Membrane Structure and Function

I. Membrane Structure
   A. Phospholipids and most other membrane constituents are **amphipathic molecules.** That is, they have both hydrophobic regions and hydrophilic regions.
   B. The arrangement of phospholipids and proteins in biological membranes is described by the **fluid mosaic model.**
   C. In this model, the hydrophilic regions of proteins and phospholipids are in maximum contact with water, and the hydrophobic regions are in a nonaqueous environment within the membrane.

II. Membranes are fluid.
   A. Membrane molecules are held in place by relatively weak hydrophobic interactions.
   B. Most of the lipids and some proteins drift laterally in the plane of the membrane, but rarely flip-flop from one phospholipid layer to the other. The lateral movements of phospholipids are rapid, about 2 microns per second. A phospholipid can travel the length of a typical bacterial cell in 1 second.
   C. Many larger membrane proteins drift within the phospholipid bilayer, although they move more slowly than the phospholipids. Some proteins never move and are anchored to the cytoskeleton.
   D. Membrane fluidity is influenced by temperature. As temperatures cool, membranes switch from a fluid state to a solid state as the phospholipids pack more closely.
   E. Membrane fluidity is also influenced by its components. Membranes rich in unsaturated fatty acids are more fluid that those dominated by saturated fatty acids because the kinks in the unsaturated fatty acid tails at the locations of the double bonds prevent tight packing. The steroid cholesterol is wedged between phospholipid molecules in the plasma membrane of animal cells. At warm temperatures (such as 37°C), cholesterol restrains the movement of phospholipids and reduces fluidity. At cool temperatures, it maintains fluidity by preventing tight packing. Thus, cholesterol acts as a “temperature buffer” for the membrane, resisting changes in membrane fluidity as temperature changes.
   F. To work properly with active enzymes and appropriate permeability, membranes must be about as fluid as salad oil.
   G. Cells can alter the lipid composition of membranes to compensate for changes in fluidity caused by changing temperatures. For example, cold-adapted organisms such as winter wheat increase the percentage of unsaturated phospholipids in their membranes in the autumn. This prevents membranes from solidifying during winter.

III. Membranes are mosaics of structure and function.
   A. A membrane is a collage of different proteins embedded in the fluid matrix of the lipid bilayer. These proteins determine most of the membrane’s specific functions.
   B. There are two major populations of membrane proteins.
      1. **Peripheral proteins** are not embedded in the lipid bilayer at all. Instead, they are loosely bound to the surface of the protein, often connected to integral proteins.
      2. **Integral proteins** penetrate the hydrophobic core of the lipid bilayer, often completely spanning the membrane (as *transmembrane* proteins). The hydrophobic regions embedded in the membrane’s core consist of stretches of nonpolar amino acids, often coiled into alpha helices. Where integral proteins are in contact with the aqueous environment, they have hydrophilic regions of amino acids.
      3. On the cytoplasmic side of the membrane, some membrane proteins connect to the cytoskeleton.
      4. On the exterior side of the membrane, some membrane proteins attach to the fibers of the extracellular matrix.

5. The proteins of the plasma membrane have six major functions:
    a. Transport of specific solutes into or out of cells.
    b. Enzymatic activity, sometimes catalyzing one of a number of steps of a metabolic pathway.
    c. Signal transduction, relaying hormonal messages to the cell.
    d. Cell-cell recognition, allowing other proteins to attach two adjacent cells together.
    e. Intercellular joining of adjacent cells with gap or tight junctions.
    f. **Attachment to the cytoskeleton and extracellular matrix,** maintaining cell shape and stabilizing the location of certain membrane proteins.

IV. Membrane carbohydrates are important for cell-cell recognition.

A. Cell-cell recognition, the ability of a cell to distinguish one type of neighboring cell from another, is crucial to the functioning of an organism. It is important in the sorting and organization of cells into tissues and organs during development and is the basis for rejection of foreign cells by the immune system.

B. Cells recognize other cells by binding to surface molecules, often carbohydrates, on the plasma membrane. Membrane carbohydrates are usually branched oligosaccharides with fewer than 15 sugar units. They may be covalently bonded to lipids, forming glycolipids, or more commonly to proteins, forming glycoproteins.

C. The oligosaccharides on the external side of the plasma membrane vary from species to species, from individual to individual, and even from cell type to cell type within the same individual. This variation distinguishes each cell type.

V. Membranes have distinctive inside and outside faces.

A. The two layers may differ in lipid composition. Each protein in the membrane has a directional orientation in the membrane.

B. The asymmetrical orientation of proteins, lipids and associated carbohydrates begins during the synthesis of membrane in the ER and Golgi apparatus.

C. Membrane lipids and proteins are synthesized in the endoplasmic reticulum. Carbohydrates are added to proteins in the ER, and the resulting glycoproteins are further modified in the Golgi apparatus. Glycolipids are also produced in the Golgi apparatus.

D. When a vesicle fuses with the plasma membrane, the outside layer of the vesicle becomes continuous with the inside layer of the plasma membrane. In that way, molecules that originate on the inside face of the ER end up on the outside face of the plasma membrane.

VI. Traffic across Membranes

A. A membrane's molecular organization results in selective permeability and a steady traffic of small molecules and ions moves across the plasma membrane in both directions.

