' face of Golgi apparatus. The vesicles fuse with Golgi apparatus and release their molecules into it. Here, the compounds are further processed. Enzymes present in the Golgi lumen convert them into glycoproteins and glycolipids.

Recalling:

Golgi apparatus was discovered by Camillo Golgi.

Camillo Golgi was investigating the nervous system by using a new staining technique (known as Golgi staining). He observed a structure inside cells and named it as reticular apparatus. He publicly announced his discovery in 1898 and the structure was named after him as the Golgi apparatus. Many scientists did not believe that what Golgi observed was a real organelle and instead argued that the apparent body was a visual distortion caused by staining. The invention of the electron microscope in the twentieth century finally confirmed that the Golgi apparatus is a cellular organelle.

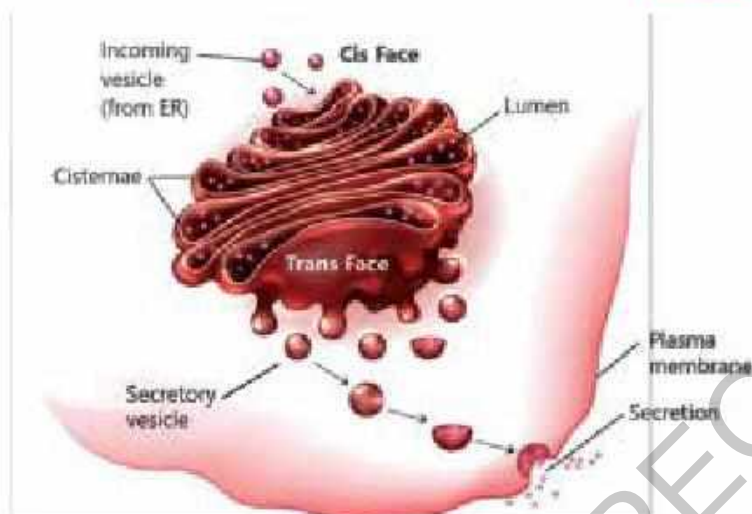


Figure 3.21:
Structure of
Golgi apparatus
and its
functioning

The product is extruded from the 'trans' face of the Golgi apparatus in a vesicle and directed to its final destination inside or outside the cell. The exported products are known as secretions. Other products are returned to the endoplasmic reticulum or may undergo maturation to become lysosomes. In addition, the Golgi apparatus in plant cells produces pectin and other polysaccharides specifically needed for plant structure and metabolism.

7- Lysosomes

Lysosomes are spherical organelles bounded by a single membrane. They serve as digestive compartments of the cell. Lysosomes are found in most eukaryotic cells. In animals, they are most numerous in disease-fighting cells, such as white blood cells. This is because white blood cells must digest materials like bacteria, viruses, and other foreign intruders.

They are also involved in breaking the cellular materials that have exceeded their lifetime or are no longer useful. In this regard, the lysosomes perform **autophagy**. They break down cellular waste products, fats, carbohydrates, proteins, and other macromolecules into simple compounds, which are then transferred back into the cytoplasm for making new materials.

Recalling:

Lysosomes were discovered by a Belgian scientist Christian René de Duve. They contain strong digestive enzymes.

The cell is safe from the enzymes of lysosomes. These enzymes require acidic environment (of pH of about 4.8). The lysosomal matrix is acidic but cytosol is a neutral environment. So, even if a lysosome is ruptured, its digestive enzymes become inactive and the cell remains uninjured.

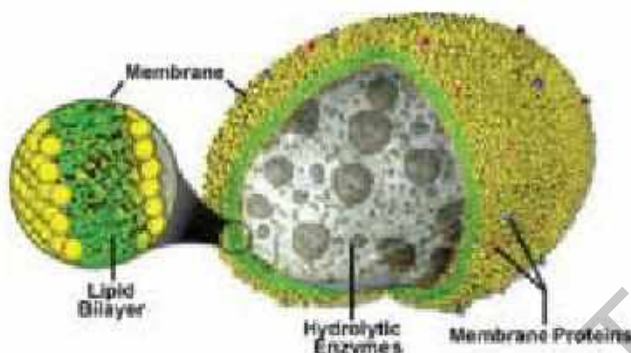


Figure 3.22: Structure of lysosome

Lysosomes have about 40 different hydrolytic enzymes, all of which are manufactured in the endoplasmic reticulum and modified in the Golgi apparatus. The membrane covering of the lysosome protects the rest of the cell from the harsh digestive enzymes contained in the lysosomes, which would otherwise cause significant damage.

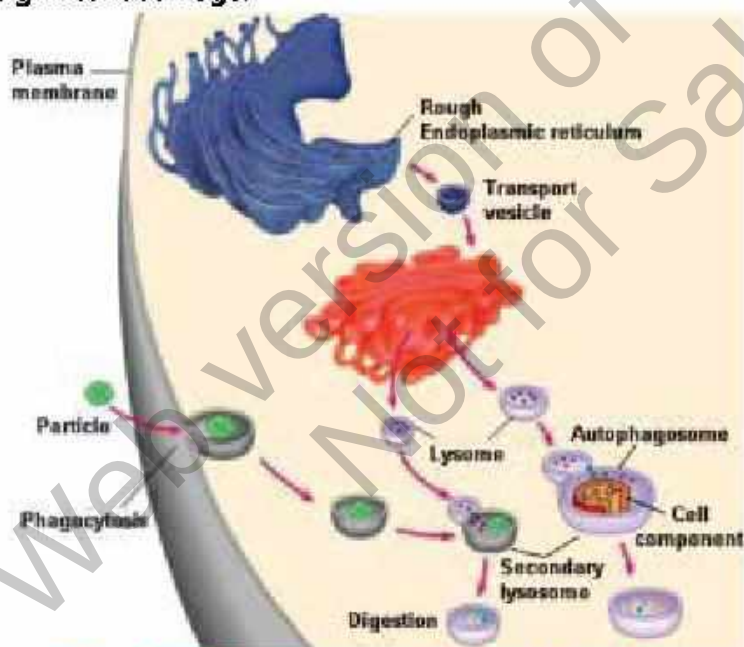


Figure 3.23: Role of lysosome in the breakdown of the phagocytosed particle and cellular component

In the mid-18th century, Belgian scientist Christian René de Duve was investigating carbohydrate metabolism in liver cells. He observed that when cells are damaged in the centrifuge, they release acid phosphatase. He suggested that this digestive enzyme was encased in some membrane bounded organelle within the cell, which he named as lysosome.

