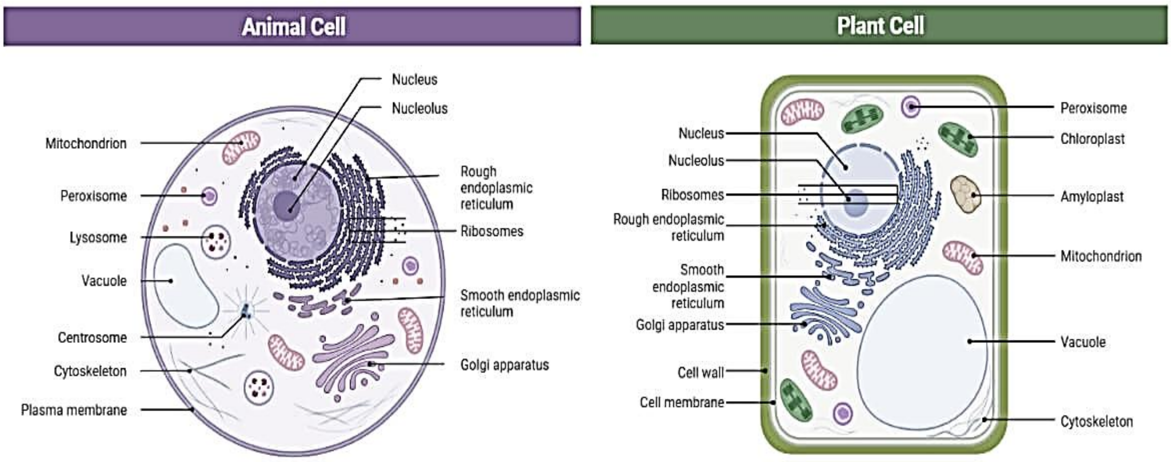
CELL THEORY AND CELL STRUCTURE

Cell Theory- Definition, History, Modern, Exceptions

According to the cell theory, all biological organisms are made up of cells, the basic building blocks of life, and all life evolved from preexisting life.

It is the cell theory that emphasizes the unity underlying the diversity of forms, i.e., the cellular organization of all life forms.



Cell Theory

The cell theory explains that all life, whether unicellular, colonial, or multicellular in an organization, is punctuated by periods of minimal organization, whether spores or zygotes.

Schleiden & Schwann were the first to introduce the idea of the cell theory in 1839, and it has remained the cornerstone of modern biology ever since. The cell theory continues to be the dominant theory of biology despite the numerous concepts that ultrastructural research and modern molecular biology have introduced.

Progression of Cell Theory

The discovery of cells would not have been possible without the advancement of the microscope. Objects that are too small to be seen with the naked eye are magnified with the help of a microscope.

Robert Hooke was the first person to coin the term cell (L., *Cella* = hollow space) in 1665. He used a custom-built compound microscope to look at a tiny slice of dry cork that had been cut from a larger piece. He then published a collection of essays under the title *Micrographia* which described cork as a honeycomb of chambers or “cells”. It is now recognized that the chambers or cells are void spaces left behind after the living components of the cell have broken down.

The development of a more sophisticated microscope by **Anton van Leeuwenhoek** in 1673 led to his observation of numerous minute “animalcules” in water. Additionally, he conducted more research on sperm and red blood cells. Nevertheless, Leeuwenhoek’s findings on bacteria and spermatozoa were largely disregarded for a long time.

Marcello Malpighi and Nehemiah Grew performed in-depth analyses of plant cells and confirmed that cellular structures are present throughout the entire plant body.

Malpighi referred to cells as “utriculi” and “saccule” in his 1671 publication “Anatome plantarum.” Grew used the terms “bladders”, “cells” and “pore” in his book “The Anatomy of

Plants" and offered several illustrations of plant material that show he was aware of the cellular structure.

In 1838, a German botanist, **Matthias Schleiden** noticed that all plants are made up of many types of cells that constitute the plant's tissues after studying many plants.

Theodore Schwann (1839), a British zoologist, researched many animal cell types around the same time and found that cells had a thin outer layer known as the **"plasma membrane."** Similarly, he also concluded that the presence of **a cell wall** is a distinctive feature of plant cells based on his research on plant tissues.
Based on this, Schwann proposed the hypothesis that the bodies of animals and plants are composed of **cells and products of cells**.

He summarized his observations into three conclusions about cells:

1. The cell is the unit of structure, physiology, and organization in living things.
2. The cell retains a dual existence as a distinct entity and a building block in the construction of organisms.
3. Cells form by free-cell formation, similar to the formation of crystals.

However, Schwann's third conclusion stating that cells formed similarly to crystals, was discounted as this observation refers to the spontaneous generation of life. Schwann's theory also did not explain how new cells were formed.

Rudolf Virchow, a German pathologist, first explained that cells divide and new cells are formed from pre-existing cells and famously wrote **"*omnis cellula-e cellula.*"** He modified the hypothesis of Schleiden and Schwann to give the cell theory a final shape.
Therefore, the cell theory states,

1. All organisms are composed of one or more cells.
2. The cell is the basic unit of life in all living things.
3. All cells are produced by the division of pre-existing cells.

Modern Cell Theory

The original cell theory proposed by Schleiden and Schwann is supplemented by a few additional principles in the modern version; the three basic components of cell theory, plus four additional statements:

1. The cell pass information from cell to cell during cell division using DNA.
2. All cells have basically the same chemical composition and metabolic activities.
3. All cells have basically the same chemical & physiological functions
4. Cell activity depends on the activities of structures within the cell (organelles, nucleus, plasma membrane).

Exception of cell Theory

Cell theory does not have a universal application, i.e., certain living organisms do not have true cells.

Viruses do not easily fit into the parameters of a true cell. They lack a plasma membrane and metabolic machinery for energy production and the synthesis of proteins.

The protozoan *Paramecium*, the fungus *Rhizopus*, and the algae *Vaucheria* are a few examples of additional organisms that do not fall inside the cell theory's purview. All of these organisms have bodies made up of a single, undivided mass of protoplasm that lacks any cellular organization and has several nuclei.

Membrane Carbohydrates: Types, Structure, Functions

Cell membranes are selective barriers that separate individual cells and cellular compartments. Membranes are assemblies of carbohydrates, proteins, and lipids held together by binding forces. Carbohydrates are covalently linked to proteins (glycoproteins) or lipids (glycolipids) and also an important part of cell membranes, and function as adhesion and address loci for cells.

The Fluid Mosaic Model describes membranes as a fluid lipid bilayer with floating proteins and carbohydrates. Membrane carbohydrates are chemically bound to glycolipids and glycoproteins.

However, some membrane carbohydrates are part of proteoglycans that insert their amino acid chain among the lipid fatty acids. Although some carbohydrates can be found associated with intracellular membranes, most of them are located in the outer monolayer of the plasma membrane, facing the extracellular space.

Membrane Carbohydrate types

Carbohydrate groups are present only on the outer surface of the plasma membrane and are attached to proteins, forming glycoproteins, or lipids, forming glycolipids.

Glycoproteins

Most of the membrane carbohydrates are found linked to proteins, known as glycoproteins. Nearly all the membrane proteins have carbohydrates.

In the glycoproteins, the majority of the molecule consist of proteins; they have one or more oligosaccharides attached to a protein, and they are usually branched and do not have serial repeats, so they are rich in information, forming highly specific sites for recognition and high-affinity binding by other proteins.

As in glycolipids, the sugar residues are added in the lumen of the ER and Golgi apparatus. For this reason, the oligosaccharide chains are always present on the non-cytosolic side of the membrane.

The sugars can be attached to a protein in two locations in the cell, the endoplasmic reticulum, which produces N-linked sugars, and the Golgi apparatus, which produces O-linked sugars. The N-linked glycoproteins have a sugar attached to a nitrogen atom, and O-linked glycoproteins have a sugar attached to an oxygen atom. The different structure of N- and O-linked sugars give them different functions.

Membrane-bound glycoproteins participate in a wide range of cellular phenomena, including cell recognition, cell surface antigenicity, etc.

