BIO102-Foundations of Biology (I)

Membrane structure

INDRAPRASTHA INSTITUTE *of* INFORMATION TECHNOLOGY **DELHI**

Dr. Jaspreet Kaur Dhanjal
Assistant Professor, Center for Computational Biology
Email ID: jaspreet@iiitd.ac.in

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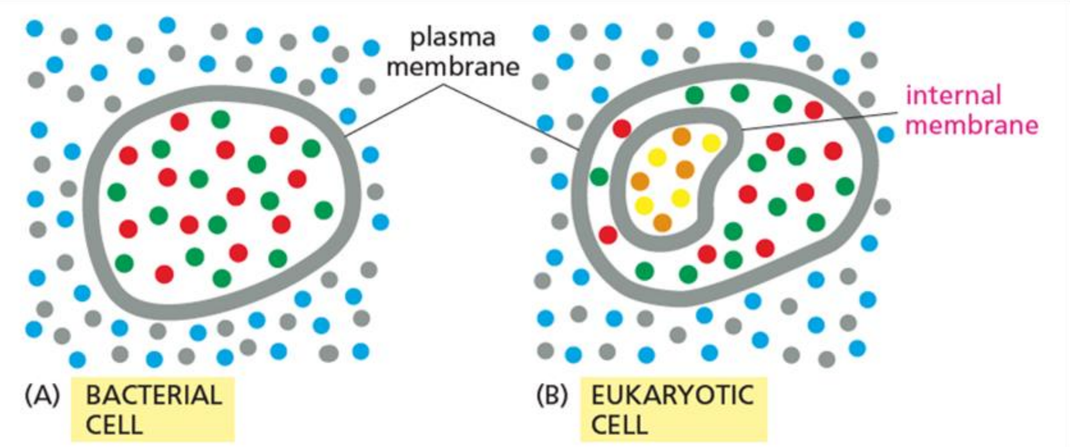
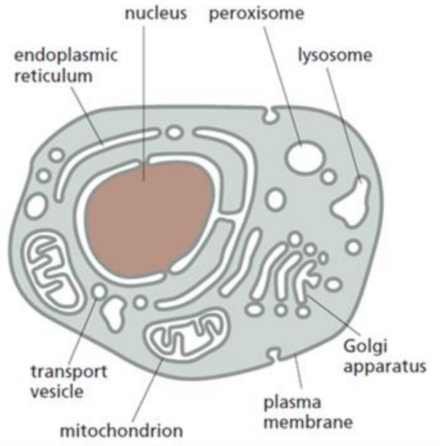
Plasma membrane

- Every cell on Earth uses such a membrane, called plasma membrane, to separate and protect its chemical components from the outside environment.
- Plasma membrane is directly visible under the light microscope.
- In some bacteria, the plasma membrane is the only membrane, however eukaryotic cells also have internal membranes that enclose individual organelles.

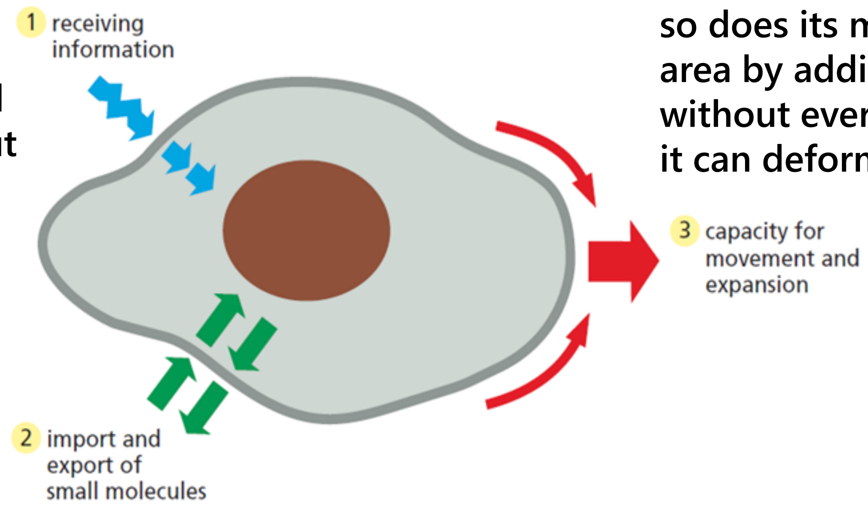




Plasma membrane

A barrier to prevent the contents of the cell from escaping and mixing with the surrounding medium.

Sensors, or receptors, proteins that enable the cell to receive information about changes in its environment and respond to them in appropriate ways.



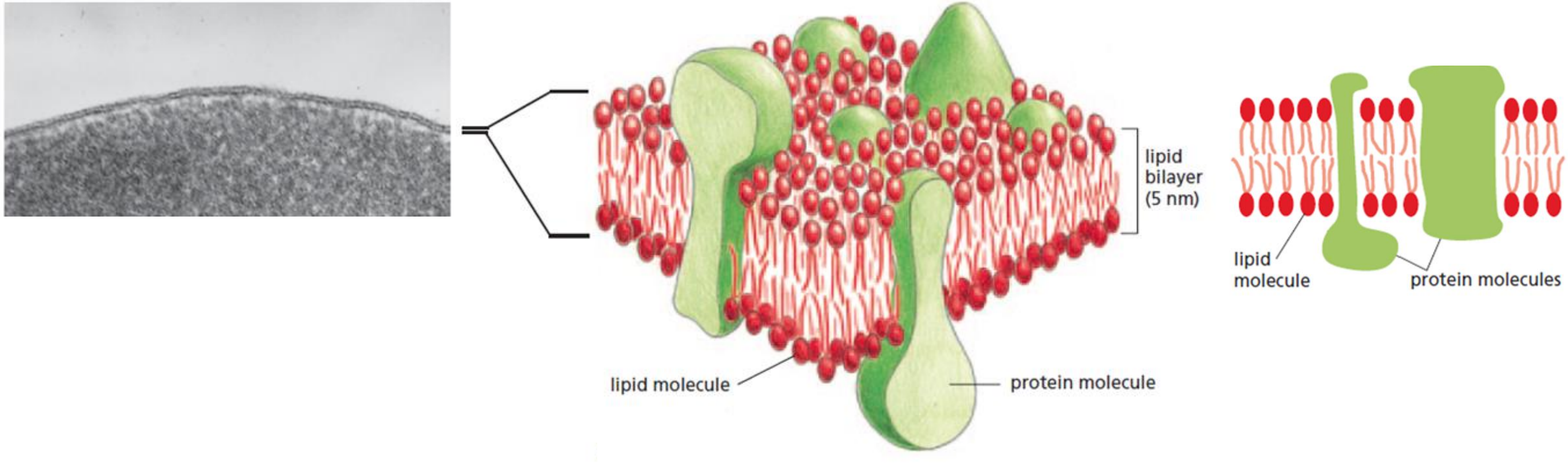
When a cell grows or changes shape, so does its membrane: it enlarges in area by adding new membrane without ever losing its continuity, and it can deform without tearing.

