mucilages are polysaccharides derived from galactose and mannose. Mucilage is abundantly found in the leaves and flowers of *Hibiscus* (china rose), fruits of Lady's finger, seeds of isabgol *(Plantago)*, linseed (*Linum*) etc. Many sea weeds yield mucilaginous substances such as agar, alginic acid and carrageenan of great commercial value.

5. **Mineralization.** The deposition of minerals on the cell walls by the process of infiltration or by deposition of inorganic salts is known as mineralisation. The minerals usually deposited are silica, carbonates and oxalates of calcium. The phenomena of silica and calcium deposition are known as silicification and calcification, respectively.

Functions of Cell Wall

The cell wall in general performs two important functions–(i) it provides mechanical support and gives a definite shape and protection to the cell and cellular contents and (ii) being hydrophilic in nature, it is capable of imbibing water and helps in the movement of water and solutes towards the protoplasm. It also acts as a permeable structure during absorption of minerals and solutes.

PROTOPLASM

Protoplasm is the living, colloidal, semifluid substance of changing consistencies. The term protoplasm was coined by a Bohemian biologist Purkinje for the living substance, universally present in all cells. Protoplasm with non-living inclusions, excluding the cell wall, is called *protoplast*. Each protoplast keeps itself in communication with neighbouring protoplasts through small openings in the cell wall known as plasmodesmata. Protoplasm is characterised by certain physical and chemical properties.

Physical properties. The protoplasm appears as a colourless, elastic, colloidal semifluid containing numerous tiny granules and droplets. The tiny particles show erratic and random movements within the protoplasm. The phenomenon is referred to as *Brownian movement*. In plant cells, vacuoles are also present, and the protoplast shows a state of movement around these vacuoles, referred to as cyclosis. The cyclosis can be easily seen in the cells of *Hydrilla, Eleocharis, Nitella, Chara,* staminal hairs of *Tradescantia* and *Rhoeo discolor* etc. The protoplasm exhibits sol-gel properties and frequently undergoes such transformations by taking in or losing water. Optically, the protoplast is transparent and permits to pass through it the wavelengths of visible spectrum. The *tyndall effect* is also observed. The viscosity of protoplasm is affected by mechanical injury, electric shocks, temperature and pH changes. To the best, the protoplasm is considered as *a complex polyphasic colloidal system.*

Chemical nature. Water is the chief constituent of an active protoplast and normally constitutes 90% of the system. In woody parts of the plants, water is about 50%, but in soft parts 75%, in succulent parts 85–95%, in hydrophytes 95-98% and in dry seeds only 10% water is found. The remaining part of the protoplast contains two types of constituents, *i.e.* organic and inorganic materials.

The common organic compounds are carbohydrates, proteins, nucleic acids, lipids, fats, phosphatides etc. Protein is one of the main constituents which constitutes about 40–60% of the total dry weight of the protoplasm. Carbohydrates form 12-

14% of the dry matter. Nucleic acids exist in both free and combined forms with proteins, in the form of nucleoproteins, forming about 1.5% of the protoplasm. About 12–14% of the protoplasm (dry matter) is lipid, which occurs in the form of natural fats, fatty acids, fatty oils, phosphatides, waxes and steroids. The average chemical composition of a plant body is summarised below:

Table 1.2. An Average Chemical Composition of the Plant Body.

Elements	*% wt.*	*Elements*	*% wt.*
Oxygen	62	Hydrogen	10
Carbon	20	Nitrogen	3
Phosphorus	1.14	Sulphur	0.14
Chlorine	0.16	Potassium	0.11
Iodine	0.014	Magnesium	0.07
Calcium	2.50	Iron	0.01
Other trace elements	0.756	Sodium	0.1

Thirteen elements are constantly found in plant ash. Among metals are potassium, calcium, magnesium, iron and sodium and among non-metals are carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, chlorine and silicon. The other important elements found in traces are boron, manganese, zinc, copper, molybdenum, aluminium etc. Being found in extremely minute quantities these are called trace elements.

Protoplasm consists of cytoplasm and nucleus and is externally bounded by the cell membrane or plasmalemma.

CELL MEMBRANE

All cells remain enclosed by a thin, film-like pliable membrane called plasma membrane or plasmalemma. In addition, the eukaryotic cell also possesses intracellular membranes that surround the vacuole and organelles. The plasma membrane and the subcellular membranes are collectively called biological membrane.