In **lysosomal storage diseases** the patient lacks one of the hydrolytic enzymes of lysosome. The abnormal lysosome fills with

Many cells in your brain die during development. This directed suicide is accomplished by the rupture of the lysosomes within the cells that are being eliminated.

indigestible substances, which interfere with cellular functions. For example, in Pompe's disease the lysosome lacks a glycogen-digesting enzyme. So, harmful amounts of glycogen accumulate in liver cells. In **Tay-Sachs** disease an essential lipid-digesting enzyme is missing. Accumulation of these lipids in the nerve cells of brain damages the nervous system, causes mental retardation, and death in early childhood.

Lysosomes also function in the elimination of whole cell. Selective cell death is a mechanism used by multicellular organisms in their development. For example, when a tadpole develops into a frog, the cells of the tail are destroyed by the enzymes of lysosomes.

8- Peroxisomes

Peroxisomes are single membrane bounded organelles in all eukaryotic cells. These were discovered by Christian de Duve, who also discovered lysosomes.

Peroxisomes contain a variety of enzymes. Many of these enzymes are oxidative that carry out oxidation i.e. the removal of electrons and hydrogens. These enzymes primarily function to rid the cell of toxic substances. Some peroxisomes, such as those in liver cells, detoxify alcohol and other harmful compounds by carrying out their oxidation.

Some peroxisomes contain catalase enzymes, which break down hydrogen peroxide (a common by-product of cellular metabolism) into



water and oxygen.

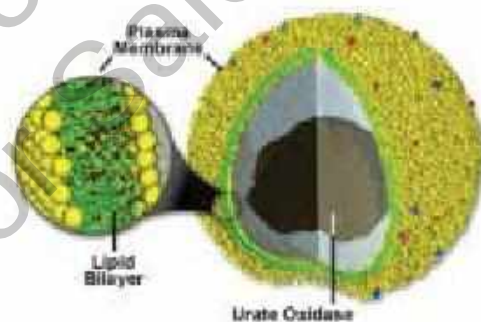


Figure 3.24: Structure of peroxisome

Defects in peroxisomes cause a number of metabolic disorders. The most serious of these disorders is Zellweger syndrome, which is characterized by absence or reduced number of peroxisomes in the cells. It is congenital disorder (present at birth) and has no cure or effective treatment and usually causes death within the first year of life.

9- Glyoxysomes

Glyoxysomes are similar to peroxisomes but are found only in plant cells. These organelles contain enzymes that convert lipids into carbohydrates. They are most abundant in the cells of lipid-rich seeds (e.g. castor beans and soyabeans). During germination, these organelles convert stored lipids into carbohydrates that provide energy for seed germination.

10- Vacuoles

These are membrane-bounded sacs. Vacuoles function in several ways. For example, in mature plant cells, a single large vacuole provides structural support, as well as serves functions in storage, waste disposal, protection, and growth. Vacuoles in animal cells, however, are much smaller, and are more commonly used to temporarily store materials or to transport substances.

Many plant cells have a large, single central vacuole. This large vacuole slowly develops by fusion of smaller vacuoles. It takes up most of the space in the cell (80 percent or more). The vacuole in plant cells is enclosed by a membrane called tonoplast. The material inside the vacuole is called cell sap. The cell sap differs markedly from the surrounding cytoplasm.

The central vacuole in plant cells plays an important structural role for the plant. This role of the vacuole is related to its ability to control turgor pressure. Turgor pressure makes the rigidity of the cell.

Under optimum conditions, a plant receives adequate amounts of water and the central vacuoles of its cells swell as the liquid collects within them. It creates a high turgor pressure, which helps maintain the structural integrity of the plant, along with the support from the cell wall. Vacuoles also often store the pigments that give certain flowers their colours, which aid them in the attraction of bees and other pollinators. Vacuoles also

release molecules that are poisonous to various insects and animals, thus discouraging them from consuming the plant.

11- Centrioles

In the cells of animals and most protists, centrioles are organelles

Recalling:

Vacuoles are fluid filled single-membrane bounded organelles. Cells have many small vacuoles in their cytoplasm. However, when a plant cell matures its small vacuoles fuse to form a single large vacuole.

Several materials commonly stored in plant vacuoles have been found to be useful for humans, such as opium, rubber, and garlic flavouring.



Figure 3.25: Structure of vacuole in plant cell

Recalling:

Centrioles are hollow and cylindrical organelles. A centriole is made of nine triplets of microtubules.

associated with the assembly and organization of the fibres of cytoskeleton i.e., microtubules (including spindle fibres).

In eukaryotic cells centrioles occur in pairs. The two centrioles are located at right angles to one another near the nuclear envelope. In ciliated or flagellated cells centrioles are involved in the formation of cilia and flagella. Each cilium and flagellum is anchored by a centriole, known as **basal body**.

The cells of plants and fungi lack centrioles and basal bodies, and their microtubules and spindle fibres are organized from the structures of cytoplasm.

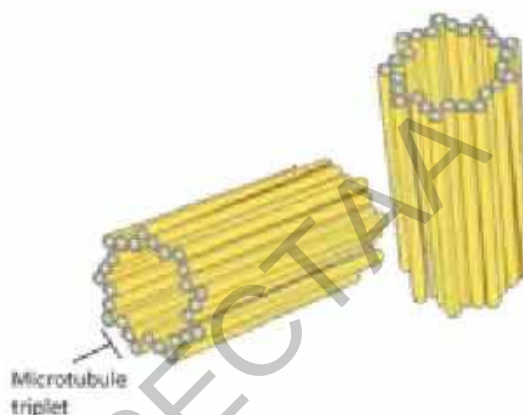


Figure 3.26: Two centrioles

12- Cytoskeleton

It is a network of protein fibres present in cytoplasm. It includes the following types of fibres:

1. **Microfilaments:** These are present in all eukaryotic cells. Microfilaments are solid rods made of a globular protein, called **actin**. Microfilaments disassemble and re-assemble and help the cells to change shape and move. Microfilaments also enable a dividing cell to pinch off into two cells. In association with myosin, microfilaments help in cellular contraction.
2. **Microtubules:** These straight, hollow cylinders are composed of subunits. Each subunit is made of two different **tubulin** proteins known as *alpha*-tubulin and *beta*-tubulin. Microtubules give structure and shape to a cell. They also serve as highways for the transport of organelles. Moreover, microtubules are the major components of cilia and flagella, and participate in the formation of spindle fibres during cell division.
3. **Intermediate filaments:** These are found only in some higher animal groups. They are made of different proteins but the most common type of protein subunit is **vimentin**. Some cells may have intermediate filaments made of other proteins. For example, skin cells contain a protein **keratin**. Intermediate filaments maintain cell shape and rigidity, and serve to anchor several organelles, including the nucleus.