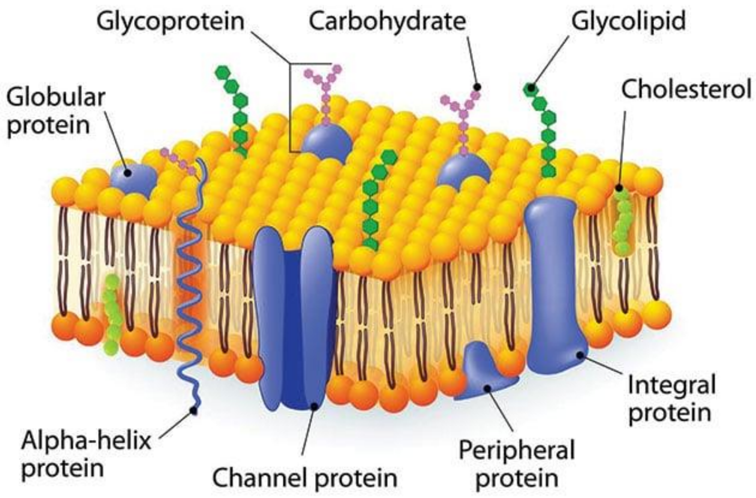
Glycolipids

Glycolipids are membrane lipids in which the hydrophilic head groups are oligosaccharides. Three types of glycolipids are found in membranes: **glycosphingolipids,** which are the most abundant in the animal cells, **glycoglycerolipids,** and **glycophosphatidylinositol.** Glycoglycerolipids are more frequent in the plasma membrane of plant cells. Only 5 % of lipids in membranes are glycolipids. As in glycoproteins, glycolipids act as specific sites for recognition by carbohydrate-binding proteins.

Proteoglycans

Polysaccharide chains of an integral membrane are called as proteoglycan molecules. Proteoglycans, which consist of long polysaccharide chains linked covalently to a protein core, are found mainly outside the cell as part of the extracellular matrix. But for some proteoglycans, the protein core either extends across the lipid bilayer or is attached to the bilayer by a glycophosphatidylinositol (GPI) anchor.

Membrane Carbohydrate Structure



Carbohydrates present in the plasma membrane as short sometimes branched chains of sugars attached either to exterior peripheral proteins (forming glycoproteins) or to the polar ends of phospholipid molecules in the outer lipid layer (forming glycolipids). Carbohydrate chains may consist of 2-60 monosaccharide units and can be either straight or branched.

The oligosaccharide chains of membrane glycoproteins and glycolipids are formed by various combinations of six principal sugars D-galactose, D-mannose, L-fucose, N-acetylneuraminic acid (also called sialic acid), N-acetyl-D-glucosamine, and N-acetyl-D-galactosamine. All of these may be derived from glucose.

The oligosaccharide side chains of glycoproteins and glycolipids are enormously diverse in their arrangement of sugars. Although they usually contain fewer than 15 sugars, they are often branched, and the sugars can be bonded together by a variety of covalent linkages—unlike the amino acids in a polypeptide chain, which are all linked by identical peptide bonds.

Even three sugars can be put together to form hundreds of different trisaccharides. In principle, both the diversity and the exposed position of the oligosaccharides on the cell surface make them especially well-suited to a function in specific cell-recognition processes.

Functions of Membrane Carbohydrates

Membrane carbohydrates perform two main functions:

1.Participate in cell recognition and adhesion, either cell-cell signalling or cell-pathogen interactions, and

2. They have a structural role as a physical barrier.

Blood groups are determined by cell surface carbohydrates of erythrocytes, and they also have the ability to trigger immunological responses. After an infection, endothelial cells near the injured tissue expose a type of proteins, known as **selectins**, in their plasma membranes. They recognize and bind carbohydrates of the plasma membrane of lymphocytes that go through the bloodstream. In this way, lymphocytes get attached to the blood vessel walls, can cross the endothelium and move to the infection focus.

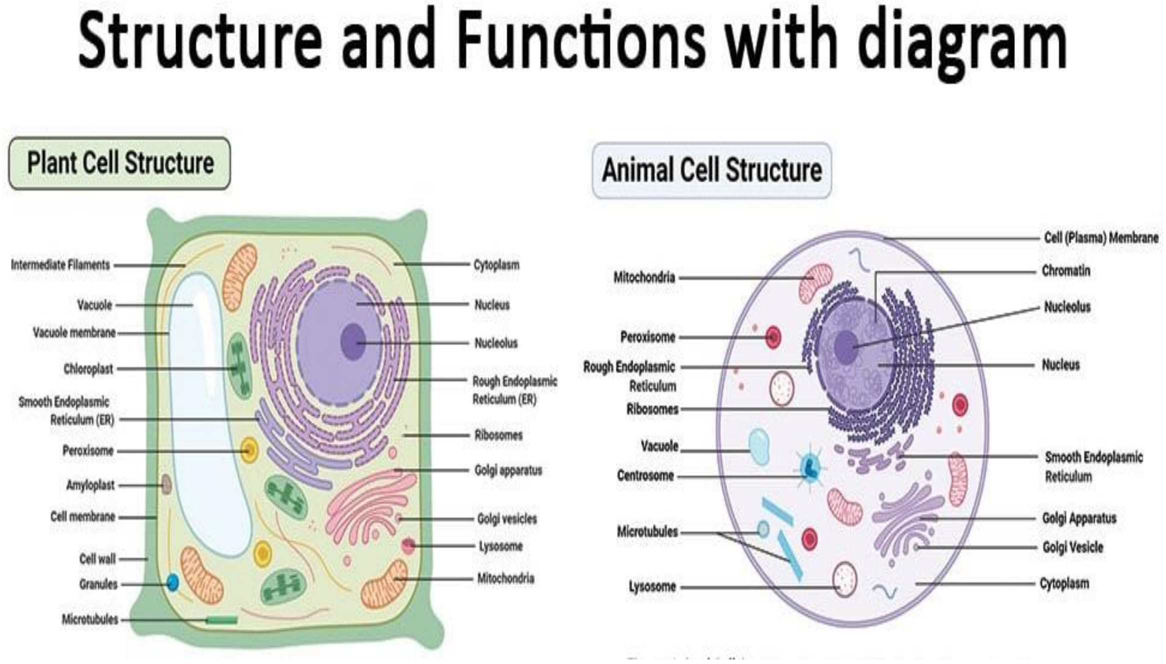
- Carbohydrates as recognition molecules are also important during embryonic development.
- Carbohydrates of the plasma membrane are major recognition and attaching sites for pathogens during infection.

- The glycocalyx also has important functions in humans. It allows cells on the inside of blood vessels to withstand the strong flow of liquid across their surfaces.
- It protects microvilli in the gut, which absorb nutrients, and the glycocalyx even aids in the breakdown of food for this absorption by holding digestive enzymes in its coat.
- Certain plasma transport proteins, hormones, and enzymes are glycoproteins, and in these molecules, carbohydrate is important to physiological activity.

Cell Organelles: Structures, Functions & Diagram

Cell organelles are specialized entities present inside a particular type of cell that performs a specific function.

There are various cell organelles, out of which, some are common in most types of cells like cell membranes, nucleus, and cytoplasm. However, some organelles are specific to one particular type of cell-like plastids and cell walls in plant cells.



List of 24 Cell organelles

1. Cell membrane (Plasma membrane/ Plasmalemma)
2. Centriole
3. Chloroplast
4. Cytoskeleton
5. Endosomes
6. Golgi Apparatus/ Golgi Complex/ Golgi Body
7. Lysozyme
8. Microtubules
9. Mitochondria
10. Peroxisomes
11. Plastids
12. Storage granules
13. Vesicles
14. Cell Wall
15. Cilia and Flagella
16. Cytoplasm
17. Endoplasmic Reticulum (ER)
18. Intermediate filaments
19. Microfilaments
20. Microvilli
21. Nucleus
22. Plasmodesmata
23. Ribosomes
24. Vacuole

Animal Cell Explained: Structure, Parts & Vital Functions

An animal cell is a eukaryotic cell that lacks a cell wall, and it is enclosed by the plasma membrane. The cell organelles are enclosed by the plasma membrane including the cell nucleus. Unlike the animal cell lacking the cell wall, plant cells have a cell wall.

- Animals are a large group of diverse living organisms that make up three-quarters of all species on earth. With their ability to move, respond to stimuli, respond to environmental changes, and adapt to different modes of feeding defence mechanisms and reproduction, all these mechanisms are enhanced by their constituent elements in the body. However, animals cannot manufacture their own food like plants and hence they depend on plants in one way or another.

- All living things are made up of cells that make up their body structure. Some of these living things are single-celled (**unicellular**) and other organisms are made up of more than one cell (**Multicellular**).
- Most cells are covered by a protective membrane known as the **cell wall** which gives the cells their shape and rigidity.
- Since animal cells lack a rigid cell wall it allows them to develop a great diversity of cell types, tissues, and organs. The nerves and muscles are made up of specialized cells that plant cells cannot evolve to form, hence giving these nerve and muscle cells have the ability to move.