Composition of Membrane

Cell membrane mainly consists of proteins and lipids but in certain cases, polysaccharides, sialic acid, RNA and DNA have also been found.

Proteins. Three different categories of membrane proteins have been found present, (*i*) structural proteins, (*ii*) enzymatic proteins and (*iii*) carrier proteins.

(*i*) ***Structural proteins*** form the backbone of the membrane. Lenard and Singer (1966) suggested that these are strongly lipophilic in nature in which one-fourth to one-third of the amino acid residues show α-helix secondary conformation (arrangement) and the remaining portion forms the random coils. There may be several types of structural proteins in a membrane.

(*ii*) ***Enzymatic proteins*** vary considerably in structure and amount some 30 enzymes have been detected from the membrane. A few of them are – *Na^+ – K^+ activated Mg^{++} ATPase, alkaline phosphatase, acid phosphomonoesterase* etc. Some enzymatic proteins specify the physiological function of the membrane, for example, *glucose-6-phosphatase* of ER and *cytochrome oxidases* of mitochondria. These are called *marker enzymes*.

(iii) ***Carrier proteins*** of the membrane are not well defined. But these have definitely been reported in *Salmonella typhimurium* and *Escherichia coli* where these act as sulphate carrier and glucose binding factor, respectively. The structural and carrier proteins are of low molecular weight and interestingly, in certain cases, both of these may have dual functions.

Lipids. The amount of lipids found in the membrane varies from 30 per cent (in mitochondria) to 70 per cent of the total dry matter of the cell membrane. The lipids are mostly in the form of phospholipids of which five different types have been identified. One is simple phosphatidic acid (diglyceride with the phosphate molecule attached to the glycerol) and the other four are complex in nature. These have either choline, inositol, ethanolamine or serine in addition. The choline containing lipid is called lecithin which forms more than half of the total phospholipid content of the membrane.

The ratio of lipid and protein shows variation depending upon physico-chemical and functional differences. For instance, the proportion of lipids to proteins may vary from 1:0.8 to 1:4.

Other constituents. Some polysaccharides, sialic acid, RNA and DNA have also been found in certain cases. The amount of polysaccharide found in the membrane is extremely low. Bal (1966) reported the presence of RNA in the membrane of the nucleus, endoplasmic reticulum and plasma membrane of *Allium cepa.* DNA has been detected in the membranes of mitochondria, chloroplast and plasma membrane but in most cases, this DNA is easily separable.

Other components playing vital roles in membrane physiology have also been found, such as certain metals (Ca, Mg, Zn), coenzymes, porphyrins etc.

Structure of Membrane

Electron microscopic studies revealed the finer structure of the plasmalemma to be 6 nm to (10 nm = 100 Å; 1 nm = 10^{-6} mm) on the surface of all cells. Plasma membranes of two cells remain separated usually by a space of 11–15 nm. Several models have been proposed to explain the organisation of a cell membrane. A few of them are Danielli-Davson model, Unit membrane hypothesis, Kavanau's lipid pillars, Hydrophobic binding models, Benson's model, Lenard and Singer's model, Mosaic membrane concept, Composite model, Fluid mosaic model etc. Only a few are explained here.

Unit membrane concept. Robertson (1962) studied the structure of a membrane with the help of an electron microscope and found that all biological membranes show three layers, viz., two outer layers (electron dense) separated by a lighter middle layer. These correspond to two layers of proteins and a middle layer of phospholipids. Together, these form a unit membrane. His findings confirmed the observations of Danielli and Davson (1930) who proposed that the plasma membrane is made up of lipid layer, sandwiched between two continuous layers of proteins. The protein and lipid molecule layers are electrostatically held together, the former being positively charged and the latter negatively charged. In this sandwich, lipid molecules show orderly arrangement and remain set at right angles to the surface. The lipophilic tails of fatty acids face one another along the double row and their hydrophilic heads face outwards. Each protein layer is found to be 20 Å thick and lipid layers,