Facilitates the exchange - nutrients (inward) and waste (out), for cells' growth and survival.

Channels and transporters - proteins that allow import and export of specific, small molecules and ions.

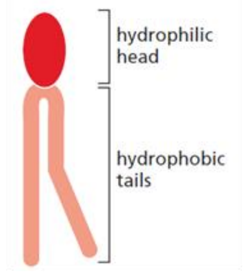
Structure of plasma membrane

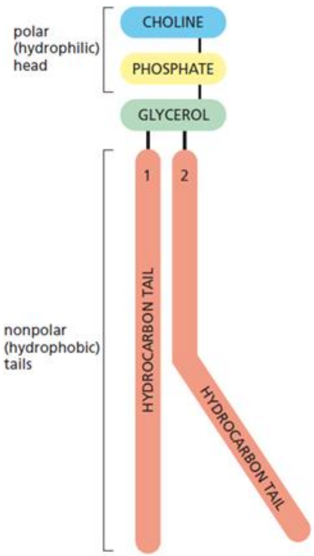
- Regardless of the location, all cell membranes are composed of lipids and proteins and share a common general structure.
- The lipids are arranged in two closely apposed sheets, forming a lipid bilayer. This lipid bilayer serves as a permeability barrier to most water-soluble molecules.
- The proteins carry out the other functions of the membrane and give different membranes their individual characteristics.



Lipids in plasma membrane

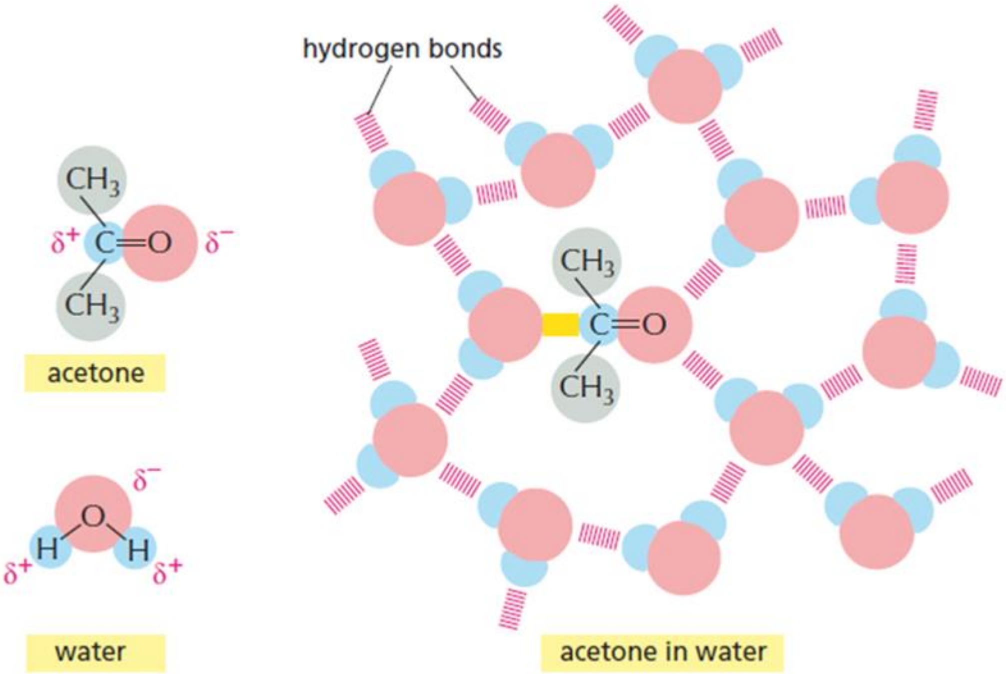
- The lipids in cell membranes combine two very different properties in a single molecule (amphipathic) - each lipid has a hydrophilic ("water-loving") head and a hydrophobic ("water-fearing") tail.
- The most abundant lipids in cell membranes are the phospholipids, which have a phosphate-containing, hydrophilic head linked to a pair of hydrophobic tails. Phosphatidylcholine, for example, has the small molecule choline attached to a phosphate group as its hydrophilic head.
- The plasma membranes of animal cells contain four major phospholipids - phosphatidylcholine, phosphatidylethanolamine, phosphatidylserine, and sphingomyelin. The other types of membrane lipids include cholesterol and glycolipids.
- Amphipathic nature of lipid molecules is crucial to assemble into bilayers in an aqueous environment.





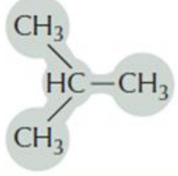
Hydrophilic molecules attract water molecules

- Hydrophilic molecules dissolve readily in water because they contain either charged groups or uncharged polar groups that can form either electrostatic attractions or hydrogen bonds with water molecules.

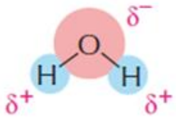


Hydrophobic molecules tend to avoid water

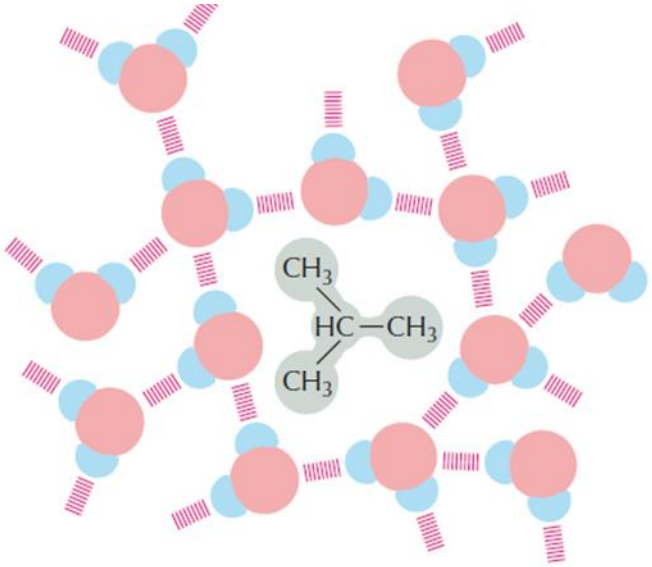
- Hydrophobic molecules are insoluble in water because almost all of their atoms are uncharged and nonpolar; they therefore cannot form favorable interactions with water.
- They force adjacent water molecules to reorganize into a cage-like structure around them. Because this cage-like structure is more highly ordered than the rest of the water, its formation requires free energy. This energy cost is minimized when the hydrophobic molecules cluster together, limiting their contacts with the surrounding water molecules. Thus purely hydrophobic molecules, like the fats found in animal fat cells and the oils found in plant seeds, coalesce into a single large drop when dispersed in water.