Animal cell size and shape

- Animal cells come in all kinds of shapes and sizes, with their size ranging from a few millimeters to micrometers. The largest animal cell is the ostrich egg which has a 5-inch diameter, weighing about 1.2-1.4 kg and the smallest animal cells are neurons of about 100 microns in diameter.
- Animal cells are smaller than the plant cells and they are generally irregular in shape taking various forms of shapes, due to lack of the cell wall. Some cells are round, oval, flattened or rod-shaped, spherical, concave, rectangular. This is due to the lack of a cell wall. Note: most of the cells are microscopic hence they can only be seen under a microscope in order to study their anatomy.
- But animal cells share other cellular organelles with plant cells as both have evolved from eukaryotic cells.
- As noted earlier, animal cells are eukaryotic cells with a membrane-bound nucleus. therefore they have their genetic material in the form of DNA enclosed in the nucleus. They also have several structural organelles within the plasma membrane which perform various specific functions for proper cell function and generally to maintain the body normal mechanisms.
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List of 16 animal cell organelles

1. Plasma membrane (Cell membrane)
2. Cytoplasm

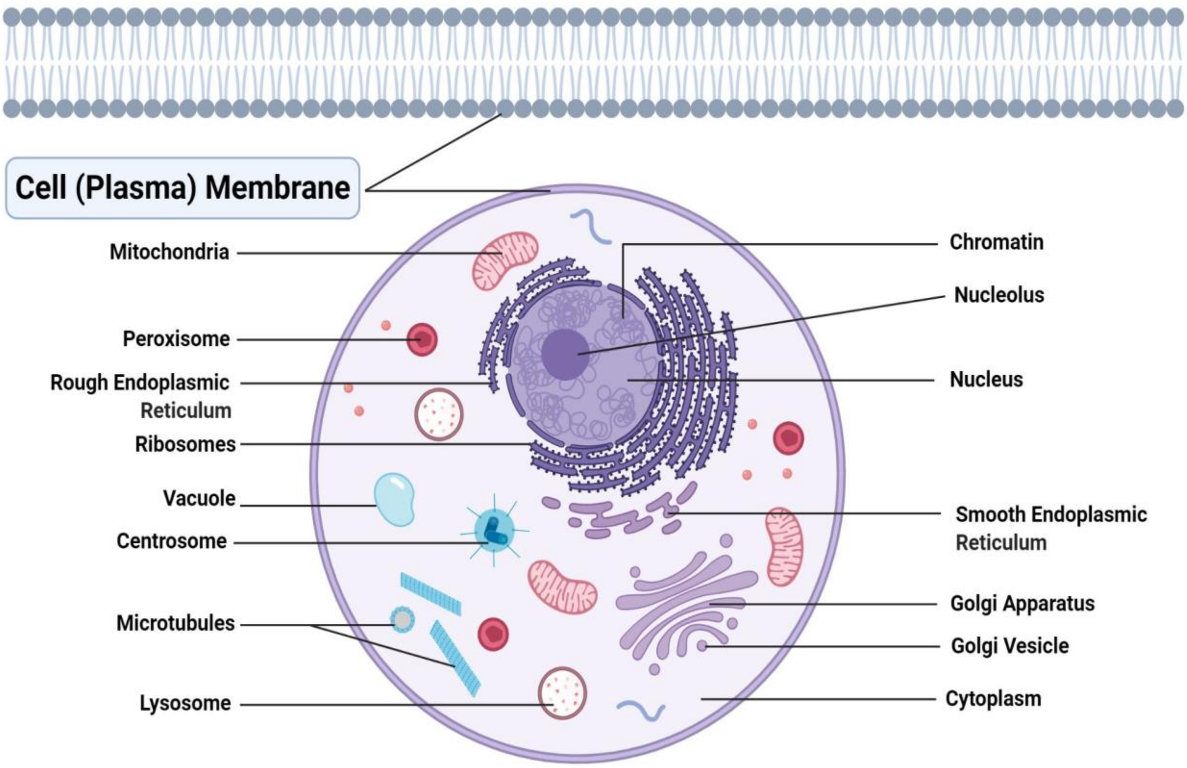
9. Nucleus
10. Mitochondria

3. Ribosomes
4. Golgi apparatus (Golgi bodies/Golgi complex)
5. Cytoskeleton
6. Centrioles
7. Cilia and Flagella
8. Vacuoles
11. Endoplasmic Reticulum (ER)
12. Lysosomes
13. Microtubules
14. Peroxisomes
15. Endosome
16. Microvilli

Animal cell organelles
The major cell organelles include:

1. **Plasma membrane (Cell membrane)**

It is a thin semipermeable protein-membrane layer that surrounds an animal cell.



Structure of Plasma membrane (Cell membrane)
- Thin semi-permeable membrane
- It contains a percentage of lipids making a semi-permeable barrier between the cell and its physical environment.
- It has some protein components a
- It is very consistent around the cell
- All living cells have a plasma membrane.

Functions of Plasma membrane (Cell membrane)
- To enclose and protect the cell content
- To also regulate the molecules that pass into and out of the cell, through the plasma membrane. Therefore it controls homeostasis.
- The proteins are actively involved in transporting materials across the membrane

- The proteins and lipids allow cell communication, and carbohydrates (sugars and sugar chains), which decorate both the proteins and lipids and help cells recognize each other.

Nucleus

Definition of Nucleus

- This is a spherical structured organelle found majorly at the center of a cell surrounded by a double-layered nuclear membrane separating it from the cytoplasm.
- It is held together to the cytoplasm with the help of the filaments and microtubules.
- It holds other cells organelles including the nucleolus, nucleosomes, and chromatins.
- A cell has one nucleus which divides producing multinucleated cells e.g. the skeletal muscle cell fibres.
- Some cells lose their nuclei after maturations e.g. the red blood cells.

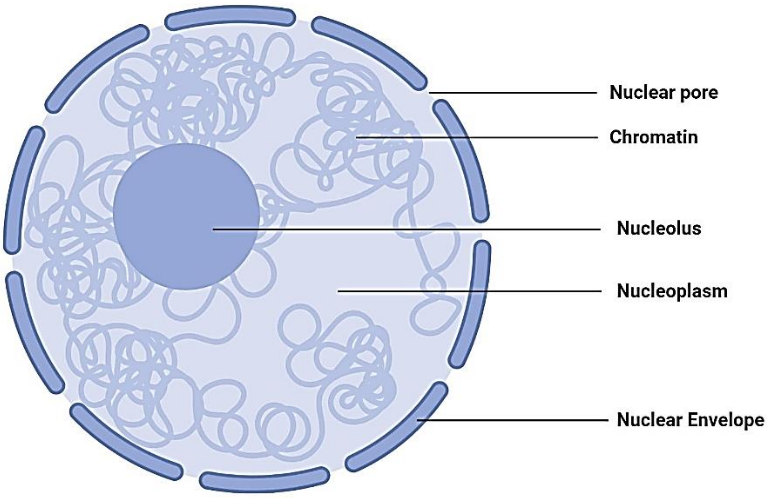


Diagram of Nucleus

Structure of Nucleus

- The double-layered membrane is a continuous channel of membrane from the endoplasmic reticulum network.
- The membrane has pores which allow entry of large molecule
- Nucleoli (Singular; nucleolus) are tiny/small bodies found in the nucleus
- The nucleus and its component organelles are suspended in the **nucleoplasm (**House of the chromosomal DNA and genetic materials)

Functions of Nucleus

- The primary role of the nucleus is to control and regulate cell activities of growth and maintain cell metabolisms.
- It also carries the genes that have hereditary information of the cell.
- The chromosomal DNA and genetic materials, which are made up of genetic coded ultimately make up their proteins' amino acid sequences for use by the cell.
- Therefore, the nucleus is the information centre.
- It is the site for Transcription (formation of mRNA from DNA) and the mRNA is transported to the nuclear envelope.

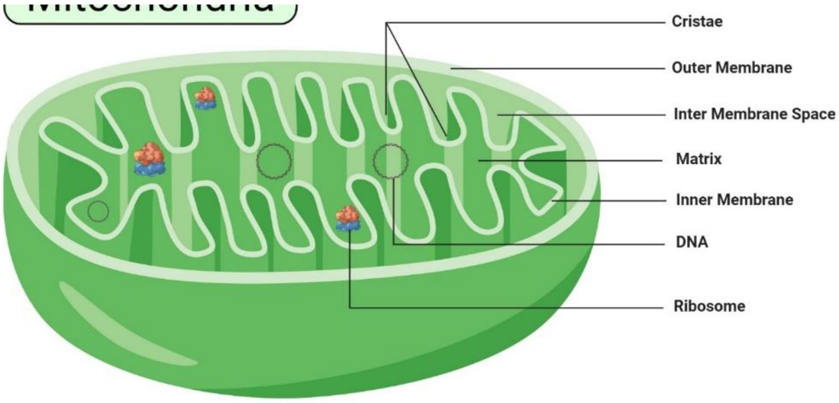
Cytoplasm

Definition of Cytoplasm

- This is a gel-like material that contains all the cell organelles, enclosed within the cell membrane.
- These organelles include; Mitochondria, ribosomes, Endoplasmic reticulum, Golgi apparatus, lysosomes intermediate filaments, microfilaments microtubules, vesicles.

