PLASMA MEMBRANE & CYTOPLASM
(PHYSIOCHEMICAL NATURE)

All cells contain at least some membranes, and cells of eukaryotes contain numerous organelles composed of membranes. These membranes commonly termed **biological membranes** perform many important tasks in cell metabolism. They regulate the passage of molecules into and out of cells and organelles; they divide the cell into numerous compartments, each with its own specialized metabolism; and they act as surfaces that hold enzymes. This suggests that without membranes, life would be impossible. The structure of the membrane is key to its function. All biological membranes contain basically the same constituents, and arrangement of these components is largely responsible for the function of the membranes.

PLASMA MEMBRANE

Plasma membrane is the membrane that completely covers the surface of the protoplasm. Among biological membranes, plasma membrane seems to accomplish the impossible. This membrane mediates the transport of substances into and out of the protoplast. Plasma membrane functions selectively, some substances such as O_2, CO_2 and H_2O can pass through freely, but others like sugars, amino acids and inorganic ions are blocked. It allows the passage of essential substances but at the same time prevent the loss of cellular constituents. It also transports large molecules and solid particles that involve vesicles (**exocytosis**, **endocytosis**). Plasma membrane also facilitates communication between cells by **diffusion**, **osmosis**, **facilitated diffusion** and **active transport**; or by direct cytoplasmic connections, the **plasmodesmata**. Plasma membrane also facilitates long distance communication that involves reception and processing of chemical signals arriving from various parts of the plant.

Chemical Composition of Plasma Membrane

Plasma membrane consists of **proteins** and two layers of **phospholipid molecules** (lipid bilayer) usually in the ratio of 60% and 40% respectively. The lipid bilayer provides the basic structure and impermeable nature of cellular membranes, while the proteins are responsible for most membrane functions. Some membrane proteins are enzymes that catalyze membrane-associated reactions, whereas others are carriers involved in transport of the cell or organelle. Still others act as receptors for receiving and transducing chemical signals from the cell's internal or external environment.

Lipids

The main lipid components of plant plasma membrane are the abundant **phospholipids** and **sterols**, particularly stigmasterols. A lipid molecule basically consists of two parts, a **head** (glycerol) that is water soluble or **hydrophilic**, and two **tails** (fatty acids) that are water insoluble or **hydrophobic**. In quite water, phospholipids form a **monolayer** at the surface with their hydrophilic ends forming hydrogen bonds to water molecules and their hydrophobic ends forming hydrogen bonds to water molecules and their hydrophobic ends projecting out of water. But if the water is agitated, lipid layer doubles over and makes a **bilayer** in which all fatty acids are away from the water and all phosphate groups are in full contact with it. The two layers of the bilayer have different concentrations of each. The lipid bilayer is a very thin solution and if it contains several types of lipid, they can diffuse laterally throughout the membrane because they are not bonded to each other, but they can diffuse vertically from the membrane into the surrounding solution.