2-methylpropane



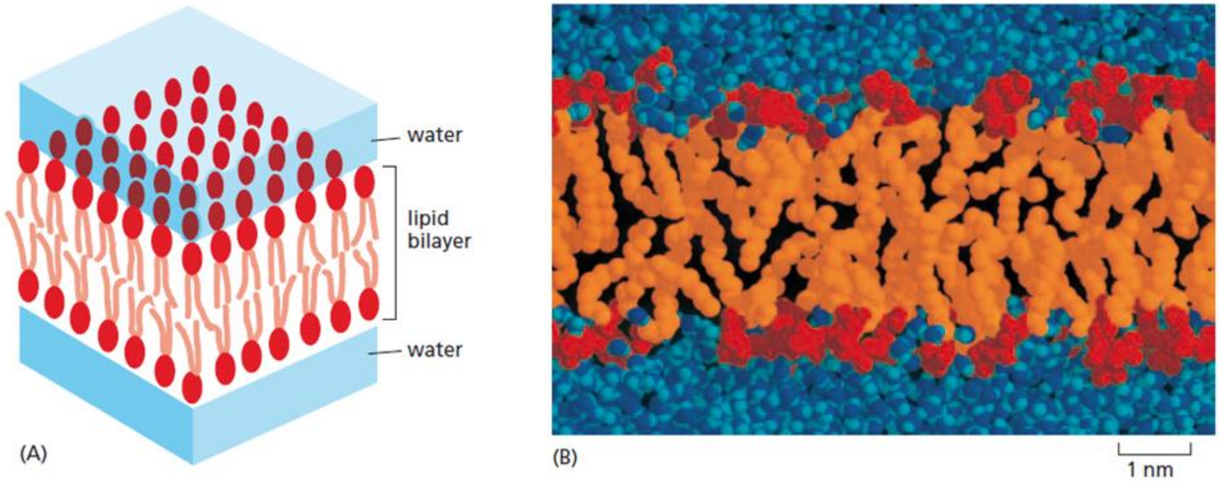
water



2-methylpropane in water

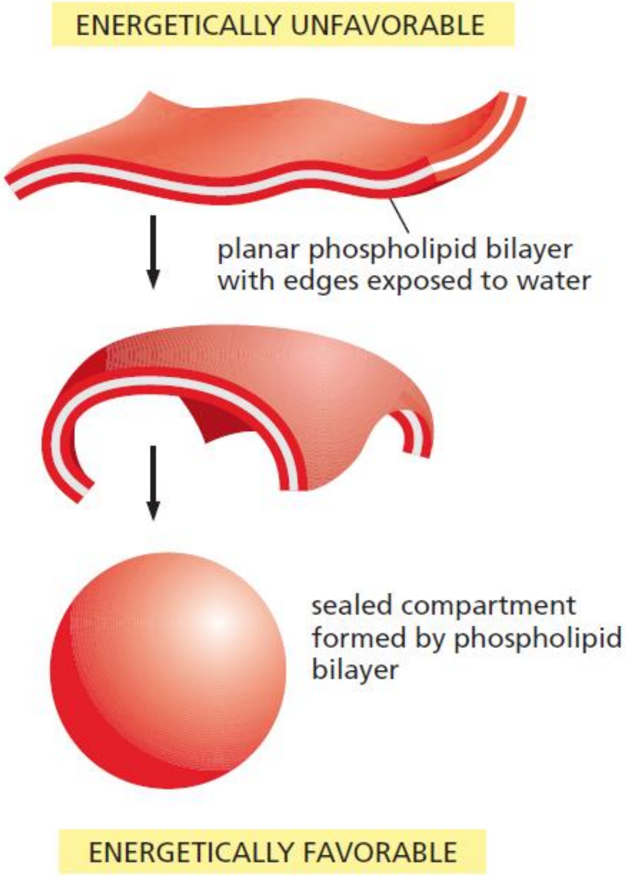
Lipid bilayer

- Amphipathic molecules, such as phospholipids, are subject to two conflicting forces: the hydrophilic head is attracted to water, while the hydrophobic tails shun water and seek to aggregate with other hydrophobic molecules.
- This leads to the formation of a lipid bilayer—an arrangement that satisfies all parties and is energetically most favorable. The hydrophilic heads face water on both surfaces of the bilayer; but the hydrophobic tails are all shielded from the water, as they lie next to one another in the interior, like the filling in a sandwich.



Lipid bilayer

- Phospholipid bilayers spontaneously close in on themselves to form sealed compartments.
- The closed structure is stable because it avoids the exposure of the hydrophobic hydrocarbon tails to water, which would be energetically unfavorable.