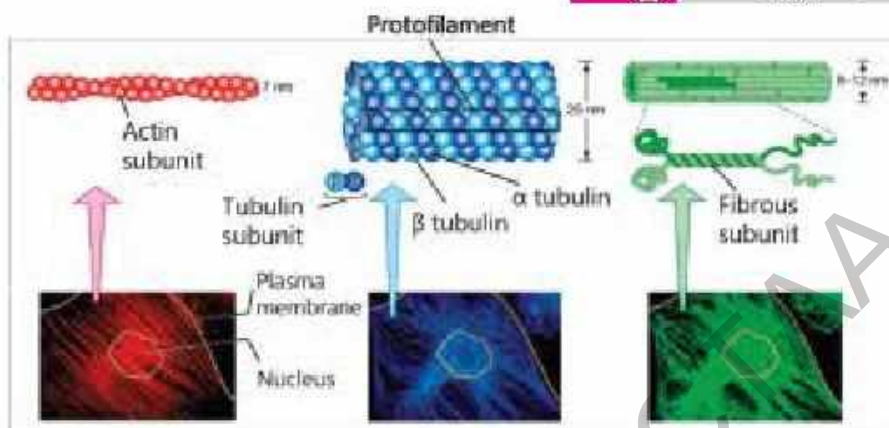


Figure 3.27: Components of cytoskeleton

13- Cilia and Flagella

Cilium (plural *cilia*) and flagellum (plural *flagella*) are the locomotor appendages that protrude from certain cells. They are thin, tail-like projections extending from the cell body. Cilia are short in length and are usually numerous in number; while flagella are longer but less numerous in number. Cilia are rare in plants. Many protozoans (ciliates) possess cilia. Larger eukaryotes such as mammals have cilia on some cells' surfaces. For example, in humans, cilia are found in the lining of the trachea where they sweep mucus and dirt out of breathing tubes.

The core of eukaryotic cilia and flagella is called **axoneme**. It contains two central microtubules that are surrounded by an outer ring of nine doublet microtubules. Dynein molecules are located around the circumference of the axoneme. These dynein molecules bridge the gaps between adjacent microtubule doublets.

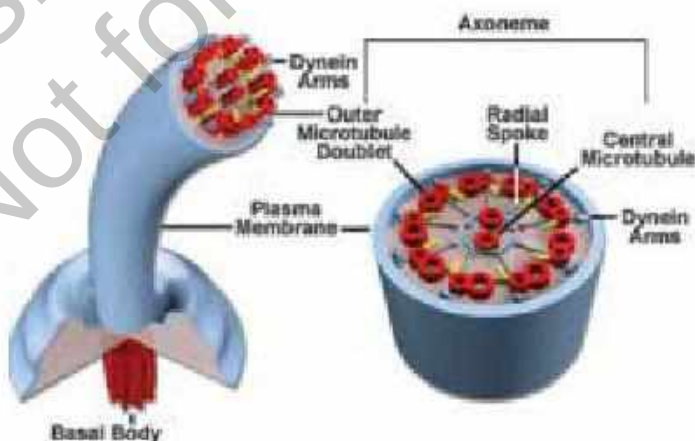


Figure 3.28: Structure of eukaryotic cilium and flagellum

Biologists refer to this organization as a "9 + 2" structure. A plasma membrane surrounds the entire axoneme. At the base of the cilium its organising centre, called basal body, is present. Basal body has the same basic structure of the outer ring of

axoneme, but each of the nine sets of outer filaments is composed of three microtubules, rather than a doublet of microtubules. The basal body is actually the centriole. Prokaryotic flagella have a completely different structure built from the protein flagellin.

3.5- PROKARYOTIC AND EUKARYOTIC CELLS

Bacteria and archaea are made of prokaryotic cells whereas all other forms are composed of eukaryotic cells. Both prokaryotic and eukaryotic cells have DNA as their genetic material; both have plasma membranes as their coverings; and both have ribosomes for protein synthesis. You have gone through the details of the cell organelles.

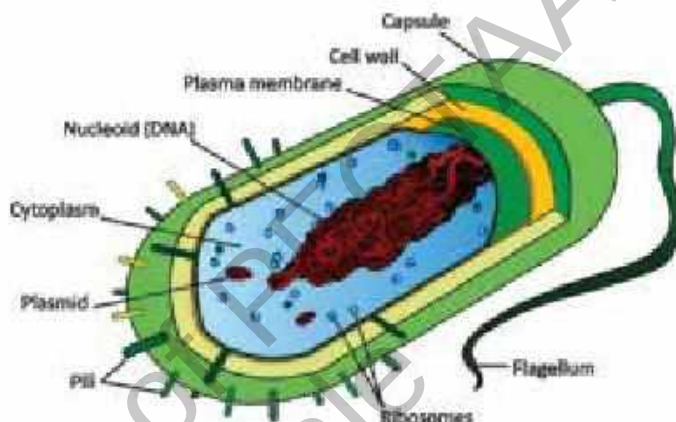


Figure 3.29: Structure of a generalized prokaryotic cell

Prokaryotic cells are much simpler than eukaryotic ones. Most prokaryotic cells range from 2 to 8 μm in length i.e., about one-tenth of the size of a typical eukaryotic cell. A prokaryotic cell lacks a nucleus. The much less extensive DNA of prokaryotic cell is present in the more-or-less central region known as nucleoid (*nucleus-like*).

A prokaryotic cell also lacks other membrane-bounded organelles like endoplasmic reticulum, mitochondria, chloroplasts, Golgi apparatus, lysosomes, peroxisomes etc. The entire cytoplasm of a prokaryotic cell is one unit with no internal support structures. Ribosomes are present in prokaryotic cell but these are smaller in size than those of eukaryotic cells.

The Svedberg values (sedimentation rates) of the smaller and larger subunits of ribosomes of prokaryotic cells are 30S and 50S respectively. The sedimentation rate of a complete ribosome is 70S. Surrounding the plasma membrane of most prokaryotic cells is a cell wall but it does not contain cellulose. It is composed of peptidoglycan that is a single large polymer of amino acids and sugar. In bacteria the cell wall may also be surrounded by a capsule and may also have extensions for attachment known as pili (singular *pilus*). Prokaryotic flagella are made of repeating units of the protein flagellin and they do not contain microtubule triplets. Mitosis and meiosis are missing in prokaryotic cell and it divides by direct division (binary fission).