Mitochondria

- These are membrane-bound organelles located in the cytoplasm of all eukaryotic cells
- The number of mitochondria found in each cell varies widely depending on the function of the cell it performs.
- For example, erythrocytes do not have mitochondria while the liver and muscle cells have thousands of mitochondria.



Structure of Mitochondria

- They are rod-shaped or oval or spherically shaped, with a size of 0.5 to 10 μm.
- Mitochondria have two special membranes – outer and inner membrane.
- They have a mitochondrial gel-matric in the central mass.
- The membranes bend into folds known as **cristae**.

Functions of Mitochondria

- Their primary function is to generate energy for the cell i.e they are the power generators, producing energy in form of Adenosine Tri-phosphate (ATP), by converting nutrients and oxygen into energy enabling the cell to perform its function and to also release excess energy from the cell.
- Mitochondria also store calcium which assists in cell signalling activity, generating cellular and mechanical heat and mediating cellular growth and death.
- The outer membrane is permeable, allowing the transport of small molecules and a special channel to transport large molecules.
- The inner mitochondrial membrane is less permeable thus allowing very small molecules into the mitochondrial gel-matrix in the central mass. The gel matrix is composed of the mitochondria DNA and enzymes for the Tricarboxylic Acid (TCA) cycle or the Kreb's Cycle.
- The TCA cycle uses up the nutrients, converting them into by-products that the mitochondria use for producing energy. These processes take place in the inner membrane because the membrane bends into folds called the **cristae**, where the protein components used for the main energy production system cells, known as the Electron Transport Chain (ETC). ETC is the main source of ATP production in the body.
- The ETC involves several sequences of oxidation-reduction reactions to transport electrons from one protein component to another, thus producing energy that is used for

phosphorylation of ADP (Adenosine diphosphate) to ATP. This process is called the **chemiosmotic coupling of oxidative phosphorylation.** This mechanism gives energy to most cellular activities including muscle movement and they power up the general brain function.

- Some if not all proteins and molecules that make up the mitochondria come from the cell nucleus. The mitochondrial nucleus genome has 37 genes of which 13 of these genes produce most of the components of the ETC. However, mitochondrial DNA is very vulnerable to mutations because they don't possess a large DNA repair mechanism, a common element found in other nuclear DNAs.
- Moreover, **Reactive Oxygen Species** ((ROS)) also called **free radicals** are produced in the mitochondrion, because of the preference for abnormal production of free electrons. These electrons are neutralized by antioxidant proteins in the mitochondrion. However, some of the free radicals can damage mitochondrial DNA (mtDNA).
- Equally, consumption of alcohol can cause damage to the mtDNA because excess ethanol in the body causes saturation of the detoxifying enzymes leading to the production and leakage of highly reactive electrons into the cytoplasmic membrane and into the mitochondrial matrix, combining with other cellular molecules forming numerous radicals that significantly cause cell damage.
- Most organisms inherit the mtDNA from their mother. This is because the maternal egg donates most of the cytoplasm to the embryo while the mitochondria inherited from the father's sperm is destroyed. This causes the origin of inherited and acquired mitochondrial diseases due to mutations transmitted into the embryo from the maternal and paternal DNA or maternal mtDNA. Such diseases include Alzheimer's disease and Parkinson's disease. When mutated mtDNA accumulates over time has been linked to aging and the development of certain cancers and diseases.
- Naturally, mitochondria play a major role in programmed cell death (apoptosis) and due to mutations in the mtDNA can inhibit cell death-causing the development of cancer.

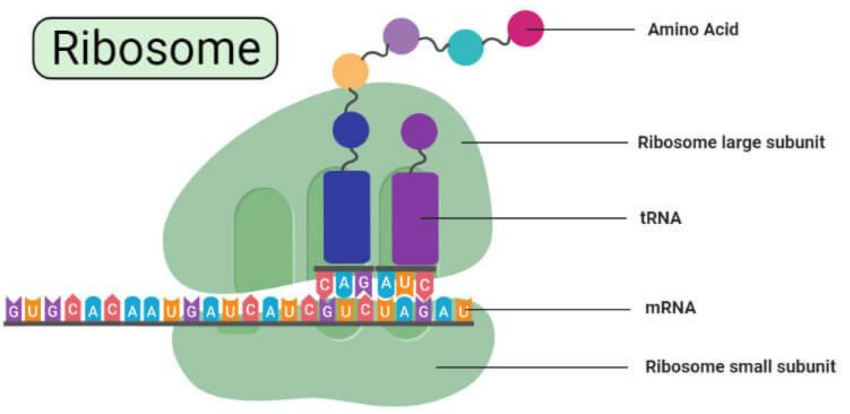
Ribosomes: Structure, Types, Functions and Diagram

The ribosome word is derived – 'ribo' from ribonucleic acid and 'somes' from the Greek word 'soma' which means 'body'.

Ribosomes are tiny spheroidal dense particles (of 150 to 200 A^0 diameters) that are primarily found in most prokaryotic and eukaryotic.

- They are sites of **protein synthesis**.
- They contain approximately equal amounts of RNA and proteins and serve as a platform for the ordered interaction of the numerous molecules involved in protein synthesis.
- The ribosomes occur in cells, both prokaryotic and eukaryotic cells.
- In prokaryotic cells, the ribosomes often occur freely in the cytoplasm.
- In eukaryotic cells, the ribosomes either occur freely in the cytoplasm or remain attached to the outer surface of the membrane of the endoplasmic reticulum.
- The location of the ribosomes in a cell determines what kind of protein it makes.
- If the ribosomes are floating freely throughout the cell, it will make proteins that will be utilized within the cell itself.

- When ribosomes are attached to the endoplasmic reticulum, it is referred to as rough endoplasmic reticulum or rough ER. Proteins made on the rough ER are used for usage inside the cell or outside the cell.
- The number of ribosomes in a cell depends on the activity of the cell. On average in a mammalian cell, there can be about 10 million ribosomes.



Structure of Ribosomes

- A ribosome is made from complexes of RNAs and proteins and is, therefore, a ribonucleoprotein. Around 37 to 62% of ribonucleoprotein is comprised of RNA and the rest is proteins.

  Each ribosome is divided into two subunits:

1. **A smaller subunit** which binds to a larger subunit and the mRNA pattern, and
2. **A larger subunit** which binds to the tRNA, the amino acids, and the smaller subunit.

- Prokaryotes have 70S ribosomes respectively subunits comprising the little subunit of 30S and the bigger subunit of 50S. Their small subunit has a 16S RNA subunit (consisting of 1540 nucleotides) bound to 21 proteins. The large subunit is composed of a 5S RNA subunit (120 nucleotides), a 23S RNA subunit (2900 nucleotides) and 31 proteins.

- Eukaryotes have 80S ribosomes respectively comprising of little (40S) and substantial (60S) subunits. The smaller 40S ribosomal subunit is prolate ellipsoid in shape and consists of one molecule of 18S ribosomal RNA (or rRNA) and 30 proteins (named as S1, S2, S3, and so on). The larger 60S ribosomal subunit is round in shape and contains a channel through which growing polypeptide chain makes its exit.

- The differences between the ribosomes of bacterial and eukaryotic are used to create antibiotics that can destroy bacterial infection without harming human cells.
- The ribosomes seen in the chloroplasts of mitochondria of eukaryotes are comprised of big and little subunits composed of proteins inside a 70S particle. The ribosomes share a core structure that is similar to all ribosomes despite differences in its size.
- The two subunits fit together and work as one to translate the mRNA into a polypeptide chain during protein synthesis. Because they are formed from two subunits of non-equal size, they are slightly longer in the axis than in diameter. During protein synthesis, when

multiple ribosomes are attached to the same mRNA strand, this structure is known as **polysome**. The existence of ribosomes is temporary, after the synthesis of polypeptide the two sub-units separate and are reused or broken up.

Types of Ribosomes

Based on the size and the sedimentation coefficient (S), ribosomes are of two types:

- 70S ribosome
- 80S ribosome

70S ribosome

- They are smaller in size.
- Sedimentation coefficient: 70S
- Molecular weight: 2.7× 106 daltons.
- They are found in:
  - prokaryotic cells of the blue-green algae and bacteria.
  - mitochondria and chloroplasts of eukaryotic cells.

80S ribosome

- Sedimentation coefficient: 80S
- Molecular weight: 40 × 106 daltons.
- They are found in the eukaryotic cells i.e. in plants and animals.
- The ribosomes present in mitochondria and chloroplasts are smaller than 80S cytoplasmic ribosomes.
- In the 80S ribosome of yeast, 79r-protein are present where only 12 r-protein are found to be specific.