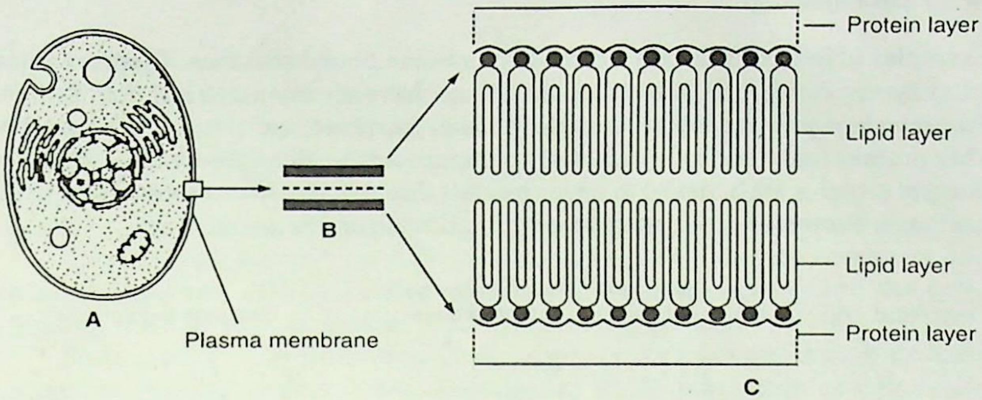

Fig. 1.5. Structural details of a plasma membrane. A–as seen under ordinary magnification of an electron microscope, B–a portion more magnified, and C–a detailed structure showing sandwich arrangement.

35 Å thick, thus making the sandwich 75–100 Å thick. At places, the lipid layers are penetrated by pores of variable sizes. The pores may form or reform.

This model cannot be applied to all membranes, as it reveals the definite proportion of lipids and proteins, which has not been found true. Moreover, recent studies reveal that proteins are found in the form of particles and not as a continuous layer.

Fluid-mosaic model. Singer and Nicholson (1972) proposed the fluid-mosaic model of a cell membrane. They proposed that a central bilipid layer composed of phospholipids, with their spherical, polar head groups on the outer surfaces, form the basic structure of a membrane (Fig. 1.6). The two non-polar tails of each molecule point inwards. This arrangement forms a water-resistant barrier through which lipid soluble substances can pass through. Lipid molecules show various kinds of motions such as :

(*i*) internal motion within each lipid molecule.
(*ii*) lipid molecules might diffuse laterally.
(*iii*) lipid molecules may rotate rapidly as a whole, about their long axes, and
(*iv*) transfer of lipid molecules from one side of the bilayer to the other. It is referred to as *flip flop movement*.

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As regards proteins, they described the model as *protein icebergs in a sea of lipids*. In fact, proteins are found in the form of discrete particles which may be either embedded in the lipid layer (integral proteins or *intrinsic* proteins) or superficially attached (peripheral proteins or *extrinsic* proteins).

The **peripheral proteins** are separated by mild treatment, soluble in aqueous solutions and are usually free of lipids, *e.g. Cytochrome c* found in mitochondrial membrane and *glyceraldehyde 3 P-dehydrogenase*. The intergral proteins represent more than 70 per cent of the membrane proteins, and for their removal, the membrane has to be disrupted. These are insoluble in water solutions and are associated with lipids. These proteins may be attached to oligosaccharides, thus forming glycoproteins.

Examples of integral proteins are most membrane-bound enzymes. There are some 30 enzymes in the cell membrane, and these have an asymmetrical distribution. *Bacteriorhodopsin* is another example found in the membrane of halophilic bacteria. This protein functions as proton (H^+) pump driven by light. Some large globular integral proteins are believed to have channels through which water soluble material can pass. Proteins are asymmetrically distributed in the membrane.