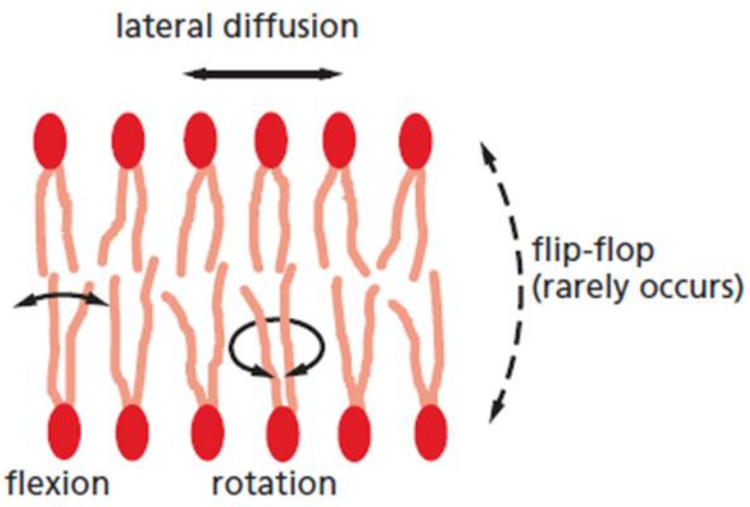


The lipid bilayer is a flexible two-dimensional fluid

- The aqueous environment inside and outside a cell prevents membrane lipids from escaping from the bilayer, but nothing stops these molecules from moving about and changing places with one another within the plane of the bilayer.
- The membrane therefore behaves as a two-dimensional fluid, a fact that is crucial for membrane function and integrity.
- The lipid bilayer is also flexible—that is, it is able to bend. Like fluidity, flexibility is important for membrane function, and it sets a lower limit of about 25 nm to the size of vesicle that cell membranes can form.

Membrane phospholipids are motile

- Phospholipid molecules very rarely tumble from one half of the bilayer, or monolayer, to the other. On the other hand, as the result of random thermal motions, lipid molecules continuously exchange places with their neighbors in the same monolayer. This exchange leads to rapid lateral diffusion of lipid molecules within the plane of each monolayer.
- Individual lipid molecules not only flex their hydrocarbon tails, but they also rotate rapidly about their long axis—some reaching speeds of 500 revolutions per second.



The fluidity of a lipid bilayer depends on its composition

- The fluidity of a cell membrane—the ease with which its lipid molecules move within the plane of the bilayer—is important for membrane function.
- Fluidity a lipid bilayer at a given temperature depends on its phospholipid composition and on the nature of the hydrocarbon tails: the closer and more regular the packing of the tails, the more viscous and less fluid the bilayer will be.
- Two major properties of hydrocarbon tails affect how tightly they pack in the bilayer: their length and the number of double bonds they contain.
- A shorter chain length reduces the tendency of the hydrocarbon tails to interact with one another and therefore increases the fluidity of the bilayer. The hydrocarbon tails of membrane phospholipids vary in length between 14 and 24 carbon atoms, with 18–20 atoms being most usual.
- Most phospholipids contain one hydrocarbon tail that has one or more double bonds between adjacent carbon atoms, and a second tail with single bonds only. Each double bond in an unsaturated tail creates a small kink in the tail, which makes it more difficult for the tails to pack against one another.

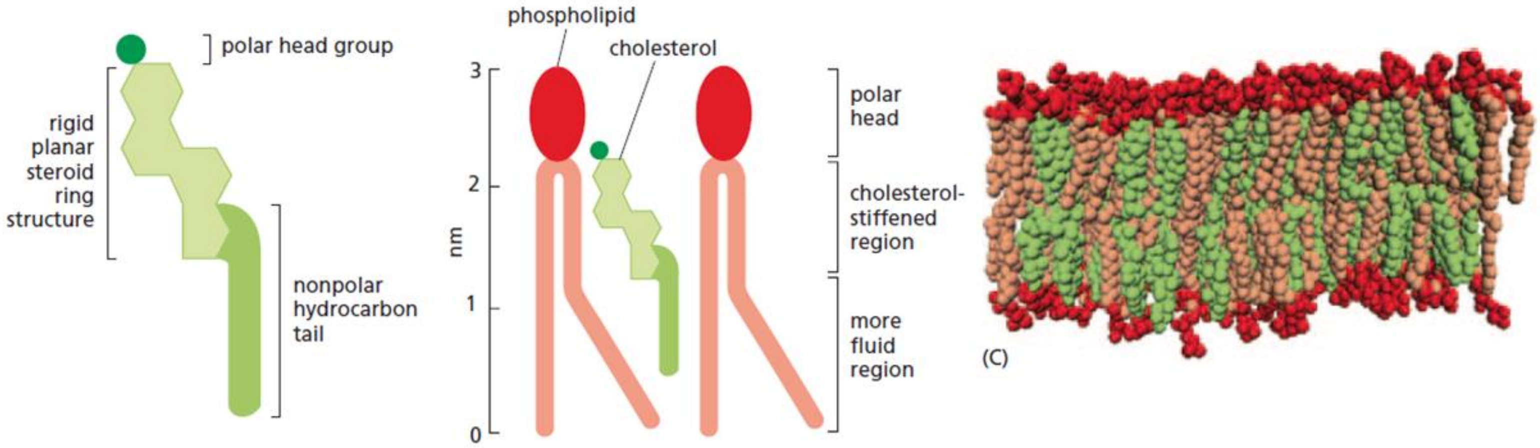
The fluidity of a lipid bilayer depends on its composition

- In bacterial and yeast cells, which have to adapt to varying temperatures, both the lengths and the unsaturation of the hydrocarbon tails in the bilayer are constantly adjusted to maintain the membrane at a relatively constant fluidity: at higher temperatures, for example, the cell makes membrane lipids with tails that are longer and that contain fewer double bonds.

- Manufacturing of margarine from vegetable oils. The fats produced by plants are generally unsaturated and therefore liquid at room temperature, unlike animal fats such as butter or lard, which are generally saturated and therefore solid at room temperature. Margarine is made of hydrogenated vegetable oils; their double bonds have been removed by the addition of hydrogen, so that they are more solid and butter-like at room temperature.

The fluidity of a lipid bilayer depends on its composition

- In animal cells, membrane fluidity is modulated by the inclusion of the cholesterol, which is a sterol.
- Cholesterol is present in especially large amounts in the plasma membrane, where it constitutes approximately 20% of the lipids in the membrane by weight.
- Cholesterol molecules are short and rigid, they fill the spaces between neighboring phospholipid molecules left by the kinks in their unsaturated hydrocarbon tails. Cholesterol tends to stiffen the bilayer, making it less flexible, as well as less permeable.