Proteins

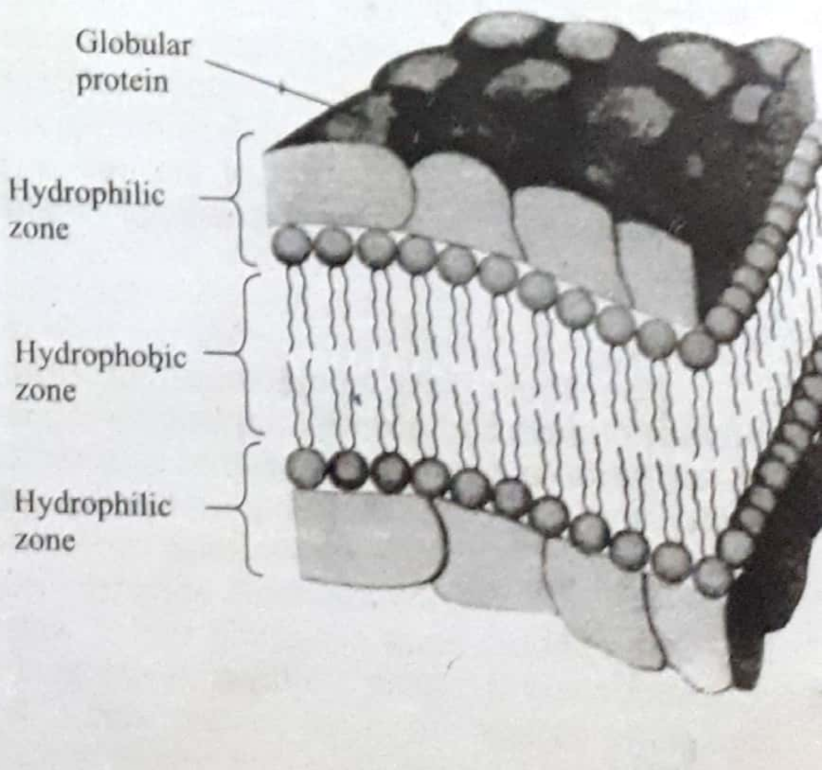
Most membrane proteins have large hydrophilic regions, so they associate mostly with the phospholipid phosphates and with water. Many proteins also have hydrophobic regions that allow them to sink into the membrane, associate with the fatty acids. Certain proteins sit on the membrane surface, others are partly embedded in the lipid bilayer, while still others span bilipid layer completely with active site on either or both sides or the membrane or within it. All these proteins are termed **intrinsic proteins** and are more than 70% of the total protein contents of the membrane. The proteins that span lipid bilayer act as hydrophilic channels that permit hydrophilic molecules to pass through the membrane. Some intrinsic proteins contribute to the membrane's fluid nature and these can diffuse laterally. Other proteins interact with adjacent proteins forming small discrete regions called **domains**. Certain proteins called **extrinsic proteins** or **peripheral proteins** are located outside the membrane and merely lie next to it. These can be separated by mild treatment. The extrinsic proteins perform important enzymatic functions, but they are not integral part of the membrane's structure. **(Fig. Mauseth P-75)**

Glycoproteins and Glycolipids

Some membranes contain a small amount of sugar, usually less than 8%. The sugars occur as short chain oligosaccharides, each with about 4 to 15 sugar residues. These oligosaccharides are bound to certain intrinsic proteins, converting them into **glycoproteins**. Rarely sugars are attached to membrane lipids forming **glycolipids**. Glycoproteins and glycolipids are less important in plants, however in animal cells these occur almost exclusively on outer surface of the membrane and covers the cell. These are believed to play an important role in recognition of molecules such as hormones, the coat proteins of viruses and molecules on the surfaces of bacteria especially in animals that have an immune system.

Physical Nature of Plasma Membrane

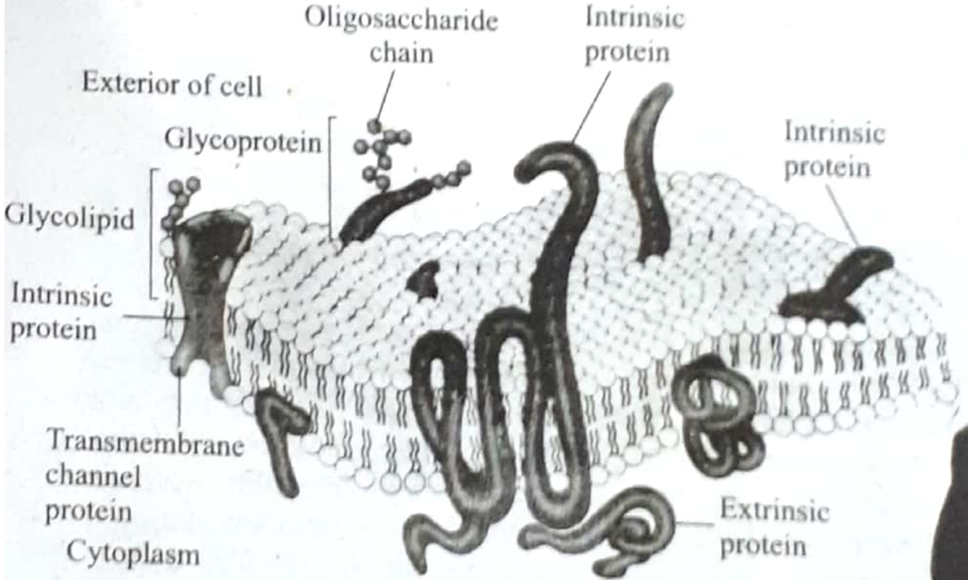
Under an electron microscope, all biological membranes including the plasma membrane exhibit a three-layered appearance, two dark layers separated by a lighter layer. For a considerable period of time, the two dark layers were considered to consist of protein and the space between them a lipid bilayer. In 1960, **J. David Robertson** proposed the **unit membrane model**, which emphasized a general protein-lipid-protein structure for all biological membranes (a lipid bilayer sandwiched between two protein layers). He proposed that dark lines were proteins and polar groups of lipids and light region consists of non-polar groups of lipids.