Chemical Composition of Ribosomes

- Ribosomal RNAs
- Ribosomal proteins
- Metallic ions, divalent metallic ions**:** Mg++, Ca++ and Mn++

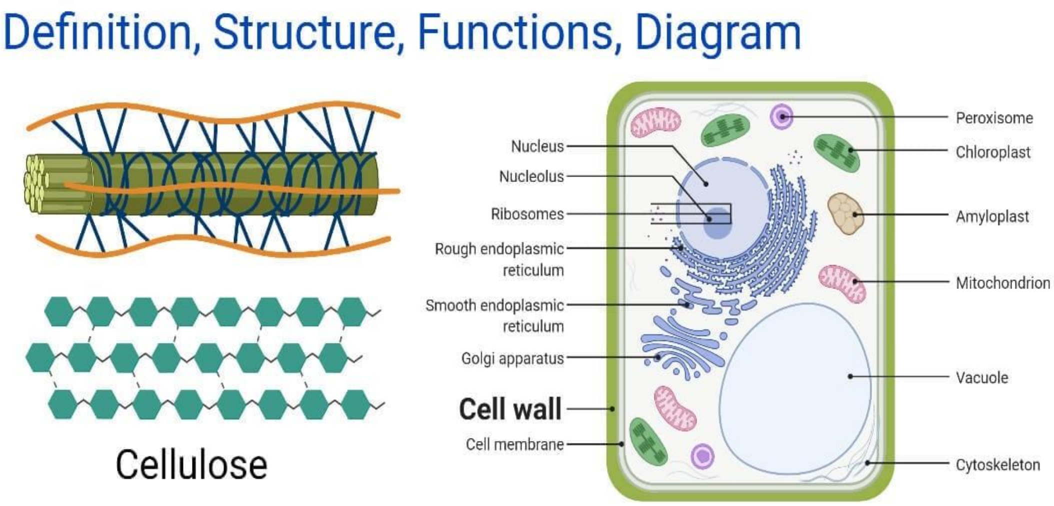
Functions of Ribosomes

- The ribosome is a complex molecular machine, found within all living cells, that serves as the site of biological protein synthesis (translation).
- Ribosomes link amino acids together in the order specified by messenger RNA (mRNA) molecules.
- Ribosomes act as catalysts in two extremely important biological processes called peptidyl transfer and peptidyl hydrolysis.
- The nascent polypeptide chain is protected from the activity of protein digestive enzymes.

Plant Cell Wall: Structure, Functions, Diagram

- A cell wall is an outer rigid semi-elastic supportive and protective layer.
- It is present around the plasma membrane.
- It provides mechanical support and helps in maintaining the shape of the plant cell.

- The cell wall is present in the plant cell and absent in the animal cell which distinguishes them from each other.
- The cell wall is formed by the protoplast. Any plant cell which is devoid of the cell wall is called the protoplast.
- The plant cellwall is mostly made up of the following components: **Cellulose, Hemicellulose, Pectin and Protein**



Plant Cell Wall Diagram

- In both the primary and secondary cell walls of the plant, cellulose is present.
- Cellulose is an insoluble carbohydrate.
- The fibrous structure present in the cell wall maintains the integrity of the structure.
- In the primary cell wall, Pectin is present predominantly.
- It plays the important role in:
- Expansion, Strength, Porosity, Adhesion and Intercellular signalling
- Other non-cellulosic polysaccharides include xyloglucan, glucan, xylan, mannan, and callose.
- Based on the sugar substitutes and side chains, pectic and non-cellulosic polysaccharides can be distinguished further too.
- During biosynthesis, these components are attached to the polysaccharides.
- These substituents are important in determining the solubility and viscosity within the cell wall.
- They are also responsible for determining the interaction between polysaccharides and proteins.
- The cell wall of fungi is made of chitin.
- The cell wall of bacteria is made of the protein, lipid, and polysaccharides complex.

Structure of plant cell wall

- It is derived from the living protoplast.
- It consists of the **middle lamella**, **primary cell wall, plasmodesmata**, **secondary cell wall,** and **pits.**

Middle lamella

- After the cytokinesis, it is the first-formed layer.
- It is present in between the two adjacent cells.
- It is made up of calcium and magnesium pectate.
- It helps to join the two adjacent cells.

Primary cell wall

- It is the first formed cell wall.
- It is present in the inner side of the middle lamella.
- It is the thin and permeable layer that can be expanded.
- Cutin and cutin waxes are present in some epidermal cells of the leaf and stem. It makes the primary cell wall impermeable.
- It is made up of matrix and microfibrils.
- Matrix is made up of water, **hemicelluloses**, **pectin, lipids**, and **proteins.**
- Microfibrils are embedded in the gel-like matrix.
- The primary cell wall of the plant is made of cellulose.
- In the fungi, chitin makes the primary cell wall, and in bacteria murein makes it.
- Primary cell wall forms the only cell wall in the immature meristematic and parenchymatous cells.
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Plasmodesma (plural: plasmodesmata)

- Plasmodesmata are cytoplasmic or protoplasmic bridges present in the primary cell wall of adjacent cells.
- They form a protoplasmic us flow called symplast.
- They transfer cytoplasmic materials between adjacent cells.

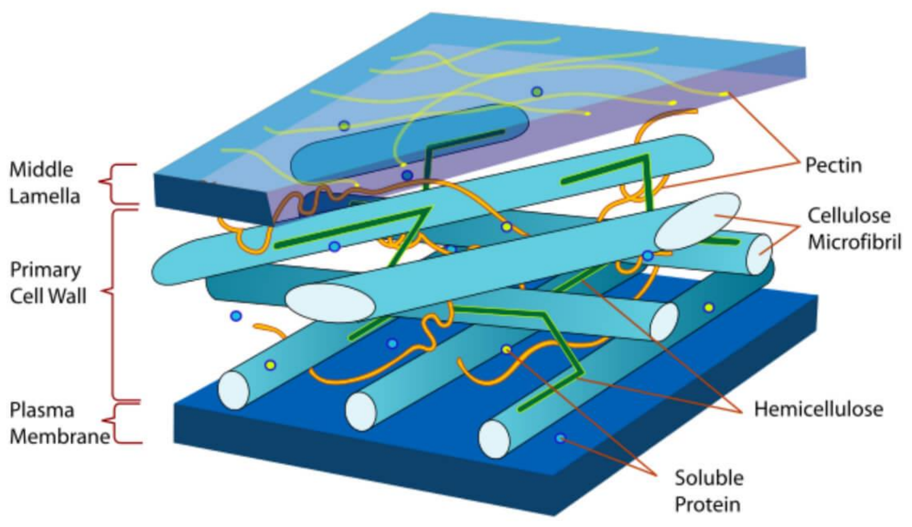


Figure: Structure of Plant Cell wall

Secondary cell wall

- The secondary cell wall is situated inner to the primary cell wall.
- This is the thick layer, permeable, and cannot be expanded.
- It forms after the growth and development of the cell.

- It is present in the cells of the thick-walled dead tissue of the plant. Eg: Cells of sclerenchyma, tracheids, and vessels.
- It is differentiated into the outer layer (S_1), middle layer (S_2), and inner layer (S_3).
- Each layer is made up of a matrix and microfibrils.
- The chemical composition of the matrix is almost similar to the matrix of the primary cell.
- Microfibrils of the secondary cell wall is made up of cellulose and lignin.
- Some chemicals like suberin, silica, wax, resins, oils, etc. are also deposited in the secondary cell wall.

Pits

- In the secondary cell wall, pits are the unthickened areas or depressed areas.
- A pit consists of a pit cavity or pit chamber and pit membrane.
- The pit membrane consists of the primary cell wall and middle lamella.
- The pit membrane is permeable.
- So pit helps in rapid translocation of materials between two adjacent cells.

Tertiary cell wall

- In some plant cells, there is the presence of another cell wall beneath the secondary cell wall. It is known as the tertiary cell wall.
- The morphology, chemistry, and staining properties of the tertiary cell wall are different from the primary and secondary cell walls.
- In the tertiary cell wall, xylan (Greek word meaning "wood") is also present in it.