Difference between Eukaryotic and Prokaryotic cells

Characteristics	Eukaryotic Cell	Prokaryotic Cell
Distinct Nucleus	Present	Absent
Number of chromosomes	More than one	One—but not true chromosome: Plasmids
Cell Type	Usually multicellular	Usually unicellular (some cyanobacteria may be multicellular)
Example	Protozoans, Algae, Fungi, Animals, Plants	Bacteria and Archaea
Lysosomes and peroxisomes	Present	Absent
Microtubules	Present	Absent or rare
Endoplasmic reticulum	Present	Absent
Mitochondria	Present	Absent
Cytoskeleton	Present	May be absent
Vacuoles	Present	Present
Ribosomes	Larger	Smaller
Golgi apparatus	Present	Absent
Chloroplasts	Present (in plants)	Absent; chlorophyll scattered in the cytoplasm
Cell Division	Mitosis or meiosis	Mitosis and meiosis are missing; cell divides by direct division (binary fission)
Flagella	Membrane bounded; contains two central microtubules surrounded by an outer ring of nine doublet microtubules	Not membrane bounded; made of repeating units of flagellin; do not contain microtubule triplets
Cell wall	Only in plant cells and fungi (chemically simpler)	Composed of peptidoglycan (a single large polymer of amino acids and sugar)
Cell size	10–100 μm	1–10 μm

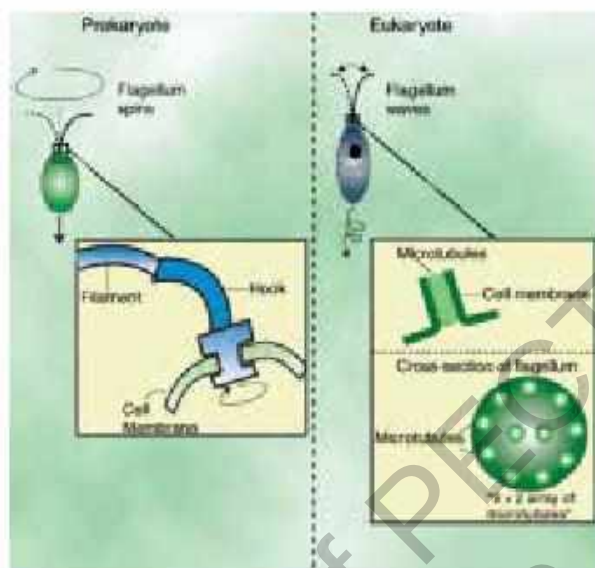


Figure 3.30: Difference between the structures of prokaryotic and eukaryotic flagella

3.6- CELL SIGNALLING

Cell signalling is the ability of cells to respond to stimuli from their environment producing cellular responses. It involves the transmission of signals between cells through a series of molecular events, often leading to a cellular response.

Steps of Cell Signalling

1- Signal Reception

Cell signalling begins when a signal molecule (ligand) binds to a receptor on the membrane of a target cell. These receptors are typically proteins embedded in the cell membrane but can also be located inside the cell. Each receptor is specific to a particular ligand.

2- Signal Transduction

Once the receptor binds to the ligand, it undergoes a conformational change that activates an intracellular signalling pathway. This often involves a series of interactions and modifications, creating a signalling cascade that amplifies the signal. Small molecules like cAMP (cyclic AMP), calcium ions, and inositol triphosphate (IP3) can act as second messengers, transmitting the signal from the receptor to target molecules inside the cell.

3- Cellular Response

The signal transduction pathway often leads to changes in gene expression, turning specific genes on or off. This can result in various cellular responses, such as cell growth, division, differentiation, or apoptosis (programmed cell death). Signalling can also lead to changes in cellular metabolism, enzyme activity, or the opening and closing of ion channels.

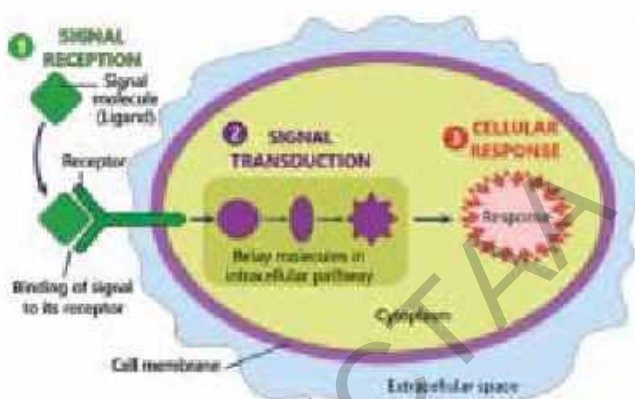


Figure 3.31: Steps of cell signalling

Pathways of Cell Signals from Outside to Inside

Cell signalling pathways involve the transmission of signals from the cell's exterior to its interior, resulting in a specific cellular response. There are two main types of signalling pathways based.

Protein/Peptide Signalling

Protein or peptide signalling molecules are water-soluble. So, they cannot pass through plasma membrane. When such ligand approaches the cell surface, it binds to its specific receptor on plasma membrane. This binding causes a conformational change in the receptor protein and activates it. The activated receptor triggers a series of reactions within the cell. These reactions generate second messenger like cyclic AMP (cAMP) which starts changes e.g., changes in gene expression. The pathway can lead to changes in metabolism, cell growth, division, or apoptosis.

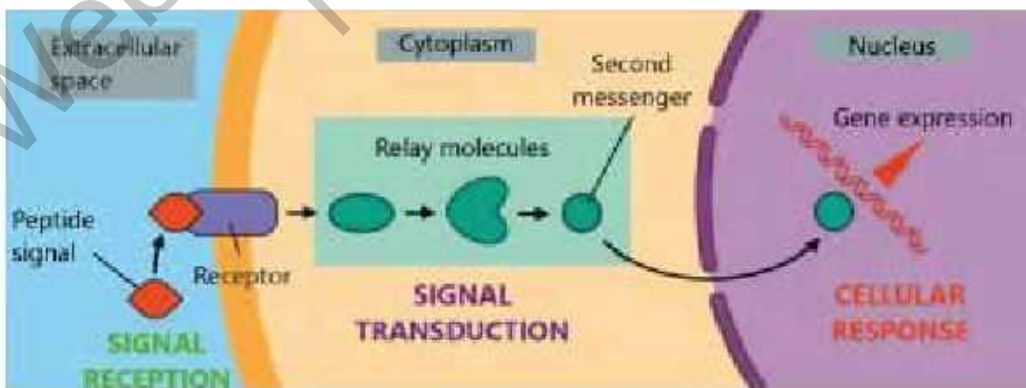


Figure 3.32: Protein/peptide signalling pathway

Steroid Signalling

Steroid hormones, being lipophilic, can diffuse through the plasma membrane of the target cell. Once inside, they bind to specific intracellular receptors located in the cytoplasm or nucleus. This binding results in the formation of active receptor-hormone complex which moves into the nucleus if it was not already there. Inside nucleus, the receptor-hormone complex binds to specific DNA sequences in target genes. This binding regulates the transcription of these genes, leading to increased or decreased production of specific proteins.