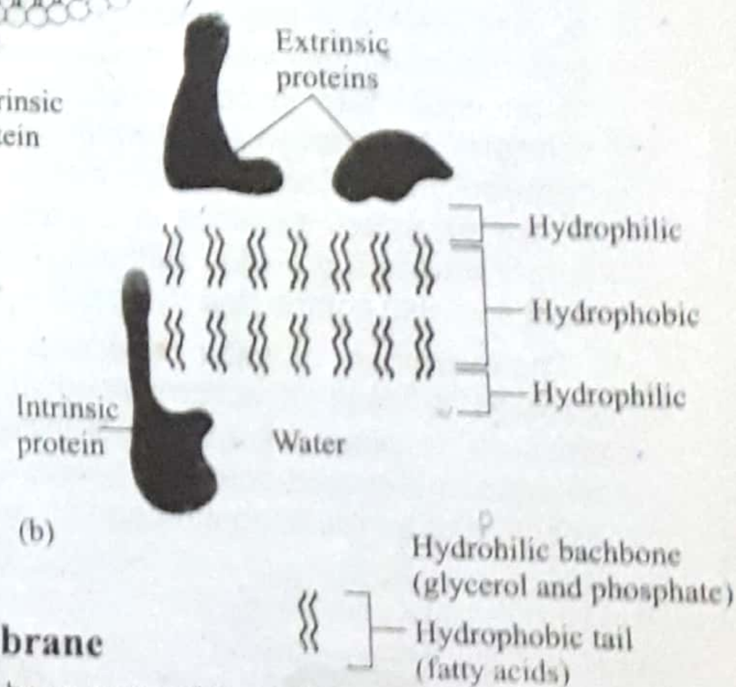


Robertson's model was widely approved, but further studies revealed that different membranes vary considerably in their protein/lipid ratio, and that the proteins do not form continuous layers on the surface of the membrane but exist as discrete globular molecules embedded in the lipid bilayer, especially in endoplasmic reticulum, mitochondria and chloroplasts.

Fluid-Mosaic Model

In 1972, **S. Jonathan Singer** and **Garth Nicolson** proposed the widely accepted fluid-mosaic model of membrane structure. According to this model, plasma membrane is mosaic of proteins embedded in a fluid lipid bilayer. The components of lipid bilayer are in constant motion and the membrane proteins also move more or less freely in the fluid bilayer. As the proteins and lipid molecules move laterally within the bilayer, the proteins form different patters or **mosaics** that vary from time to time and place to place. The whole membrane structure is quite fluid, hence the proteins can be thought of as floating "icebergs" in a lipid "sea". In animal cell this crystalline nature of membrane is maintained by cholesterol whereas in plant cell shorter-chain fatty acids with more double bonds help maintain it.