B. Substances do not move across the barrier indiscriminately; membranes are selectively permeable. The plasma membrane allows the cell to take up many varieties of small molecules and ions and exclude others. Substances that move through the membrane do so at different rates.

C. Movement of a molecule through a membrane depends on the interaction of the molecule with the hydrophobic core of the membrane. Hydrophobic molecules, such as hydrocarbons, CO_2, and O_2, can dissolve in the lipid bilayer and cross easily.

D. The hydrophobic core of the membrane impedes the direct passage of ions and polar molecules, which cross the membrane with difficulty. This includes small molecules, such as water, and larger molecules, such as glucose and other sugars. An ion, whether a charged atom or molecule, and its surrounding shell of water also has difficulty penetrating the hydrophobic core.

E. Specific ions and polar molecules can cross the lipid bilayer by passing through **transport proteins** that span the membrane.

F. Some transport proteins, called **channel proteins**, have a hydrophilic channel that certain molecules or ions can use as a tunnel through the membrane. For example, the passage of water through the membrane can be greatly facilitated by channel proteins known as **aquaporins.**

G. Other transport proteins, called **carrier proteins**, bind to molecules and change shape to shuttle them across the membrane.

H. Each transport protein is specific as to the substances that it will translocate.

VII. Passive transport is diffusion across a membrane with no energy expenditure.

A. **Diffusion** is the tendency of molecules of any substance to spread out in the available space.

1. In the absence of other forces, a substance will diffuse from where it is more concentrated to where it is less concentrated, down its **concentration gradient.** This movement continues until equilibrium is reached, at which time there is no further net movement. Each substance diffuses down its *own* concentration gradient, independent of the concentration gradients of other substances.
2. Diffusion is a spontaneous process that decreases free energy and increases entropy by creating a randomized mixture.
3. The diffusion of a substance across a biological membrane is **passive transport** because it requires no energy from the cell to make it happen.

B. Osmosis is the diffusion of water across a selectively permeable membrane.

1. Differences in the relative concentration of dissolved materials in two solutions can lead to the movement of ions from one to the other.

a. The solution with the higher concentration of solutes is **hypertonic** relative to the other solution.

b. The solution with the lower concentration of solutes is **hypotonic** relative to the other solution.

c. Solutions with equal solute concentrations are **isotonic.**solutions are isotonic.

C. Specific proteins facilitate passive transport of water and selected solutes.

1. Many polar molecules and ions that are normally impeded by the lipid bilayer of the membrane diffuse passively with the help of transport proteins that span the membrane.
2. The passive movement of molecules down their concentration gradient via transport proteins is called **facilitated diffusion.**

VIII. Some transport proteins can move solutes across membranes against their concentration gradient, from the side where they are less concentrated to the side where they are more concentrated. This **active transport** requires the cell to expend metabolic energy.

A. Active transport enables a cell to maintain its internal concentrations of small molecules that would otherwise diffuse across the membrane.

B. Active transport is performed by specific proteins embedded in the membranes.

C. ATP supplies the energy for most active transport.

D. ATP can power active transport by transferring a phosphate group from ATP (forming ADP) to the transport protein. This may induce a conformational change in the transport protein, translocating the solute across the membrane.

IX. In cotransport, a membrane protein couples the transport of two solutes.

A. A single ATP-powered pump that transports one solute can indirectly drive the active transport of several other solutes in a mechanism called **cotransport.**

B. As the solute that has been actively transported diffuses back passively through a transport protein, its movement can be coupled with the active transport of another substance against its concentration gradient.

C. Plants commonly use the gradient of hydrogen ions generated by proton pumps to drive the active transport of amino acids, sugars, and other nutrients into the cell.

X. Exocytosis and endocytosis transport large molecules across membranes.

A. Small molecules and water enter or leave the cell through the lipid bilayer or by transport proteins. Large molecules, such as polysaccharides and proteins, cross the membrane via vesicles.

B. During **exocytosis,** a transport vesicle budded from the Golgi apparatus is moved by the cytoskeleton to the plasma membrane. When the two membranes come in contact, the bilayers fuse and spill the contents to the outside. Many secretory cells use exocytosis to export their products.

C. During **endocytosis,** a cell brings in macromolecules and particulate matter by forming new vesicles from the plasma membrane. Endocytosis is a reversal of exocytosis, although different proteins are involved in the two processes.

1. A small area of the plasma membrane sinks inward to form a pocket.
2. As the pocket deepens, it pinches in to form a vesicle containing the material that had been outside the cell.
3. There are three types of endocytosis: phagocytosis ("cellular eating"), pinocytosis ("cellular drinking"), and receptor-mediated endocytosis.

a. In **phagocytosis,** the cell engulfs a particle by extending pseudopodia around it and packaging it in a large vacuole. The contents of the vacuole are digested when the vacuole fuses with a lysosome.

b. In **pinocytosis,** a cell creates a vesicle around a droplet of extracellular fluid. All included solutes are taken into the cell in this nonspecific process.

c. **Receptor-mediated endocytosis** allows greater specificity, transporting only certain substances.

(1) This process is triggered when extracellular substances, or **ligands,** bind to special receptors on the membrane surface. The receptor proteins are clustered in regions of the membrane called coated pits, which are lined on their cytoplasmic side by a layer of coat proteins.

(2) Binding of ligands to receptors triggers the formation of a vesicle by the coated pit, bringing the bound substances into the cell.