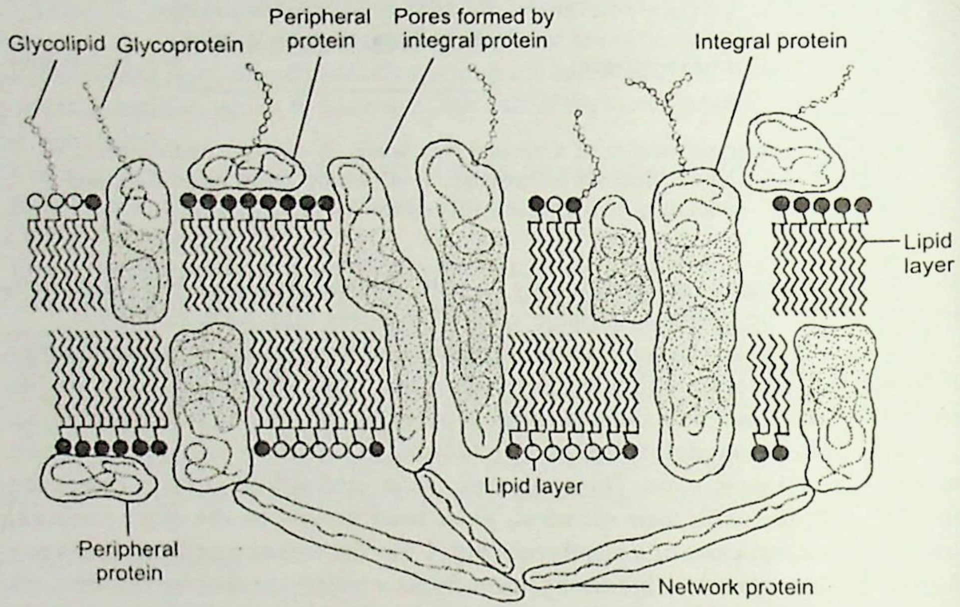

Fig. 1.6. Model of biomembrane as proposed by Singer and Nicholson (1972) showing bilipid layer, extrinsic and intrinsic proteins.

The **Fluid-Mosaic model** of the membrane postulates:

(*i*) that the lipid and integral proteins are disposed in a kind of mosaic arrangement, and

(*ii*) that biological membranes are quasifluid structures in which both, the lipids and the integral proteins are able to perform translational movements within the bilayer.

Such a model proposes that the **cohesive forces** between lipids and other proteins are relatively weak interactions, *i.e.* ionic, hydrogen bonds, and mainly hydrophobic in nature.

The fluidity of lipid is supported by X-ray diffraction, differential thermal analysis and electron spin techniques. The fluidity of integral proteins is supported by experiments on cell fusion and on those of clustering and 'capping' of surface antigens.

The **mosaic arrangement** implies that :

1. the macromolecules have a characteristic asymmetry,

2. they are oriented for carrying information across the bilayer, and
3. they have considerable freedom of movement within the bilayer (fluidity).

In certain cases, some oligosaccharides are found attached to lipids and integral proteins which project into the extracellular fluid from the outer surface of the plasma membrane. These influence the manner in which cells interact with one another. Cells recognise one another on the basis of these glycoproteins and glycolipids.

There are specific proteins in the membrane, called **membrane receptors** which play an important role in the flow of materials and information into the cell by binding with specific molecules reaching the cell surface.

Some membrane proteins function as **enzymes**, for example, the mitochondrial membrane carries electron transport enzymes which participate in respiration.

Functions of Cell Membrane

Some of the important functions of the cell membrane are as follows:

(1) It acts as a **permeability barrier** which controls and co-ordinates the rate of substrate transfer and diffusion. Compounds with polar groups, OH, – COOH, NH_2, – CHO and inorganic salts enter the cell slowly. Non polar compounds such as alcohol, chloroform etc. penetrate rapidly. Cell membrane is impermeable to polysaccharides, phospholipids and proteins.

Movement of substances across the cell membrane may be by **passive diffusion** or by several mechanisms of **active transport**.

Diffusion occurs when there is a concentration gradient and takes place from a high to a low concentration. *Diffusion of molecules* depends on the size of the molecule and the lipid solubility of the substance. *Diffusion of ions* depends on both the concentration and the electrical gradients across the membrane.

The **active transport** of neutral molecules and ions requires energy (ATP) and is generally coupled with the energy yielding mechanism of the cell (respiration).

Transport mechanism in the cell membrane is highly specific and involves **transport proteins** (*i.e.* carriers or *permeases*). The binding sites of transport proteins are able to recognize the molecule to be transported. Such *permeases* may be driven either by a passive mechanism (**facilitated diffusion**) or an active one (**active transport**). It is believed that through *carriers* and *fixed pore mechanisms*, materials are selectively transported across the membrane. The fixed pore mechanism seems more probable because it requires less energy and involves conformational changes in the molecules constituting the fixed pore.

(2) It acts as a cytoskeleton providing mechanical frames on which enzymes can be specifically oriented.

(3) It acts as a vehicle for the transport of substances from one organelle to another, from inside to the outside of a cell and from outside to the inside of a cell.

(4) It acts as an element, supporting the synthesis of various macro-molecules, particularly in chloroplast, mitochondria and cell membrane of prokaryotes.

(5) It participates in the biogenesis of the cell wall.

CYTOPLASM

The living part of the protoplast surrounding the nucleus is known as cytoplasm. Cytoplasm is bounded externally by the cell membrane and internally by the *tonoplast* or vacuolar membrane. It is semipermeable in nature and maintains connections with neighbouring cells through plasmodesmata. The cytoplasm is distinguishable into ectoplasm, mesoplasm and endoplasm. The cytoplasm functions as a medium for the transport of the various cellular products, intracellular movements and provides a matrix in which the cytoplasmic organelles remain floating.