(b)

Properties and Functions of Plasma Membrane

Membranes including plasma membrane have several important properties. These include permeability, movement of substances into and out of cells, and cell-to-cell communication.

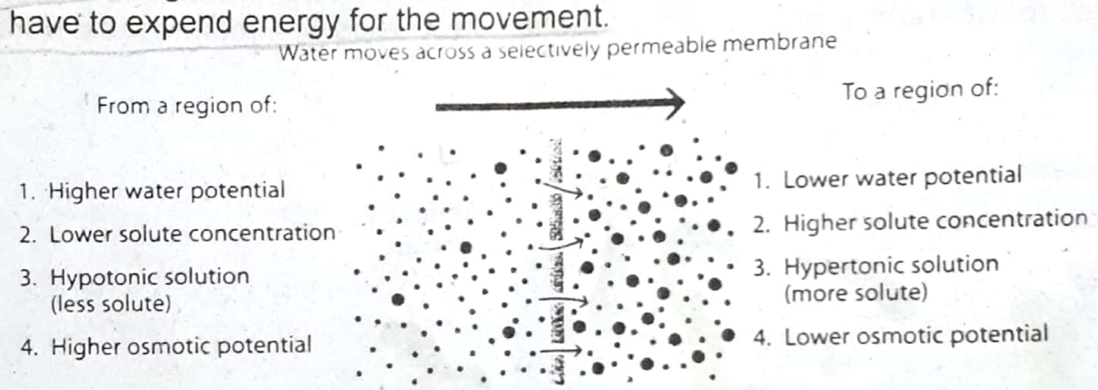
Permeability

Permeability is an important property of membranes. All biological membranes are **selectively permeable** (also called **differentially permeable**), meaning that certain substances cross the membrane more easily and rapidly than others. Because large regions of a membrane are mostly lipid, membranes are more permeable to hydrophobic substances than to anything that carries an electric charge. However, if charged compounds such as inorganic salts, sugars, and amino acids could not enter cells at all, or if they could enter only slowly, cells would starve.

Transport

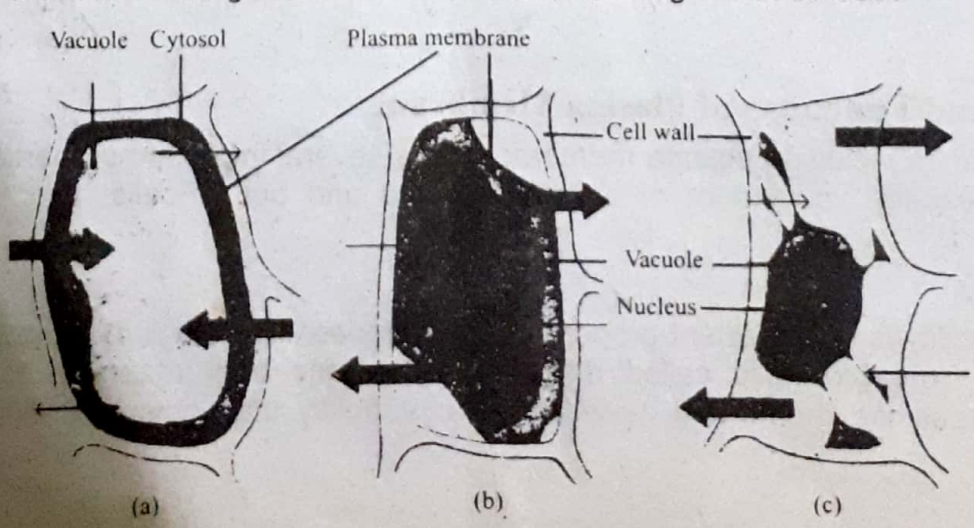
The substances can move into and out of cells by various mechanisms such as diffusion and osmosis, facilitated diffusion, active transport and vesicle-mediated transport.

i. **Diffusion and Osmosis:** Much of transport across cell membranes occurs by **diffusion**. When a substance is more concentrated on one side of a membrane than on the other, there is a tendency for the substance to diffuse across the membrane down the concentration gradient. One important example is the uptake of oxygen by a cell performing cellular respiration. The diffusion of a substance across a biological membrane is called **passive transport**, because the cell does not have to expend energy for the movement.