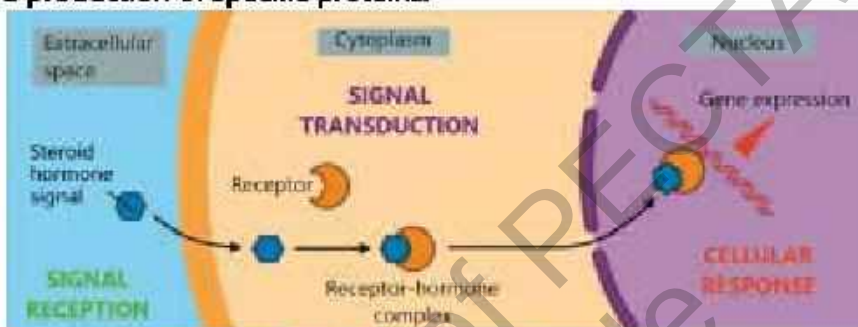


Figure 3.33: Steroid signalling pathway

3.7- MEMBRANE TRANSPORT MECHANISMS

You know that the movement of substances in and out of cells is crucial for cellular functions. These movements are done for nutrient uptake, waste elimination, gas exchange, and signal transduction. Cells rely on the plasma membrane for regulating the movement of substances in and out of the cell. Membrane transport mechanisms are essential processes that enable the cell to maintain homeostasis, acquire nutrients, remove waste products, and communicate with its environment.

While exchanging matter with cells' environment, plasma membranes maintain equilibrium inside the cell as well as outside.

These mechanisms include two mechanisms i.e., passive transport (which requires no energy input) and active transport (which utilizes energy).

Passive Transport

The movement of molecules across plasma membrane without any expenditure of energy is called passive transport. The following are the types of passive transport.

Diffusion

Diffusion is the net movement of a substance (liquid or gas) from an area of higher concentration to one of lower concentration i.e., along concentration gradient. Because a cell does not expend energy when molecules diffuse across its membrane, the diffusion of molecules is a type of **passive transport**.

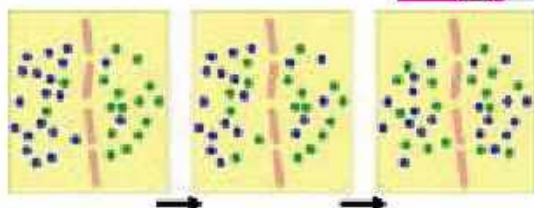


Figure 3.34: Diffusion of two types of molecules

Facilitated Diffusion

Some molecules are taken into or out of the cells with the help of **transport-proteins** present in plasma membranes. When a transport protein helps a substance to move it down its concentration gradient (from higher to lower concentration), the process is called facilitated diffusion. It is also a type of passive transport because no energy is used in facilitated diffusion. The rate of facilitated diffusion depends on how many transport-protein molecules are available in the membrane. The main types of transport proteins involved in facilitated diffusion are:

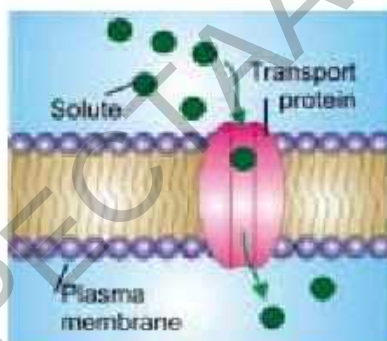


Figure 3.35: Facilitated diffusion

1. Channel Proteins: These proteins form hydrophilic channels across the membrane that allow specific molecules or ions to pass through. They can be gated or non-gated. Gated channels open or close in response to specific stimuli (such as voltage changes, ligand binding, or mechanical stress). Examples include ion channels (allow the passage of specific ions e.g., Na^+ , K^+ , Ca^{2+} , Cl^-) and aquaporins (facilitate the rapid transport of water molecules).

2. Carrier Proteins (Transporters): These proteins bind to the specific molecule they transport, undergo a conformational change, and move the molecule across the membrane. They are highly specific for the molecule they transport. They can become saturated, meaning there is a maximum rate of transport when all carrier proteins are occupied. Examples include glucose transporters (facilitate the transport of glucose) and amino acid transporters (transport specific amino acids into or out of the cell).

Difference between Simple and Facilitated Diffusion

	Simple Diffusion	Facilitated Diffusion
Mechanism	Substances move from higher concentration to lower concentration directly through	Substances move from higher concentration to lower concentration through specific

Difference between Simple and Facilitated Diffusion

	the lipid bilayer of plasma membrane.	transport proteins embedded in plasma membrane.
Energy Requirement	It is a passive transport mechanism, requiring no energy input from cell.	It is also a passive transport mechanism and does not require energy.
Types of Molecules	Typically involves small, nonpolar molecules such as oxygen, carbon dioxide, and lipid-soluble substances.	Primarily involves polar or charged molecules, such as glucose, amino acids, and ions, which cannot easily pass through the hydrophobic core of the lipid bilayer.
Rate of Movement	The rate depends on the concentration gradient, temperature, and the permeability of the membrane.	The rate can be affected by the number and availability of transport proteins and can reach a maximum rate when all transport proteins are saturated.

Osmosis

The process by which water molecules diffuse across a cell membrane from an area of higher concentration to an area of lower concentration is called osmosis. Because water is moving from a higher to lower concentration, osmosis does not require cells to expend energy. Therefore, osmosis is the passive transport of water. The direction of osmosis depends on the concentration of solutes on the two sides of membrane. Water always moves from hypotonic solution (with lower solute concentration) hypertonic solution (with higher solute concentration).

The term **tonicity** refers to the relative concentration of solutes in the solutions.

Hypertonic solutions are those in which more solute is present.

Hypotonic solutions are those with less solute.

Isotonic solutions have equal concentrations of solutes.

Osmosis occurs through selectively permeable membrane, which allows water to pass while restricting many solutes. Osmosis is crucial for maintaining cell turgor, which is vital for plant cells, and for balancing the internal water content in cells. The direction and rate of osmosis are influenced by the osmotic gradient and the permeability of the membrane to water. Specialized proteins called aquaporins facilitate the rapid transport of water molecules across the cell membrane, ensuring efficient regulation of cellular hydration and volume.