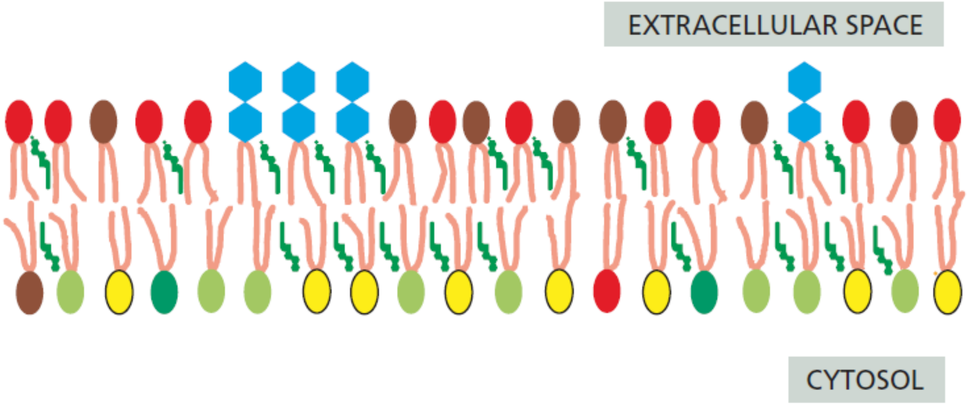
The fluidity of a lipid bilayer depends on its composition

For all cells, membrane fluidity is important for many reasons.

- It enables many membrane proteins to diffuse rapidly in the plane of the bilayer and to interact with one another, as is crucial, for example, in cell signaling.
- It permits membrane lipids and proteins to diffuse from sites where they are inserted into the bilayer after their synthesis to other regions of the cell.
- It ensures that membrane molecules are distributed evenly between daughter cells when a cell divides.
- Under appropriate conditions, it allows membranes to fuse with one another and mix their molecules.
- Crucial for the cells to live, grow, and reproduce.

Other properties of lipid bilayer

Cell membranes have distinct "inside" and "outside" faces: the cytosolic monolayer always faces the cytosol, while the non-cytosolic monolayer is exposed to either the cell exterior—in the case of the plasma membrane - or to the interior space (lumen) of an organelle.

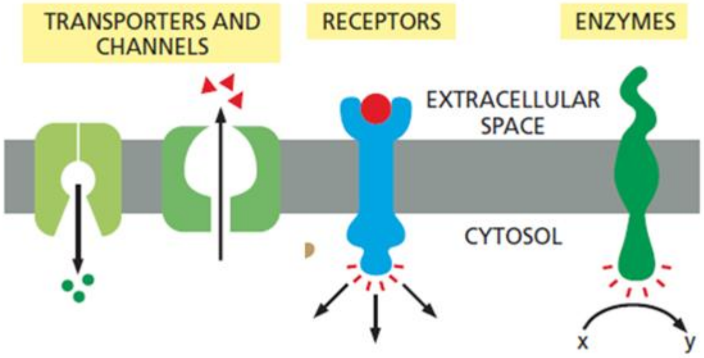


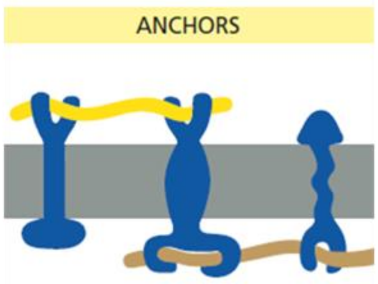
This conservation of orientation applies not only to the phospholipids that make up the membrane, but to any proteins that might be inserted in the membrane. For membrane proteins, this positioning is very important, as their orientation within the lipid bilayer is often crucial for their function.

Membrane proteins

- Although the lipid bilayer provides the basic structure of all cell membranes and serves as a permeability barrier to the hydrophilic molecules on either side of it, most membrane functions are carried out by membrane proteins.
- In animals, proteins constitute about 50% of the mass of most plasma membranes, the remainder being lipid plus the relatively small amounts of carbohydrate found on some of the lipids (glycolipids) and many of the proteins (glycoproteins).
- Because lipid molecules are much smaller than proteins, a cell membrane typically contains about 50 times more lipid molecules than protein molecules.
- Membrane proteins serve many functions. Some transport particular nutrients, metabolites, and ions across the lipid bilayer. Others anchor the membrane to macromolecules on either side. Still others function as receptors that detect chemical signals in the cell's environment and relay them into the cell interior, or work as enzymes to catalyze specific reactions at the membrane.
- Each type of cell membrane contains a different set of proteins, reflecting the specialized functions of the particular membrane.