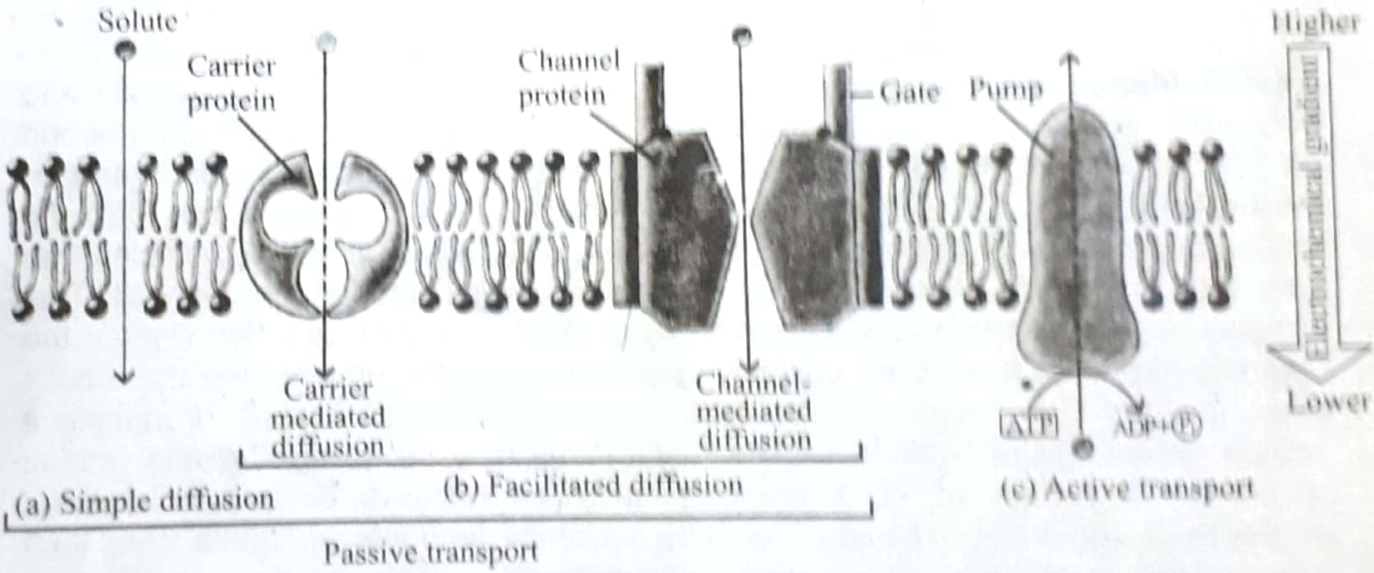
The movement of water across a selectively permeable membrane is a special case of passive transport called **osmosis**. The direction of osmosis is determined by a difference in total solute concentration. Water will move from a hypotonic to a hypertonic solution. Water moves across a membrane separating isotonic solutions at an equal rate in both directions, i.e., there is no osmosis between isotonic solutions. The movement of water across cell membranes and the balance of water between the cell and its environment are crucial to organisms. A pressure called **turgor pressure** develops in a plant cell when water enters the cell by osmosis. Turgor pressure provides stiffness (mechanical support) to the herbaceous parts of plant and also contributes to increase in size of the cell (growth).

The movement of water molecules into substances such as wood or gelatin that swell as a result of accumulation of water is called **imbibition**. A tremendous pressure develops as a result of imbibition. The germination of seed begins with changes in the seed coat that permit a massive uptake of water by imbibition. The embryo and surrounding structures then swell, bursting the seed coat.