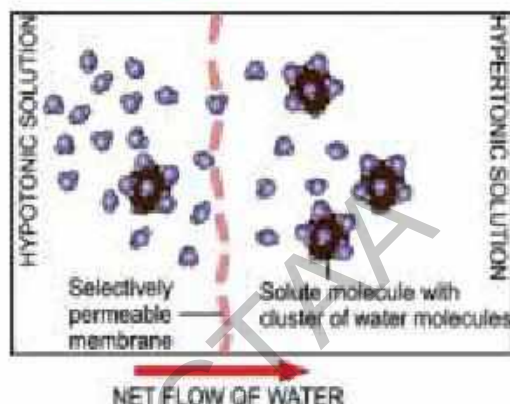
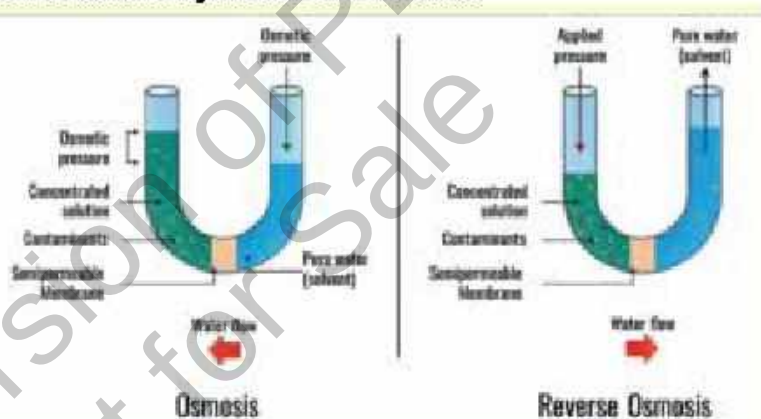


Figure 3.35: Osmosis at molecular level

Reverse osmosis

It is a widely used technology for purifying water by removing contaminants and impurities. Unlike natural osmosis, which moves water from a lower to a higher solute concentration, reverse osmosis applies external pressure to push water through a semi-permeable membrane from a higher to a lower solute concentration.



This process effectively filters out dissolved salts and other impurities, providing clean and safe drinking water. Reverse osmosis is commonly used in water treatment plants, desalination facilities, and even in household water purification systems.

Active Transport

The movement of substances across plasma membrane from lower concentration to higher concentration with the expenditure of energy is known as active transport. Following types of active transport occur through plasma membrane.

Active transport through carrier proteins

In this process, carrier (transport) proteins in the plasma membrane use energy to move the molecules against the concentration gradient. For example, the membranes of nerve cells have carrier proteins in the form of "sodium-potassium pump". In a resting (not conducting nerve impulse) nerve cell, this pump spends energy (ATP) to maintain higher concentrations of K^+ and lower concentrations of Na^+ .

inside the cell. For this purpose, the pump actively moves Na^+ to the outside of the cell and K^+ to the inside of the cell.

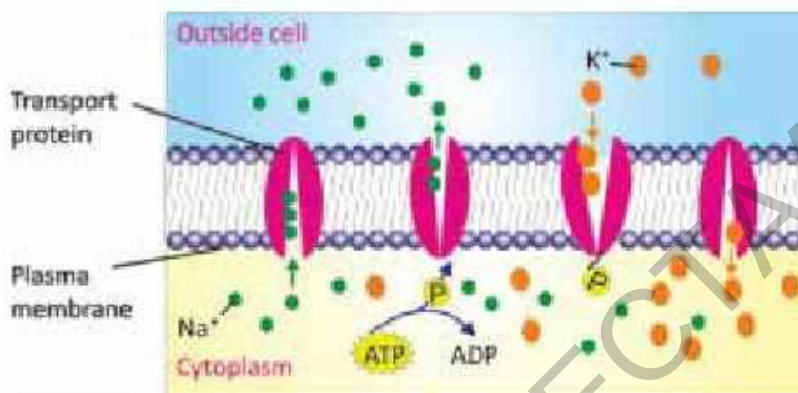


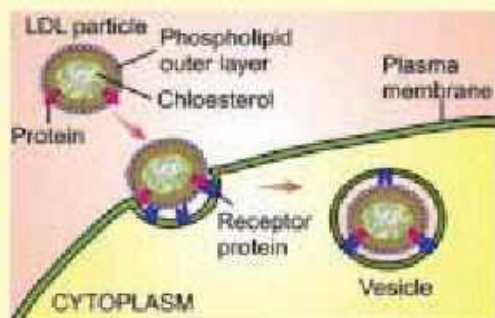
Figure 3-37: Active transport through carrier proteins

Endocytosis

In endocytosis, bulky materials are moved into the cell across plasma membrane. During endocytosis a portion of plasma membrane invaginates (depressed inward). The material from outside is taken inside the invagination, and its ends seal. Thus, a small vesicle is formed. It detaches from the plasma membrane and moves into cytoplasm. The two common forms of endocytosis are phagocytosis and pinocytosis. In **phagocytosis**, cell takes in solid material while in **pinocytosis**, cell takes in liquids in the form of droplets.

Receptor-mediated endocytosis

Specific receptor proteins of plasma membrane pick up material from outside and pinch inside to form a vesicle. For example, the cells of liver have receptor proteins for cholesterol. Cholesterol circulates in our blood in the form of low-density-lipoproteins (LDLs). The receptor proteins of plasma membrane of liver cells, recognize and take up LDLs from the blood by receptor-mediated endocytosis.



Exocytosis

It is the process through which bulky material is exported out of cell. In exocytosis, the bulky material is packed inside a membrane and a vesicle is formed. The vesicle moves to the plasma membrane and fuses with it to release its contents into the extracellular environment.

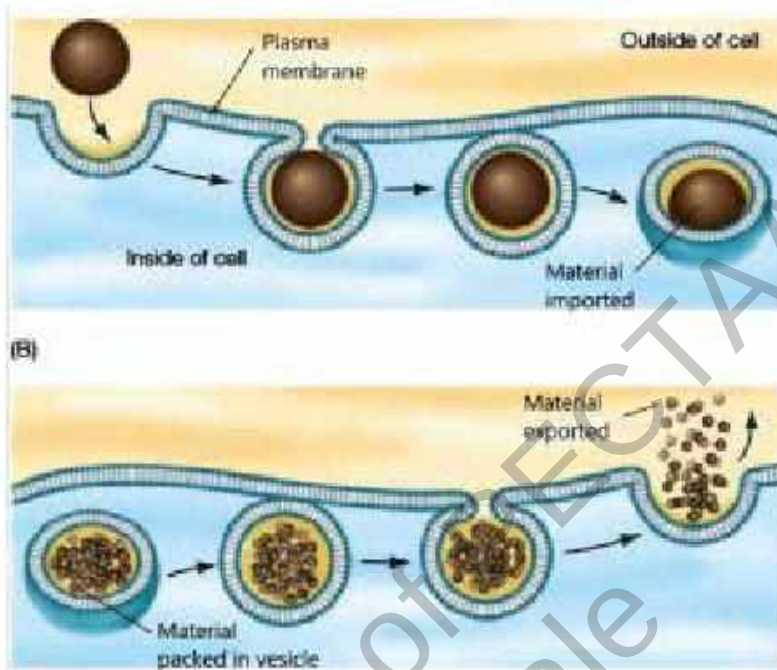


Figure 3.38: (A) Endocytosis, (B) Exocytosis

3.8- STEM CELLS

Stem cells are unique cells with the remarkable ability to develop into many different cell types in the body. When a stem cell divides, each new cell has the potential either to remain a stem cell or to become specialized cell, such as a muscle cell, a red blood cell, or a brain cell. The following are the major categories of stem cells on the basis of the number of types of cells which they can make.