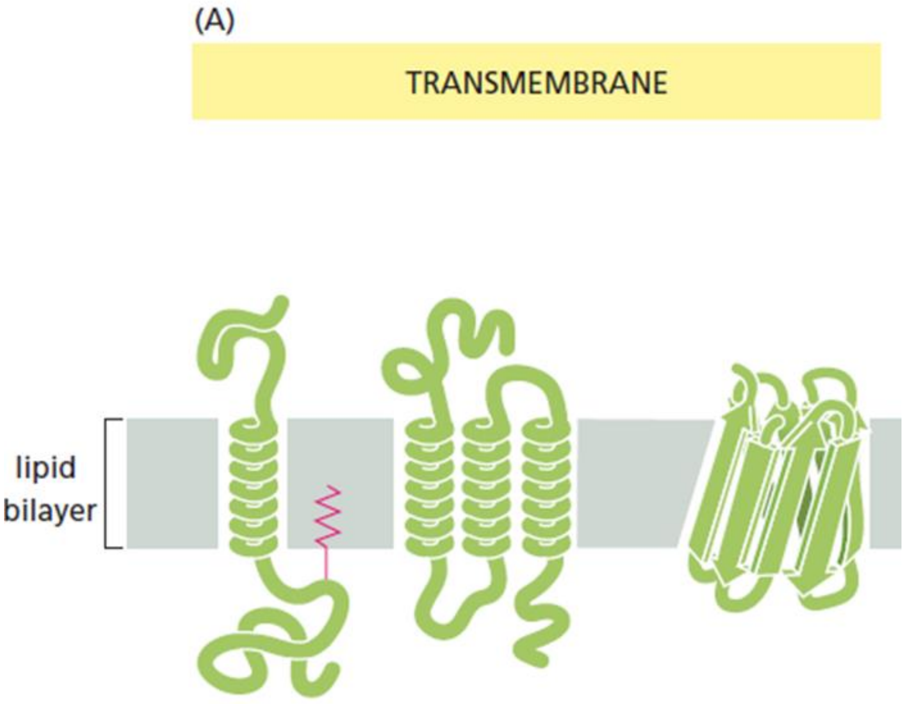
Membrane proteins





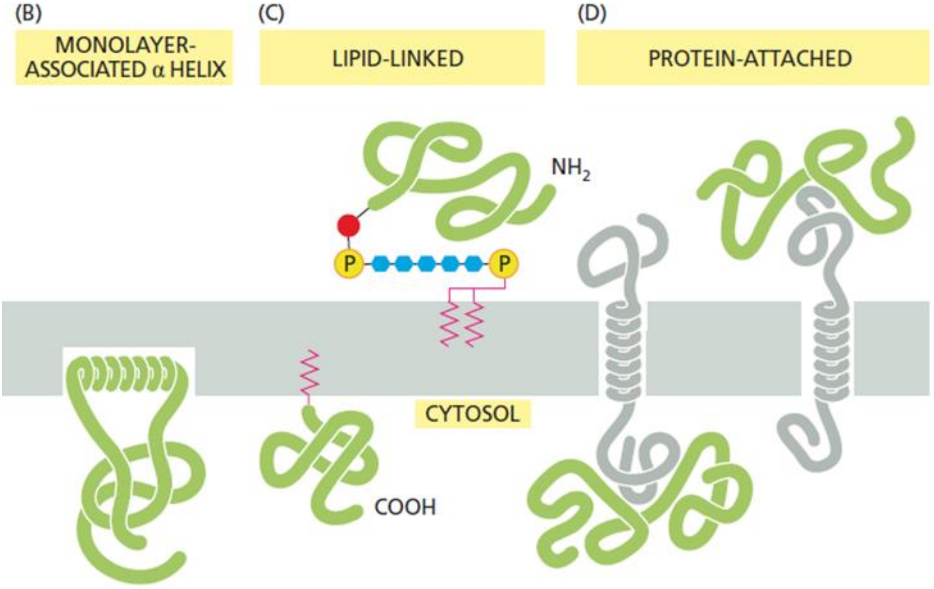
Functional Class	Protein Example	Specific Function
Transporters	Na^+ pump	actively pumps Na^+ out of cells and K^+ in
Ion channels	K^+ leak channel	allows K^+ ions to leave cells, thereby having a major influence on cell excitability
Anchors	integrins	link intracellular actin filaments to extracellular matrix proteins
Receptors	platelet-derived growth factor (PDGF) receptor	binds extracellular PDGF and, as a consequence, generates intracellular signals that cause the cell to grow and divide
Enzymes	adenylyl cyclase	catalyzes the production of the small intracellular signaling molecule cyclic AMP in response to extracellular signals

Types of membrane Proteins



- Many membrane proteins extend through the bilayer, with part of their mass on either side.
- Like their lipid neighbors, these transmembrane proteins are amphipathic, having both hydrophobic and hydrophilic regions.
- Their hydrophobic regions lie in the interior of the bilayer, nestled against the hydrophobic tails of the lipid molecules. Their hydrophilic regions are exposed to the aqueous environment on either side of the membrane.

Types of membrane Proteins

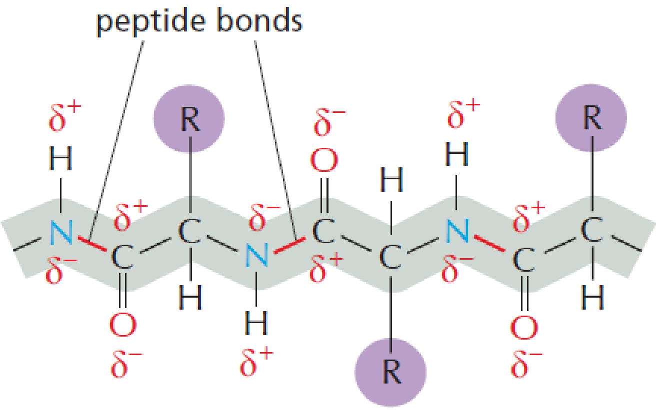


- Other membrane proteins are located almost entirely in the cytosol and are associated with the cytosolic half of the lipid bilayer by an amphipathic α helix exposed on the surface of the protein.
- Some proteins lie entirely outside the bilayer, on one side or the other, attached to the membrane only by one or more covalently attached lipid groups.
- Other proteins are bound indirectly to one or the other face of the membrane, held in place only by their interactions with other membrane proteins.

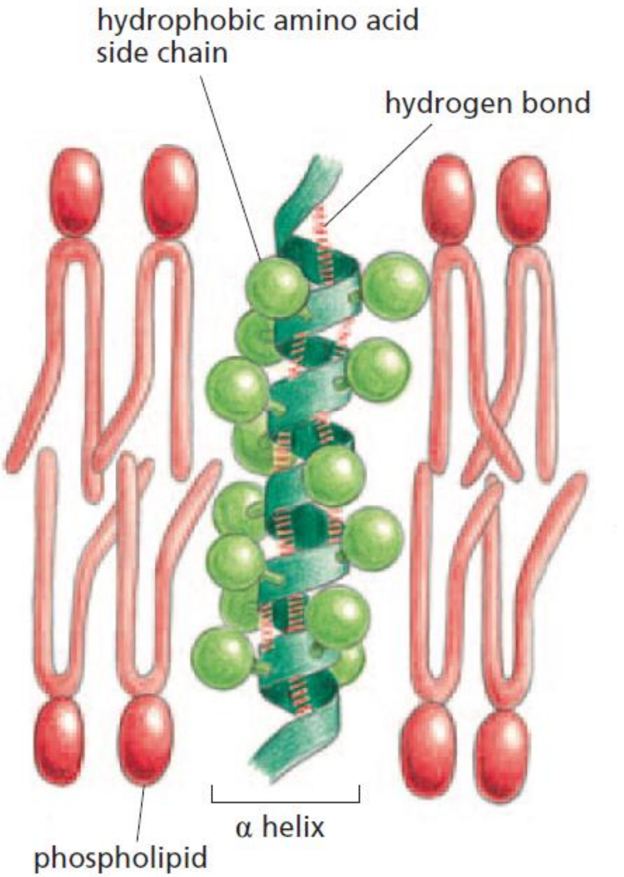
Types of membrane Proteins

- Proteins that are directly attached to the lipid bilayer—whether they are transmembrane, associated with the lipid monolayer, or lipid-linked—can be removed only by disrupting the bilayer with detergents. Such proteins are known as integral membrane proteins.
- The remaining membrane proteins are known as peripheral membrane proteins; they can be released from the membrane by more gentle extraction procedures that interfere with protein–protein interactions but leave the lipid bilayer intact.