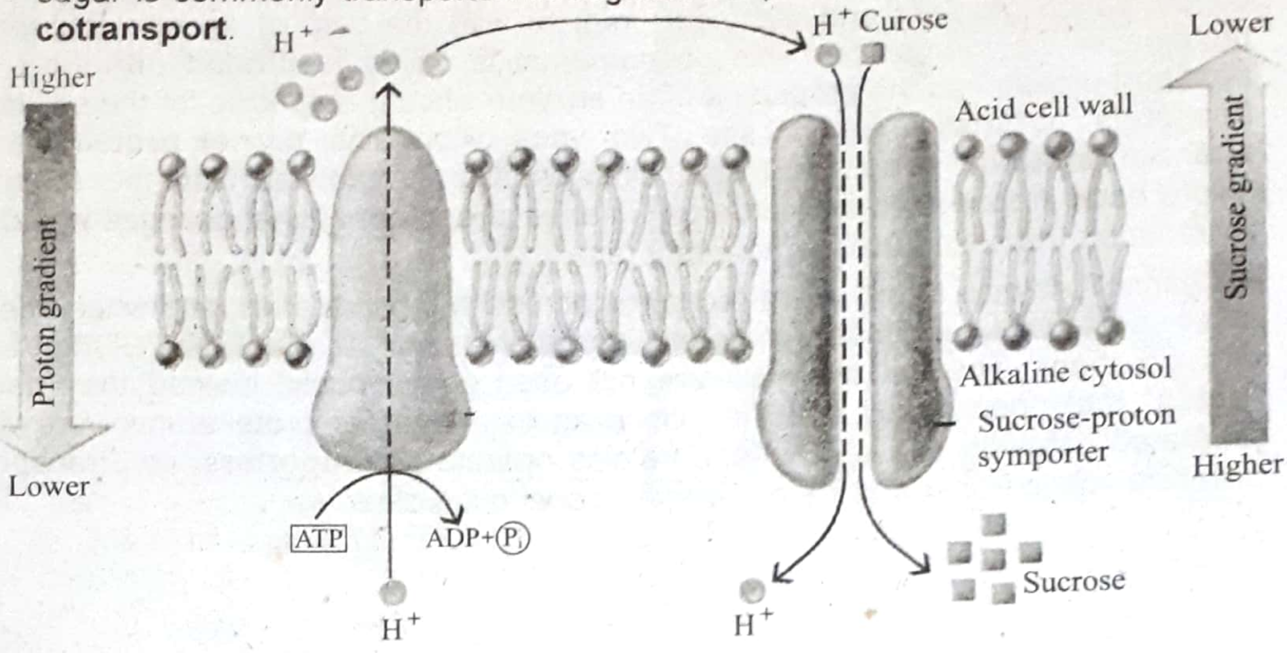
ii. **Facilitated Diffusion:** Many polar molecules and ions diffuse down their concentration gradient and electrical gradient with the help of specific transport proteins in the membrane. This phenomenon is called **facilitated diffusion**. A transport protein has the properties of an enzyme since it is specific for the solute it transports, and has a binding site. Two types of proteins, **carrier proteins** and **channel proteins** permit facilitated diffusion. Carrier proteins bind the specific solute being transported and undergo a series of conformational changes in order to transport the solute across the membrane.

Channel proteins form water-filled pores across the membranes, and when open, allow specific solutes (usually inorganic ions such as Na^+, K^+, Ca^{2+}, and Cl^-) to pass through them. The ion channels are not open continuously, instead they have "**gates**" that open briefly and then close again. All carrier proteins involved with facilitated diffusion and all channel proteins operate as **uniporters**, i.e., transport only one solute from one side of the membrane to the other.



iii. **Active Transport:** Some transport proteins can move solutes against their concentration gradient or an electrochemical gradient, across the plasma membrane from the side where they are less concentrated to the side where are more concentrated. The process involves expenditure of cell's metabolic energy (ATP) and called **active transport**. Active transport is a major factor in the ability of a cell to maintain internal concentrations of small molecules that differ from concentrations in the surrounding environment. A good example of an active transport protein is a **pump**. Pumps are driven by chemical energy (ATP), electrical energy or light energy. In plant and fungal cells they typically are **proton pumps**.