Functions of plant cell wall

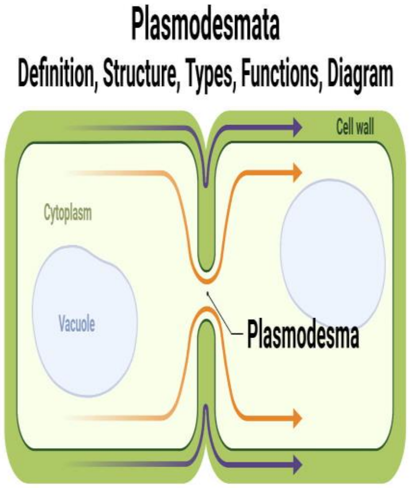
- It provides mechanical support as the skeletal framework in the plant.
- It protects the inner components of the cell from mechanical injuries.
- It is permeable to the water and solutes. It is the presence of the water-filled channels which allows the free diffusion of water and water-soluble substances. Eg: gas, salt, sugar, hormones.
- It prevents entry of the pathogenic agents inside the cell acting as the first line of defense.
- When the cell is kept in the hypotonic solution, it prevents the osmotic bursting of the cell.
- In the cell wall, cutin, wax, silica, and suberin is present which reduces the rate of transpiration.
- The cell wall of root hairs helps in the absorption of sap from the soil.
- Walls of tracheids and vessels help in the conduction of sap.
- Middle lamella helps to join the adjacent cells.
- Plasmodesmata help in the transfer of cytoplasmic materials among adjacent cells.

Cell wall in the defence mechanism

- During the infection, oligosaccharides elicitors can be released.
- These substances can be released from the host plant's cell wall i.e DAMPs (Damage-associated Molecular patterns) or they can be from the pathogen cell wall i.e PAMPs (Pathogen-associated Molecular patterns).
- It occurs during the process of degradation.
- In the plasma membrane, immune receptors are present which receive these elicitors.
- It then activates the defence responses of DAMP or PAMP-triggered immunity.

Plasmodesmata: Structure, Types, Functions, Diagram

- The primary cell and middle lamella never occur in the form of a continuous layer, but many minute apertures through the cells of a tissue maintain cytoplasmic relation with each other. Such cytoplasmic junctions or bridges between the adjacent cells are known as **plasmodesmata.**
- Plasmodesmata are found only in plant cells and algal cells. They are intracellular organelles. In animal cells, similar structures are presently called **gap junctions.**
- In a higher plant, every living cell is linked to its living neighbor's cell by fine cytoplasmic channels. This is called a plasmodesma. They allow passage of molecules directly from one cell to another and are important in cellular communication.



The plasmodesmata (singular, plasmodesma) were first reported by Strasburger in 1901 A.D.

- The word plasmodesma derives from the Latin word 'plasmo' meaning fluid and the Greek 'desma' meaning bond. They are essential for plant life because they serve as a channel for conveying water, fluid, protein, small RNAs hormone, and transport of metabolites during developmental and defence signalling. They permit the passage of molecules weighing less than 800 daltons. Transport through the plasmodesmata is also found under complex regulation which may involve Ca^{2+} and protein phosphorylation.
- The number of plasmodesmata may vary from one place to another.
- For example, in the wall of a column of cells, the number of plasmodesmata may be 15 or greater per square micrometer of the wall surface. In the other cell walls, plasmodesmata are fewer than 1 per square micrometer.
- Callose, a β-1,3-glucan polymer, appears to serve as both a structural and a regulatory element of plasmodesmata.

Plasmodesmata structure

- Different structures of plasmodesmata are identified, which range from simple (characterized by a single sheath) to complex (characterized by branched), H-shaped, and twinned structures.
- Usually, young tissue has simple plasmodesmata and complex plasmodesmata developing later, after cell expansion.
- A plasmodesma measures about 20 to 40 nm in diameter and it is a roughly cylindrical membrane-lined channel.
- They are assembled in three main compartments: **plasma membrane, cytoplasmic sleeve, Desmotubule**
- Plasmodesmata have their plasma membrane or plasmalemma which is the extension from the membrane of the cell. Its structure is similar to having the phospholipid bilayer.

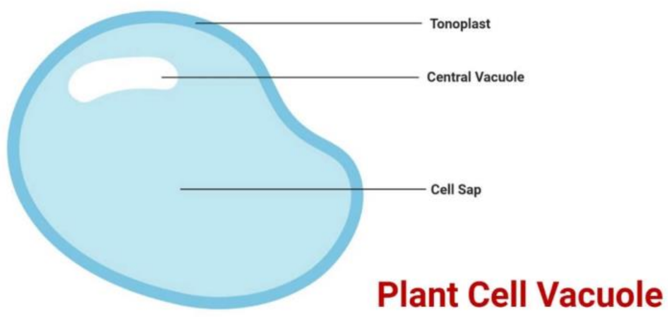
- A fluid-filled space surrounded by the cell membrane (plasmalemma) is called a cytoplasmic sleeve and is a continuous extension of the cytosol.
- Myosin-like proteins and actin filament are localized within the cytoplasmic sleeve, and proteinaceous spike-like projections that are regularly positioned within the cytoplasmic sleeve are thought to create nanochannels of varying size.
- The cytoplasmic sleeve helps to traffic the ions and molecules through plasmodesmata.
- Through the diffusion, smaller molecules and amino acids can pass through it.
- The desmotubule runs from cell to cell through the center of plasmodesmata in most cases.
- The desmotubule is a dense rod or narrower cylindrical structure, that is connected to the smooth endoplasmic reticulum of adjacent cells.
- Desmotubules are derived from the smooth endoplasmic reticulum of the connected cells.
- Now it is called desmotubules but initially, it was called the axial component.
- The annulus of the cytosol is present between the outside and inside of the desmotubule and cylindrical plasma membrane respectively.
- At each end of plasmodesmata, it appears to be constructed.
- The space between desmotubules and plasma membrane contains 8-10 microchannels.
- Electron microscopic images of plasmodesmata are, that the plasma membrane shows up as a tripartite structure that is 7.2nm wide, and the dense central rod is 1.4nm in radius.
- Width of the pale ring: 2.2 nm. It surrounds the dense central rod.

Plasmodesmata functions

1. Usually, plant cells have tough, rigid cell walls. Due to its nature, larger molecules could not pass easily to the cell wall of the plant The plasmodesmata present in the plant cells facilitate the entry of these entities inside of the cell wall.
2. Communication between one cell to another cell is predominant for plant growth and plant survival, plasmodesmata play an important role in both cellular communication and molecular translocation.
3. Passive and active pores are present in plasmodesmata. Nutrients and water pass from the passive pores.
4. Actin structure which is present in plasmodesmata helps to move transcription factors like messenger RNA, viroids, short interfering RNA, and plant viruses.
5. Plasmodesmata located protein 5(PDLP5), which is discovered by a researcher, can produce salicylic acid. It enhances defenses against plant pathogenic attacks. It also protects from pathogenic bacteria.
6. The cells present in the phloem also use plasmodesmata.
7. Plasmodesmata are involved in the short-distance movement of viruses.

Plant Cell Vacuole- Definition, Structure, Types, Functions, Diagram

The vacuole is a very large, fluid-filled vesicle which is present in the cytoplasm of a plant cell. The biosynthetic and endocytic pathways form it. The term ‘vacuole’ was first introduced by the French biologist Flexis Dujardin, and it represents the space of a protozoan contractile vesicle.
In a single cell, there can be many vacuoles. Tonoplast separates it from the cytoplasm, which is also a single unit membrane. Vacuole tends to be very large and occupy more than 30% of the cell volume, but they vary from 5 to 90% according to the cell types in mature plant cells.



Vacuoles provide structural support. They also provide functions such as storage, maintaining water balance, and disposing of waste materials. But in immature and actively dividing plant cells, the vacuoles are quite small.

Different types of cellular components are present in vacuoles such as protein, sugar, salts, acid, nitrogenous compound (such as alkaloid and anthocyanin pigment), ions, and secondary metabolites. They play a crucial role in the plant signalling system.

Structure of plant Cell Vacuole

- A vacuole is a membrane-bound structure found in the cytoplasmic matrix cell.
- Generally, they have no basic shape or size. Its structure varies according to the requirement of the cell.
- The membrane surrounding the vacuole is termed the Tonoplast, separating the vacuolar content from the cell’s cytoplasm.
- It is an important and highly integrated component of the plant’s internal membrane network (endomembrane).
- The movement of ions is regulated by the vacuole. It also isolates the harmful materials from the cells. Vacuoles are functionally and structurally related to lysosomes in animal cells and may contain many hydrolytic enzymes. In addition, they usually contain sugars, salts, acid, ions, and nitrogenous compounds such as alkaloids and anthocyanin pigment in their cell sap.

- The membranes are embedded with proteins that help in transporting molecules across the membrane. Different combination of these protein helps the vacuoles to hold different materials. The large vacuole slowly develops as it matures by the fusion of smaller vacuoles derived from the ER and Golgi apparatus.
- The pH of plant vacuole ranges from 3 to 10. Due to an abundant quantity of alkaline substances, its pH may increase to 9-10. Similarly, due to the presence of acids like citric acid, oxalic acid, and tartaric acids, pH can lower to 3.