A transmembrane polypeptide - an α helix



The backbone of a polypeptide chain is hydrophilic.



Plasma membrane is reinforced by the cell cortex

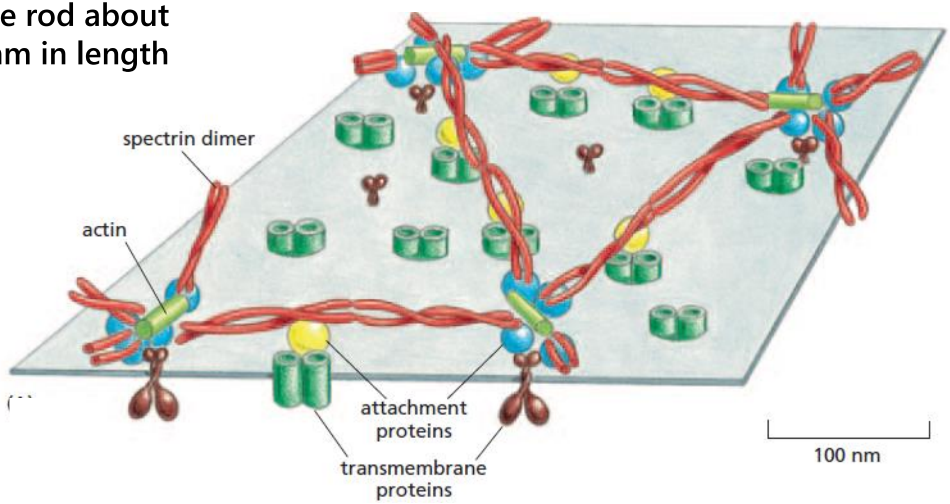
- A cell membrane by itself is extremely thin and fragile.
- Most cell membranes are therefore strengthened and supported by a framework of proteins, attached to the membrane via transmembrane proteins.
- For plants, yeasts, and bacteria, the cell's shape and mechanical properties are conferred by a rigid cell wall (a meshwork of proteins, sugars, and other macromolecules that encases the plasma membrane)
- The plasma membrane of animal cells is stabilized by a meshwork of fibrous proteins, called the cell cortex, that is attached to the underside of the membrane.

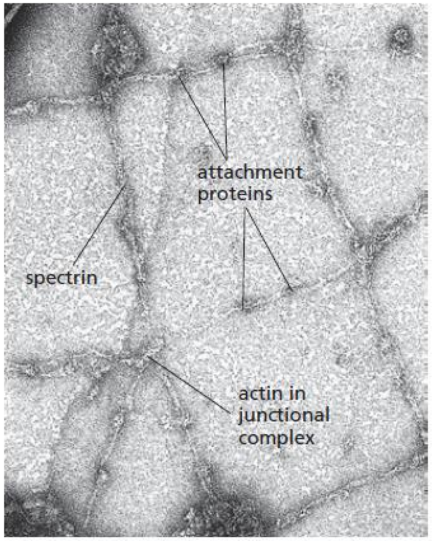
Cell cortex of Red Blood Cells

Spectrin is the main component - the dimeric protein, long, thin, flexible rod about 100 nm in length

The spectrin tetramers, together with a smaller number of actin molecules, are linked together into a mesh

Cortex in other cells is more complex and especially rich in actin and the motor protein myosin



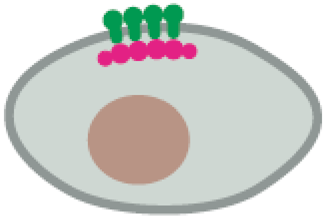


The network is attached to the plasma membrane by the binding of at least two types of attachment proteins and to two kinds of transmembrane proteins

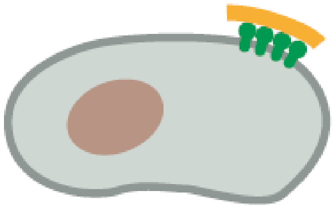
While red blood cells need their cortex mainly to provide mechanical strength as they are pumped through blood vessels, other cells also need their cortex to allow them to selectively take up materials from their environment, to change their shape actively, and to move

Cells restrict the movement of membrane proteins

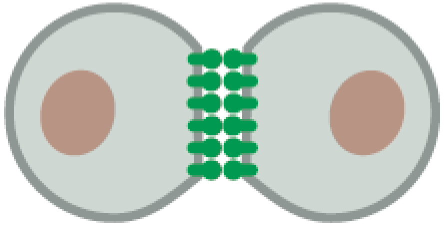
Cells have ways of confining particular proteins to localized areas within the bilayer membrane, thereby creating functionally specialized regions, or membrane domains, on the cell or organelle surface.



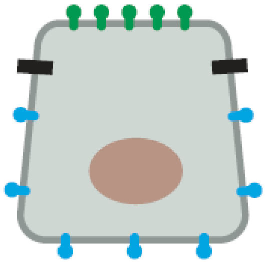
Proteins can be tethered to the cell cortex inside the cell



Proteins can be tethered to extracellular matrix molecules outside the cell



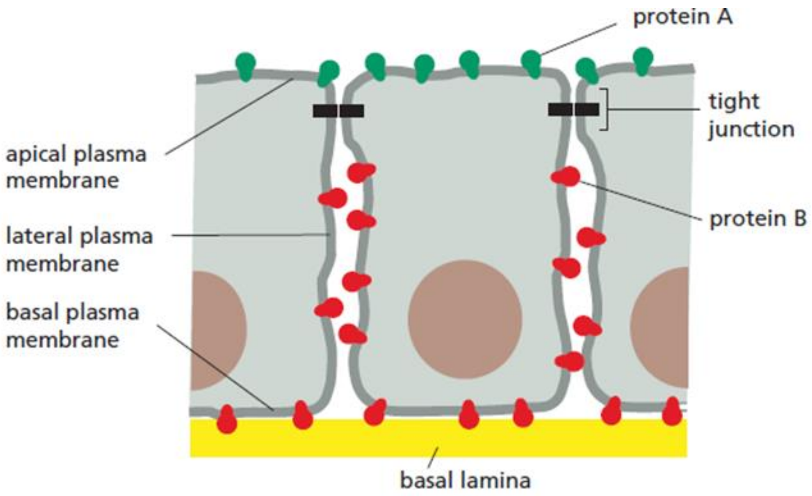
Proteins can be tethered to proteins on the surface of another cell



Diffusion barriers can restrict proteins to a particular membrane domain

Tight junctions

- Cells create barriers that restrict particular membrane components to one membrane domain.