1. **Totipotent:** These stem cells can differentiate into all possible cell types. For example, zygote and the cells produced by the first few divisions in zygote.
2. **Pluripotent:** These cells can turn into almost any cell. For example, cells from the early embryo.
3. **Multipotent:** These cells can differentiate into a closely related family of cells. For example, the hematopoietic stem cells can become red and white blood cells or platelets.
4. **Oligopotent:** These can differentiate into a few different cell types. For example, adult lymphoid or myeloid stem cells.
5. **Unipotent:** These can only produce cells of one kind, which is their own type. However, they are still stem cells because they can renew themselves. For example, adult muscle stem cells.

Use of Stem Cells

1. **Regenerative Medicine:** Stem cells have the potential to repair or replace damaged tissues and organs. Therefore, they are used for treating conditions such as spinal cord injuries, type 1 diabetes, Parkinson's disease, and heart disease.
2. **Drug Testing and Development:** By differentiating stem cells into specific cell types, researchers can create models of human diseases, allowing for more accurate testing of drug effects and reducing the reliance on animal models.
3. **Personalized Medicine:** Stem cells can be derived from a patient's own cells, reducing the risk of immune rejection when used in treatments. This personalized approach can lead to more effective and safer therapies.

Categories of Stem Cells

The following are the major categories of stem cells on the basis of their origin.

1- Embryonic Stem Cells (ESCs)

ESCs are derived from the inner cell mass of blastocysts (early-stage embryos). These stem cells are pluripotent, meaning they can differentiate into nearly all cell types in the body. They have high differentiation potential, making them extremely versatile for research and therapy. Ethical concerns of using ESCs include the use of human embryos, risk of teratoma formation, and potential immune rejection.

2- Adult Stem Cells (ASCs)

These stem cells are found in various tissues throughout the body, such as bone marrow, fat, and blood. They are multipotent, meaning they can differentiate into a limited range of cell types related to their tissue of origin. Using them involves less ethical controversy, lower risk of immune rejection when derived from the patient's own tissues. However, they have limited differentiation potential and are harder to isolate and culture.

3- Induced Pluripotent Stem Cells (iPSCs)

They are generated in the lab by reprogramming adult somatic cells to a pluripotent state using specific transcription factors. They are pluripotent, similar to embryonic stem cells.

Advantages of using iPSCs: They do not have the ethical controversies linked to embryonic stem cells, as they do not require the destruction of embryos. They can be generated from a patient's own cells, minimizing the risk of immune rejection. They offer potential for regenerating damaged tissues and organs (e.g., new heart cells for patients with heart disease or new neurons for patients with neurodegenerative conditions).

Disadvantages of using iPSCs: The reprogramming process can introduce genetic changes that may affect iPSCs. They could form tumours (teratomas) when transplanted into patients. Directing iPSCs to differentiate into specific, fully functional cell types remains a complex task. It is still difficult to ensure that these cells function properly.

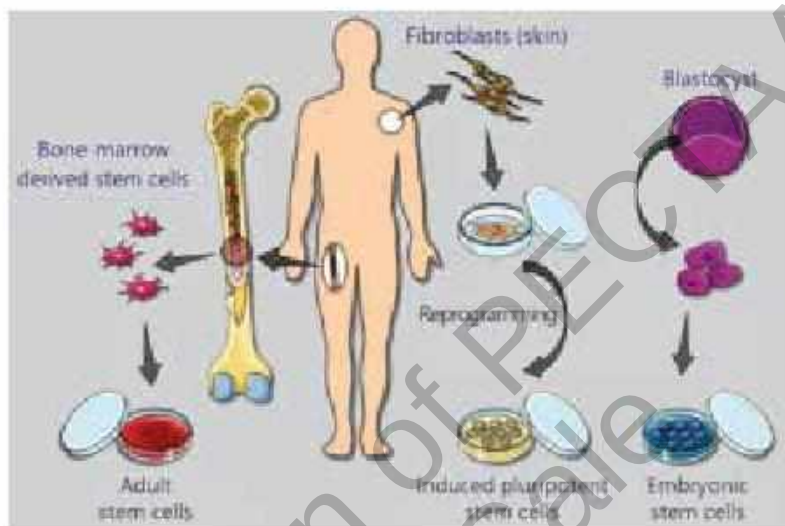


Figure 3.38: Stem cells- Sources and types

EXERCISE

SECTION 1: MULTIPLE CHOICE QUESTIONS

- Which one of the following eukaryotic cell structures does not contain DNA?
 - Nucleus
 - Mitochondrion
 - Endoplasmic reticulum
 - Chloroplast
- Which of the following is not an accurate description of a chromosome?
 - It is a coloured body localized in the nucleus
 - It is a protein and nucleic acid complex
 - It is the cellular structure that contains the genetic material
 - In eukaryotes, it is composed of many DNA molecules attached end to end
- A centriole is an organelle that is:
 - Present in the centre of a cell's cytoplasm
 - Composed of microtubules and important for organizing the spindle fibres
 - Surrounded by a membrane
 - Part of a chromosome