Types of plant Cell Vacuole

1. Lytic Vacuoles

- It is a plant specialized vacuole equivalent to animal lysosomes or yeast vacuoles, functioning as a compartment for degradation and waste storage. Lytic vacuoles contain hydrolase enzymes. These enzyme help degrade unwanted cellular substances. Lytic vacuole maintains turgor pressure, storage of metabolites, digestion of cytoplasmic components, and sequestration of xenobiotic compounds. γ- tonoplast intrinsic proteins have been associated with the lytic or degradative vacuole.

2. Protein storage vacuole

- Protein storage vacuole assembles a large amount of protein in the storage tissue of the plant. In most seeds, protein storage vacuole contains three morphologically distinct regions: **the matrix, crystalloid,** and **globoid.**
- Globoids composed of phytic acid crystal and matrix and crystalloid was known to contain storage protein.
- α- tonoplast intrinsic protein has been found in protein storage vacuoles.
- The cell sap differs from that of the surrounding cytoplasm. The membranes are composed of phospholipids.

Cell sap

- It is a fluid that is found in the plant cell vacuole. It contains a variable amount of food, waste material, inorganic salts, nitrogenous compound, water, amino acid, and glucose. It provides mechanical support and serves as a storage material, especially in non-woody plants. It plays a vital role in plant cell osmosis.
- Xylem sap carries soil nutrients from the root system to leaves; Then, water is lost through transpiration. Maple sap is xylem sap. In the late winter, it contains some sugar.
- Phloem or sieve tube sap is the fluid carrying sugar from leaves to another part of the plant in the summer.

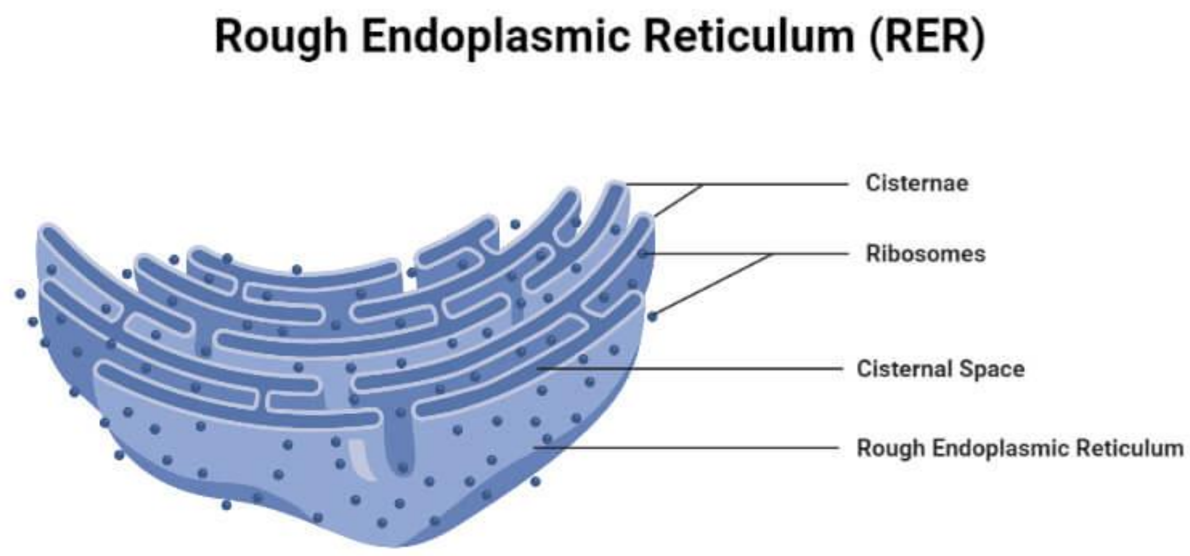
Functions of plant Vacuole

1. Turgor pressure created by the vacuole helps to maintain the shape of the cell.
2. It also helps to cope with extreme conditions.
3. Turgor pressure is the pressure that is exerted on the cell wall by the water present in the vacuoles.
4. Central vacuole is used by the developing seed cells for protein storage.
5. The plant vacuole stores salts, minerals, nutrients, proteins, and pigments, which help in plant growth.
6. For both the nutrients and the waste products, it acts as the storage organelle.
7. Vacuole plays the role in maintaining the homeostatic condition in plant cells with respect to the different alterations in the environment.
8. To maintain the acidic condition in the content of the vacuole, H^+ ions are pumped inside. Then in and out movement is controlled by the Tonoplast or vacuolar membrane selectively.
9. Inside the vacuole, the smaller vacuoles are retained, but the water can move freely.
10. The trypsin inhibitors commonly found in seeds and the wound-induced protease inhibitors of leaf cells (to inhibit both insect and microbial proteases), both accumulate in the vacuole and are presumably designed to interfere with the digestive processes of herbivores.

Rough Endoplasmic Reticulum (RER): Structure, Functions

The endoplasmic reticulum (ER) which consists of ribosomes on its surface is known as the **rough endoplasmic reticulum.** So it is also called the granular endoplasmic reticulum.

- Translocon is the binding site of the ribosome on the rough endoplasmic reticulum**.**
- These ribosomes look like studs and they can distinguish the organelle from the smooth sections of the ER.
- Proteins are synthesized from amino acids. It is with the aid ribosome.
- Ribosomes consist of four RNA molecules.
- The attachment of ribosomes over the surface of RER through two types of glycoproteins. They are:
- Riboprotein I (6500 daltons) and Riboprotein II (6400 daltons).
- RER consists of more cisternae and fewer tubules and vesicles.
- Near the nucleus, it is more abundant where it is connected with its outer membrane.
- RER is present in the cells which are involved in the active transport of protein as well as in the synthesis of enzymes. It includes:
    - Acinar cells of the pancreas
    - Plasma cells
    - Goblet cells epithelial cells that secrete mucus.
    - Cells of endocrine glands
- In conjunction with the Golgi complex, RER helps in the formation of primary lysosomes.
- It involves the synthesis, folding, and modification of proteins.
- It includes those cells which need to be transported to different cellular organelles in the cell.
- It is involved in the response of the cell to unfolded protein.
- It plays a role in the induction of apoptosis.
- It supports polysomes are strings of ribosomes that synthesize the proteins.
- Morphology also aids in the identification. Its structure is often convoluted and flattened which seems like the sac.
- It originates in proximity to the nucleus.
- RER has the membrane in association with the outer nuclear membrane.
- It forms large membrane sheets which are double.
- It is best studied within the secretory cells specialized in these functions.



Structure of rough endoplasmic reticulum (RER)

It consists of three structures. They are:

Cisternae

- Its diameter is 40 to 50 µm.
- They are long, flattened, sac-like, and unbranched tubules.
- In the bundles, they are aligned parallel.
- RER usually is present as cisternae, They are found in cells like the pancreas, brain, and notochord where the synthesis usually takes place.

Vesicles

- The diameter of the vesicle is 25 to 500 µm.
- They are oval-shaped.
- They seem like the vacuole which is bound by the membrane.
- They are usually found in the cytoplasm in isolated form.
- It is found in most cells. As compared to SER they are less abundant.

Tubules

- They are branched structures.
- It forms the reticular system.
- They are usually present in all cells.
- Its diameter is 50 to 190 µm.
- These structures are usually found in SER.

Functions of Rough Endoplasmic Reticulum (RER)

- It is the site for the synthesis of protein.
- Polypeptides are synthesized.
- Attached ribosomes synthesize proteins and enzymes.
- It then enters through the RER’s channel which is used both for intracellular use and extracellular transport.
- Some proteins are to be secreted from the cell or they need to be exported.
- Some proteins are essential in the synthesis of cellular membranes.
- Such proteins are assumed to be synthesized by the RER.

- In the nascent protein at the side of COOH, about 40 amino acids are present. They are protected inside the tunnel of free or bound ribosomes.
- Similarly, it is found that the lumen of the RER is involved in the protection of the rest of the chain at the NH_2 end.
- During the translation, nascent polypeptide chai pass to the cisternae of ER.
- When the growing polypeptide chain, reaches the cisternae, it gets trapped in it by folding it into the secondary and tertiary structure.
- It provides the surface area for the association of many things including metabolically active enzymes, amino acids, and ribosomes.
- It protects the secretory proteins from the protease enzymes which are present in the cytoplasm. So they pass in the cisternae of RER instead of passing into the cytoplasm
- By losing the ribosomes, it forms the smooth endoplasmic reticulum. For holding the ribosomes, it consists of ribophorins.
- Rough endoplasmic reticulum synthesizes the zymogens of lysosome enzymes.
- The RER provides enzyme precursors for the formation of lysosomes with the help of the Golgi complex.