Cytoplasmic inclusions. Embedded in the cytoplasm are a number of structures of immense physiological importance. These may be of 2 types–(i) Living cytoplasmic organelles and (ii) Non-living inclusions.

CYTOPLASMIC ORGANELLES

The cytoplasmic organelles are the sites of various important metabolic activities such as photosynthesis, respiration, protein synthesis etc. Some of these important organelles are briefly discussed here.

PLASTIDS

Plastids are discoid organelles about 5 μm in diameter and 3 μm in thickness, found lying free in the cytoplasm of all plant cells. The term plastid is derived from the Greek word *Plastikas,* and was first used by Schimper (1885). Three different types of plastids are recognised on the basis of their types of pigments or colouration.

(*i*) *Chromoplasts*–These are coloured plastids containing variously coloured pigments other than green photosynthetic ones. They may arise from chloroplasts, as in petals and in pericarp of fruits of Solanaceae, Rutaceae etc. or from leucoplasts, as in carrot roots. Their coloured pigments, belonging to carotenoid groups (carotenes, xanthophyll etc.) are mostly present in vacuolar sap and provide resistance to flowers against thermal fluctuations. Anthocynin is characteristically found in the vacuolar sap of petals. It is never found in chloroplasts.

(*ii*) *Leucoplasts*–These are colourless plastids, originating from proplastids and may be rod-like, spherical or oval in shape. They are usually involved in the storage of various kinds of reserve food materials and are named accordingly, as amyloplasts (storage of starch), aleuroplasts (storage of proteins) and elaioplasts or lipoplast (storage of oil).

(*iii*) *Chloroplasts.*

CHLOROPLASTS

Chloroplasts were first observed by Anton Von Leeuwenhoek in the later years of the seventeenth century and from the time Sachs (1862) observed starch grains inside chloroplasts during photosynthesis, these are believed to be the sites of photosynthesis.

The chloroplasts are small green bodies present in the cytoplasm of higher plants and green algae. The corresponding organelles of red, brown and blue-green algae and certain bacteria such as green and purple types are called chromatophores. The chloroplasts in algae exhibit a remarkable variation in size and shape, *e.g.*

star-shaped, band-shaped, or giants with linear dimensions. *Chlorella* contains a single bell-shaped chloroplast; *Chlamydomonas*, cup-shaped; *Ulothrix*, girdle-shaped; *Oedogonium*, reticulate; *Spirogyra*, band-shaped and *Zygnema*, stellate-shaped chloroplasts. A characteristic feature of algal chloroplasts is the presence of pyrenoids. The pyrenoids are irregular-shaped bodies composed of a viscous mass of proteins surounded by starch platelets.

The chloroplasts of higher plants are mainly found distributed in the mesophyll cells of a leaf. They may be flat eliipsoids or disc-shaped and in average 3–10 μm across. Haberlandt (1882) found an average of 36 chloroplasts in each palisade cell and 20 in each spongy parenchyma cell. However, this number may vary. Details of a chloroplast may be studied under the following headings.

(A) Chemical Composition of Chloroplast

The average chemical composition of the chloroplast on a dry weight basis shows :

Proteins	–	40–50%
Phospholipids	–	20–25%
Chlorophylls	–	5–10%
Carotenoids	–	1–25
RNA	–	5%
DNA	–	in traces (4–8 × 10^8 daltons)

Besides, Mg is found 2–3% of the total ash content. Fe and Cu are found in traces.

(B) Structure of Chloroplast

The important structural components found in a chloroplast are :

(*i*) Chloroplast membrane
(*ii*) Stroma or matrix
(*iii*) Thylakoids distinguishable into granal thylakoids and intergranal thylakoids.
(*iv*) Osmiophilic granules
(*v*) Ribosomes
(*vi*) DNA and RNA

ULTRA STRUCTURE OF CHLOROPLAST

Electron microscopic studies have revealed that a chloroplast has three main components :

1. The envelope (chloroplast membrane)
2. The stroma
3. The thylakoids

1. The **envelope** (chloroplast membrane). It is made up of a double limiting membrane through which molecular interchange occurs with cytosol. The inner membrane of a mature chloroplast is not in continuity with the thylakoids. Isolated membranes have a yellow colour due to the presence of small amounts of carotenoids. The envelop lacks chlorophyll and cytochromes, and contains only 1 to 2 per cent of the protein of the chloroplast.