4. The rough endoplasmic reticulum is:
 - (a) An intracellular double-membrane system to which ribosomes are attached
 - (b) An intracellular membrane that is studded with microtubular structures
 - (c) A membranous structure found within mitochondria
 - (d) Only found in prokaryotic cells
5. In the nucleus of eukaryotic cells, the genetic material is complexed with protein and organized into linear structures called:
 - (a) Centrioles
 - (b) Histones
 - (c) Chromosomes
 - (d) Plasmids
6. Which of the following statements does not apply to the nuclear envelope?
 - (a) It is a double membrane
 - (b) It is continuous with the endoplasmic reticulum
 - (c) It has pores through which material enters and leaves
 - (d) It has infoldings to form cristae
7. Lysosomes are formed by budding from which cellular organelle?
 - (a) Smooth endoplasmic reticulum
 - (b) Golgi apparatus
 - (c) Rough endoplasmic reticulum
 - (d) Nucleus
8. All peroxisomes carry out this function:
 - (a) Break down fats and amino acids into smaller molecules that can be used for energy production by mitochondria
 - (b) Digest macromolecules using the hydrolytic enzymes they contain
 - (c) Synthesize membrane components such as fatty acids and phospholipids
 - (d) Control the flow of ions into and out of the cell
9. How would the absence of peroxisomes in a cell affect its metabolism, and what would be the likely symptoms?
 - (a) The cell would be unable to carry out oxidative phosphorylation, leading to reduced ATP production.
 - (b) The cell would accumulate hydrogen peroxide, leading to oxidative stress and potential cellular damage.
 - (c) The cell would have impaired protein synthesis, leading to muscle weakness.
 - (d) The cell would fail to produce lipids, causing membrane instability

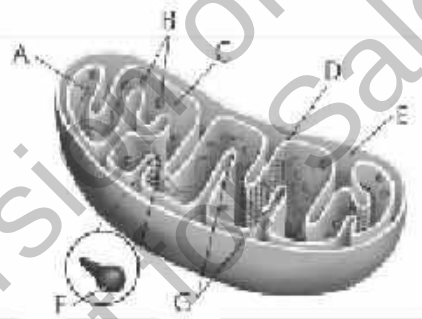
10. Which of the following does not apply to chloroplasts?
 - (a) They contain chlorophyll and the enzymes required for photosynthesis.
 - (b) They contain an internal membrane system consisting of thylakoids.
 - (c) They synthesize ATP.
 - (d) They are bounded by two membranes, the inner of which is folded into the cristae.
11. What is the correct sequence of membrane compartments through which a secretory protein moves from synthesis to release from the cell?
 - (a) SER → Golgi apparatus → RER → Cell membrane
 - (b) Cell membrane → Golgi apparatus → RER → SER
 - (c) RER → Golgi → Cell membrane → SER
 - (d) RER → SER → Golgi apparatus → Cell membrane
12. How does the process of facilitated diffusion differ from active transport?
 - (a) Facilitated diffusion requires energy, active transport does not
 - (b) Facilitated diffusion does not require energy, active transport does
 - (c) Both processes require energy
 - (d) Both processes do not require energy

SECTION 2: SHORT QUESTIONS

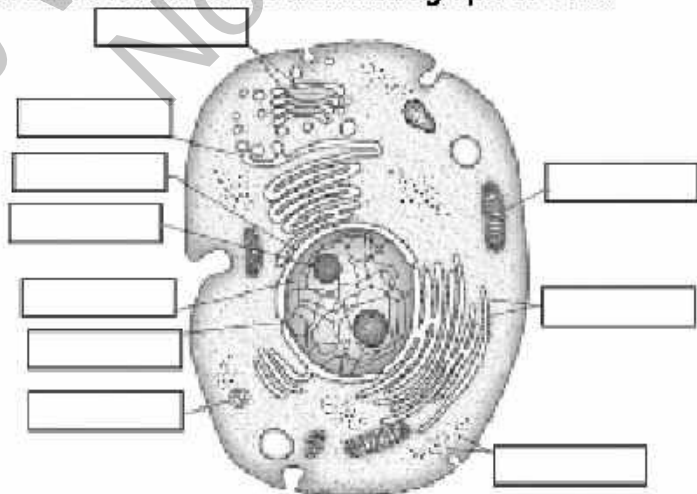
1. Compare the resolution and magnification of light microscope and electron microscope?
2. State the cell theory. How we can validate it? What are the exceptions to cell theory?
3. The table below compares the process of diffusion, facilitated diffusion and active transport. Fill in the blank cells, using the words "YES" or "NO".

Description	Process		
	Simple Diffusion	Facilitated Diffusion	Active Transport
Is ATP required?			
Are carrier proteins involved?			
Is direction of transport always from higher to lower concentration?			

4. Categorize the organelles as (i) single membrane bounded, (ii) double membrane bounded and (iii) lacking any membrane.
5. State two functions of the proteins in the plasma membrane.
6. State two features that mitochondria have in common with prokaryotes.
7. List three ways in which prokaryotic cells differ from eukaryotic cells.
8. List the structures and molecules, which can cross the nuclear envelope.
9. Distinguish each of the following pairs.
 - a- exocytosis and endocytosis
 - b- phagocytosis and pinocytosis
 - c- peroxisome and glyoxysomes
10. What are the main functions of lysosomes?
11. Describe the role of the Golgi body in forming lysosomes.
12. What are histones? Where are these found in eukaryotic cells?
13. What do you mean by "stem cell"? What are the main usages of stem cells?
14. The following diagram shows the structure of a mitochondrion. Name structures A to G.



15. The diagram below shows an electron micrograph of a cell.



- a- Label the parts of the cell.
- b- What evidence can be seen in the diagram that suggests that the cell is metabolically active and involved in secretion of enzymes?

SECTION 3: LONG QUESTIONS

1. Write details of the structure and the chemical composition of cell walls of eukaryotes and prokaryotes.
2. Explain the chemical composition and the functions of plasma membrane.
3. Identify the role of glycolipids and glycoproteins as the cell surface markers.
4. Explain the structure, chemical composition and function of ribosomes.
5. Explain the structure, and functions of Golgi complex.
6. Describe the structure, chemical composition and function of chromosome.
7. Discuss nuclear envelope and nuclear pore complex in detail.
8. Explain how Golgi apparatus is involved in making cell secretions.
9. Describe the structure and functions of smooth and rough endoplasmic reticulum.
10. Explain the role of lysosomes and peroxisomes in regulating the amounts of cellular contents.
11. Describe the structures of the three fibres that make the cytoskeleton.
12. Describe the formation and functions of lysosomes.
13. Compare mitochondria and chloroplasts as the organelles that are involved in cellular energetics.
14. Describe the basic structure of a mitochondrion, from outside inward.
15. Describe the pathway of protein signal and steroid signal from outside of a cell to inside.
16. Categorize and explain different types of stem cells.
17. What are the advantages and disadvantages of using induced Pluripotent Stem Cells?

INQUISITIVE QUESTIONS

1. If a researcher observes that a certain cell type has an exceptionally large Golgi apparatus, what can be inferred about the function of this cell?
2. If a signalling molecule is lipid-soluble, like a steroid hormone, what is the most likely mechanism for its action within the target cell?
3. Why do we categorize endocytosis and exocytosis in active transport?
4. Justify why the membrane may be described as fluid.