Protein glycosylation

- It is the process of the addition of sugar in secretory proteins. During this process, oligosaccharides get transported in the proteins. This oligosaccharide is always transferred to the NH2 group on the side chain of an asparagines residue of the protein.
- So, this oligosaccharide is said as asparagines-linked or the N-linked.
- This transfer is aided by the enzyme glycosyltransferase. It is a membrane-bound enzyme. On the luminal surface of the ER membrane, its active site is exposed.
- In the Endoplasmic membrane, the precursor oligosaccharide is held by dolichol. Dolichol is the carrier which is a special lipid molecule.

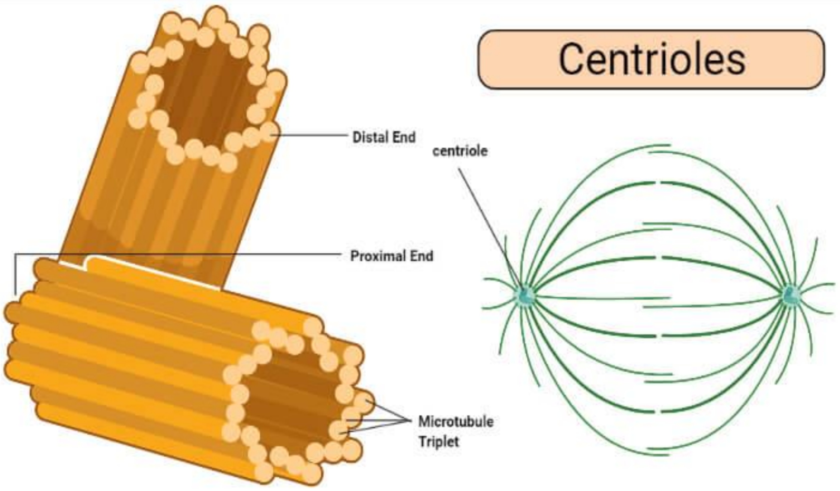
Comparison of Rough Endoplasmic Reticulum(RER) with Smooth Endoplasmic Reticulum(SER)

Ribosomes: Present in rough ER and absent in smooth ER.
Composition: Rough ER is made up of more cisternae and few tubules. Smooth ER is made up of more tubules and vesicles.
Presence: Rough ER is present in protein and enzyme-forming cells like Pancreatic cells, new cells, etc. Smooth ER is found mainly in lipid forming cells: adipocytes, interstitial cells, adrenal cortical cells, etc.
Ribophorins: Present in rough ER and absent in smooth ER.
Formation: Rough ER is believed to be formed from the outer nuclear membrane. Smooth ER is developed from rough ER by loss of ribosomes.
Function: Rough ER helps information and transportation of proteins and enzymes**.** Smooth ER helps in the formation of lipid, glycogen, and steroids.

Centrioles and Basal Bodies: Structure, Functions

- In some eukaryotic cells, near the nucleus, there is the presence of two cylindrical structures. They are rod-shaped and microtubular. They are known as the centrioles.
- A limiting membrane, DNA and RNA are absent in it. They form the spindle of microtubules. Centrioles are arranged beneath the plasma membrane for the formation of cilia or flagella.
- The centriole is present in: Algal cells (except red algae), Moss cells, Fern cells, Animal cells
- The centriole is absent in: Prokaryotes, Red algae, Yeast, Conifers, Angiosperms and Amoebae

- The **basal body** is the centriole having the flagella or the cilia. The basal body is also called: **Kinetosome, Blepharoplast, Basal granule, Basal corpuscle, Proximal centriole**



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Structure of Centrioles and Basal Bodies

- The shape of the centriole is cylindrical which is also the same in the basal bodies.
- Its diameter is 0.15–0.25µm.
- Its length is 0.3–0.7µm.
- It is short as 0.16µm and as long as 8µm.
- It is visible under the light microscope for the detailed study, an electron microscope should be used.
- When each centriole duplicates, the replication of the centrosome occurs, it occurs during the process of mitosis.
- Members of centrioles, i.e first centriole is perpendicular to the next centriole.
- A cell consists of the centrosome where a pair of centrioles is present. Two centrosomes are formed from the four centrioles surrounded by an electron-dense matrix called the pericentriolar material (PCM).
- The number of microtubules may vary from one hundred to thousands.
- When the cell is functioning normally, attachment of the motor proteins occurs in microtubules.
- Similarly, it also carries the thing which needs to be exported.
- The scaffold of the microtubule is present in the core of centrioles.
- It is formed from the nine triplet microtubules which are arranged in a radial array in a cylinder.
- The centriole is based on protein.

- The basal body performs the different functions of the cell. It organizes the cilium or flagellum.
- In the different types of the cell, the centriole is converted into the basal body.
- The centriole is the polar structure.
- From the proximal site of the centriole, there is the formation of the new centriole.
- It uses the cartwheel. At the central part, there is the presence of the hub and spokes resembling the structure of the cartwheel.
- Centriole seems like the turbine because of the presence of the triplets.
- When observation is done from the proximal end, an anticlockwise twist is seen in the triplet microtubule blade.
- Doublet microtubule is present in the *Drosophila.*
- Singlet microtubule is present in the *Caenorhabditis elegans*.

Ultrastructural components of Centrioles and Basal bodies

A. Cylinder Wall

- It consists of nine sets of microtubules. In each group, triplets are present. i.e 3 microtubules.
- They are equally spaced
- There is the presence of amorphous and electron-dense material in the space
- Absence of the outer membrane in the centriole.
- Triplets are responsible for the formation of the cylinder's wall.

- **B. Triplets**
- Presence of A, B, and C subunit microtubules. The shape of the A tubule is round while B and C are concave. A triplet microtubule consists of the A-tubule which is a complete microtubule. Other tubules are incomplete. Protofilaments in the A-tubule consist of 13 α- and β-tubulin. The partial microtubules, B-tubules, and C-tubules are assembled in it. i.e 10 protofilaments. By the sharing of 3, protofilament B and C tubules make 13 protofilament microtubules.
- Structurally A, B, C tubules are similar to other microtubules.
- Triplets are assumed to be aligned parallel to one another and in the long axis of the cylinder.
- But it does not happen in all of the cases.
- There is a reduction in the diameter of the cylinder, in the basal bodies of some organisms.
- Because at the proximal ends, the triplets get closer in such cases.
- In some of the centrioles, though the triplets are aligned parallel to one another, to the cylinder axis, they may be turned in a long pitched helix.
- Due to the presence of the three concentric rings of the microtubules, triplets are strong.
- In the triplet, a microtubule is present which is made up of tubulin.
- Tubulins are small monomers that can join together forming the tubes. It resembles the straws.
- In the somatic cell, it is present in the cytoplasm and also in the nucleus. During the process of mitosis, it is present in the spindle poles.

C. Linkers

- With the help of the protein linkers, tubule A gets linked with tubule C.
- It occurs at intervals.
- The typical radial tilt of the triplets is maintained by these linkers.

D. Cartwheel

- In the centrioles, there is an absence of the central microtubules.
- Absence of the special arms.
- Formation of the cartwheel-like pattern.
- The proximal end is determined by the cartwheel configuration.
- From the distal end, growth of the centrioles takes place.
- Cilium is formed in the basal bodies from this end.
- At the proximal end, the procentrioles are located. They form the right angles to the centriole.

E. Ciliary Rootlets

- Ciliary rootlets originate from the basal end in the basal bodies.

Ciliary rootlets are of two types: Tubular root fibrils and Striated rootlets

F. Basal Feet and Satellites

- Basal feet are the dense processes.
- Basal feet are arranged perpendicularly to the basal body.
- The structural asymmetry on the basal body is related to the direction of the ciliary beat.
- Microfilaments make the basal foot. It terminates in a dense bar.
- The microtubules get converged in it.
- Satellites or pericentriolar bodies lie near the centriole. They are the electron-dense structures that might be the nucleating sites for microtubules.

Functions of Centrioles and Basal Bodies

- The main function of the centrioles is the formation of basal bodies and the cilia in the cell.
- It acts as the focal point for the centrosome in most animal cells.
- The centrosome is also called the cell centre. During the interphase, it organizes the cytoplasmic microtubules. Then the duplication occurs at the mitosis. It nucleates the two poles of the mitotic spindle.
- In the case of a spermatozoon, the flagellum or the tail fibre is formed by one centriole.
- Centrioles and the basal bodies are responsible for the ciliary and the flagellar beat.
- They receive different signals. i.e optical, acoustic, olfactory.
- Centrioles could locate the directions of the signal source.
- Microtubules in a cell help in the transportation of the substances to various locations of the cell.
- The special glycoproteins like the sugar and protein tag the products. Then to the specific motor proteins, it acts like the signals. (Scheer, 2014)

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