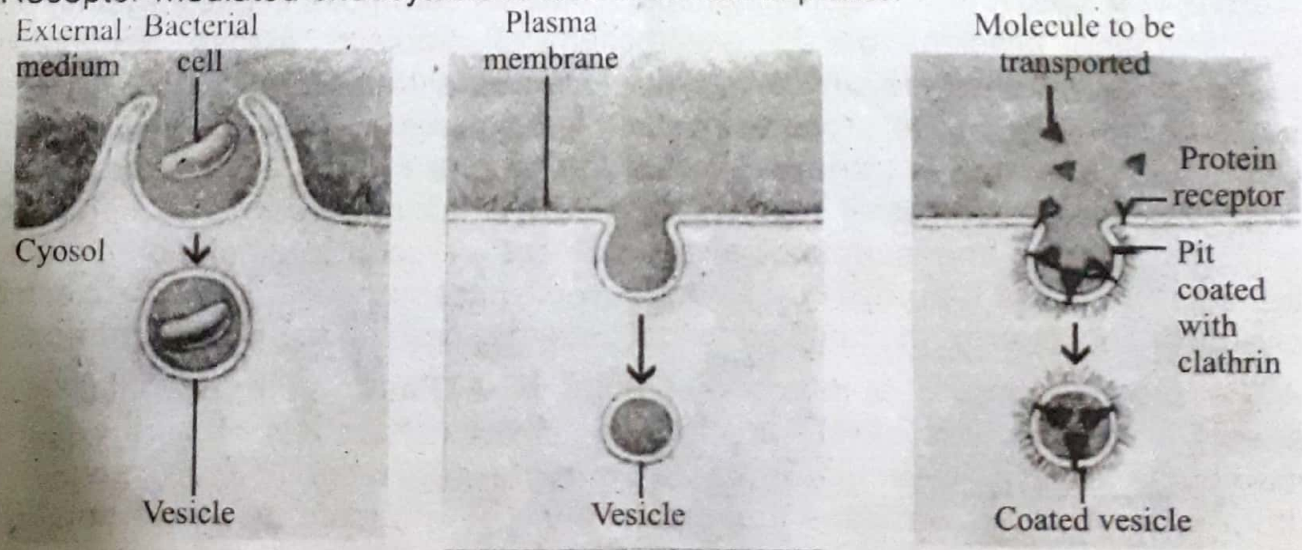
The proton pump is a membrane-bound **H^+-ATPase**, an enzyme that uses energy from hydrolysis of ATP to transport protons (H^+ ions) across the plasma membrane against their gradient. The enzyme generates a large gradient of protons across the membrane that provides the driving force for solute uptake by all proton-coupled cotransport systems. The uptake of sucrose, the form in which sugar is commonly transported throughout the plant, depends on **sucrose-proton cotransport**.



(a) Primary active transport

(b) Secondary active transport

iv. **Vesicle-Mediated Transport:** Large molecules such as proteins and polysaccharides are transported by means of vesicles or saclike structures that bud off from or fuse with the plasma membrane. This type of transport is called **vesicle-mediated transport**. The hemicelluloses, pectins and glycoproteins that form the matrix in the cell wall are carried to developing cell walls in secretory vesicles that fuse with the plasma membrane, thus releasing their contents into the wall. This process is called **exocytosis**. Transport by means of vesicles can also work in the opposite direction. It is called **endocytosis** and during the process the material is taken into the cell, induces the plasma membrane to bulge inward, producing a vesicle enclosing the substance. The endocytosis may be: **phagocytosis** (eating of solid - ingestion of solid particles such as bacteria or cellular debris), **pinocytosis** (drinking of liquid - the cells sip small amounts of liquids from their surrounding medium) and **receptor-mediated endocytosis** (particularly membrane proteins serve receptors for specific molecules that are transported into the cell). A unique example of phagocytosis in plants is found in **nodule-forming roots** of *legumes* during the release of *Rhizobium* bacteria from infection threads. Receptor-mediated endocytosis is less common in plants.