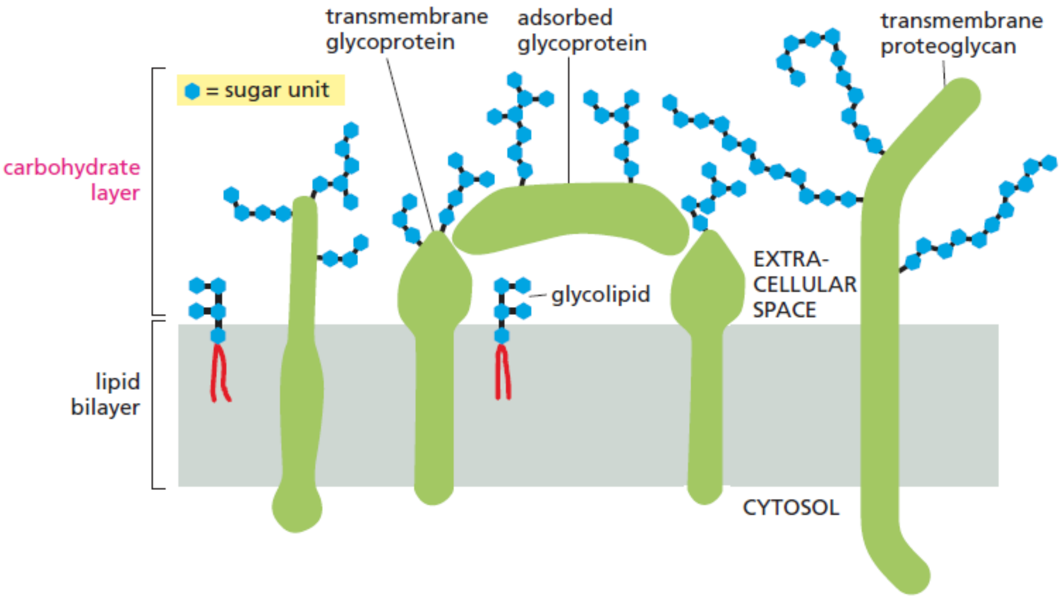


In epithelial cells that line the gut, for example, it is important that transport proteins involved in the uptake of nutrients from the gut be confined to the apical surface of the cells (the surface that faces the gut contents) and that other transport proteins involved in the export of solutes out of the epithelial cell into the tissues and bloodstream be confined to the basal and lateral surfaces.

- This asymmetric distribution of membrane proteins is maintained by a barrier formed along the line where the cell is sealed to adjacent epithelial cells by a so-called tight junction.
- At this site, specialized junctional proteins form a continuous belt around the cell where the cell contacts its neighbors, creating a seal between adjacent plasma membranes.
- Membrane proteins cannot diffuse past the junction.

Cell surface is coated with carbohydrate

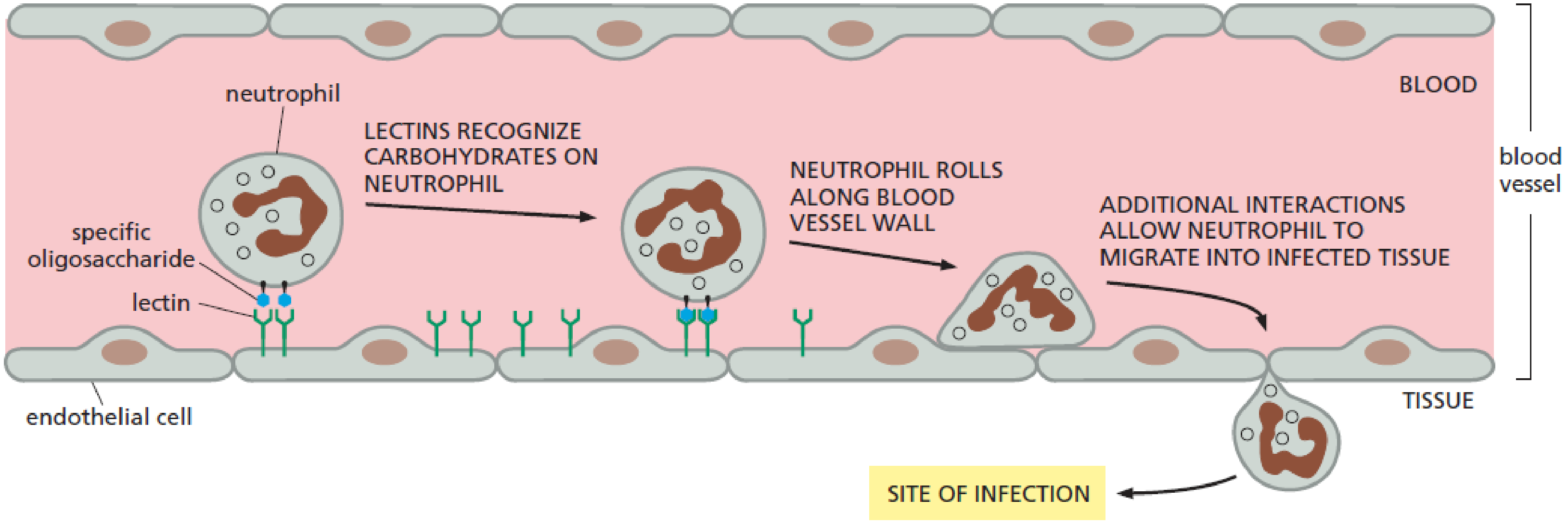
Carbohydrate on the glycoproteins, proteoglycans, and glycolipids is located on the outside of the plasma membrane, where it forms a sugar coating called the carbohydrate layer or glycocalyx.



- Helps protect the cell surface from mechanical damage.
- As the oligosaccharides and polysaccharides adsorb water, they also give the cell a slimy surface, which helps motile cells such as white blood cells squeeze through narrow spaces and prevents blood cells from sticking to one another or to the walls of blood vessels.
- They have an important role in cell–cell recognition and adhesion.

Cell surface is coated with carbohydrate

Proteins called lectins are specialized to bind to particular oligosaccharide side chains. The oligosaccharide side chains of glycoproteins and glycolipids, although short (typically fewer than 15 sugar units), are enormously diverse.



Another example - Recognition of an egg by a sperm