(a) Phagocytosis

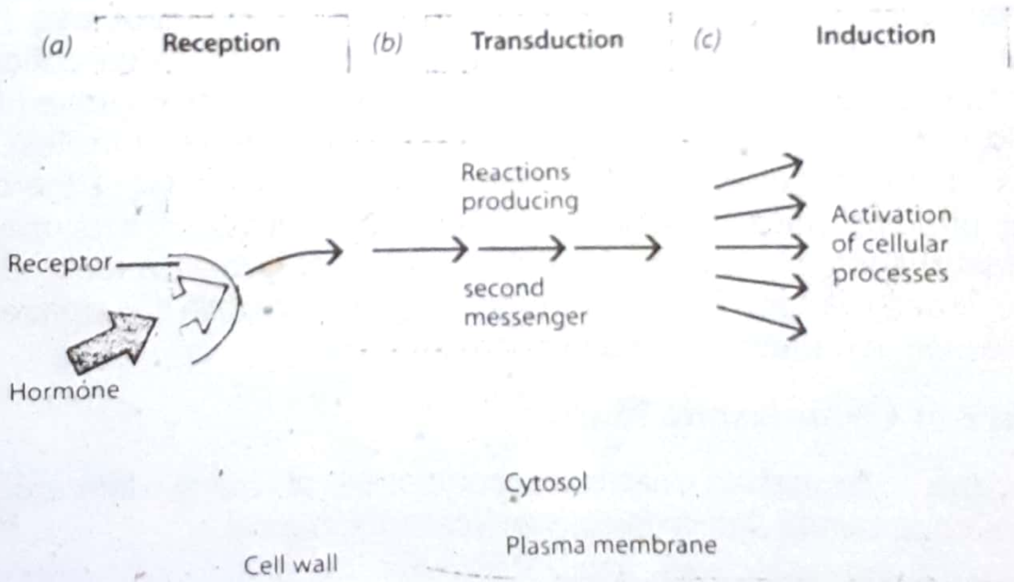
(b) Pinocytosis

(c) Receptor-mediated endocytosis

Cell-to-Cell Communication

The successful existence of multicellular organisms depends upon the ability of the individual cells to communicate with one another so that they can collaborate to create harmonious tissues and organs, and ultimately a properly functioning organism. This communication is brought by means of **chemical signals** and **plasmodesmata**.

i. **Chemical Signals:** Chemical signals are substances that are produced by one cell type or tissue in order to regulate the function of cells or tissues elsewhere in the plant body. In plants, largely **hormones** represent the chemical signals. The plasma membrane plays a key role in signal recognition. When the signal molecules reach the plasma membrane of the target cell, they may be transported into the cell by endocytosis, or they may bind to specific receptors on the outer surface of the membrane which generate messengers on the inside of the membrane. The signals trigger chemical changes within the cell. In most plant responses the messenger is calcium ions. The process by which a cell converts an extracellular signal into a response is called **signal transduction**. It involves three steps: **Reception**, a hormone or other chemical signal binds to a specific receptor in the plasma membrane; **transduction** in which the receptor stimulates the cell to produce a second messenger; and **induction** where second messenger enters the cytosol and activates cellular processes.



ii. **Plasmodesmata:** Plasmodesmata are narrow strands of cytoplasm that interconnect the protoplasts of neighbouring plant cells. These are important pathways in cell-to-cell communication because all of the interconnected protoplasts of plant body, together with their plasmodesmata constitute **symplast**. Plasmodesmata provide a more efficient pathway between neighbouring cells than the less direct, alternative route of plasma membrane and cell wall. These are capable of controlling the intercellular movement of small molecules. Moreover, recent studies indicate that some plasmodesmata have the capacity to transport macromolecules such as proteins and nucleic acids by active transport. Plant viruses are known to spread infection by moving from cell to cell via plasmodesmata.