Lecture 4 - Membranes

Plasma Membrane

The plasma membrane surrounds the cell and functions as an interface between the living interior of the cell and the nonliving exterior.

All cells have one.

It regulates the movement of molecules into and out of the cell.

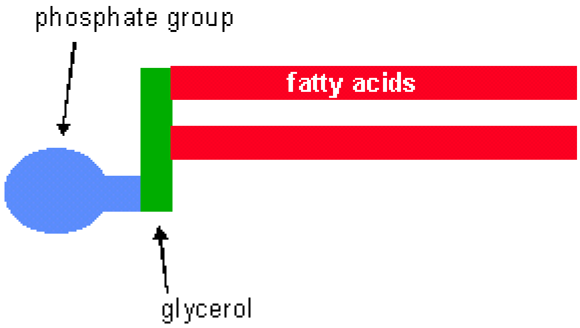
Membrane Structure

The **fluid-mosaic model** states that membranes are phospholipid bilayers with protein molecules embedded in the bilayer.

Phospholipids

Most of the lipids in a membrane are phospholipids.

Phospholipids contain glycerol, two fatty acids, and a phosphate group. The phosphate group is polar (***hydrophilic***), enabling it to interact with water. The fatty acid tails are nonpolar (***hydrophobic***) and do not interact with water.

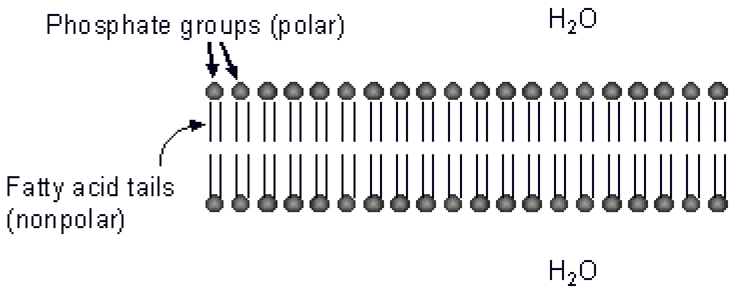


Phospholipid Bilayers

Phospholipids spontaneously form a bilayer in a watery environment. They arrange themselves so that the polar heads are oriented toward the water and the fatty acid tails are oriented toward the inside of the bilayer (see the diagram below).

In general, nonpolar molecules do not interact with polar molecules. This can be seen when oil (nonpolar) is mixed with water (polar). Polar molecules interact with other polar molecules and ions. For example table salt (ionic) dissolves in water (polar).

The bilayer arrangement shown below enables the nonpolar fatty acid tails to remain together, avoiding the water. The polar phosphate groups are oriented toward the water.



Flexibility

The fatty acid tails are flexible, causing the lipid bilayer to be fluid. This makes the cells flexible. At body temperature, membranes are a liquid with a consistency that is similar to cooking oil.

Cholesterol

In animals, cholesterol is a major membrane lipid. It may be equal in amount to phospholipids.

It is similar to phospholipids in that it one end is hydrophilic, the other end is hydrophobic.

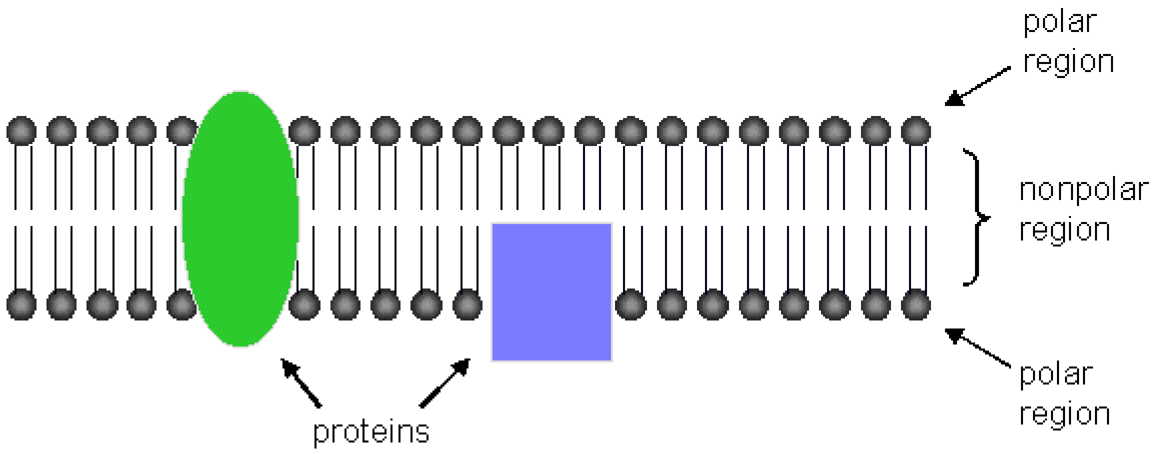
Cholesterol makes the membrane less permeable to most biological molecules.

Proteins Embedded in the Membrane

Proteins are scattered throughout the membrane.

They may be attached to inner surface, embedded in the bilayer, or attached to the outer surface.

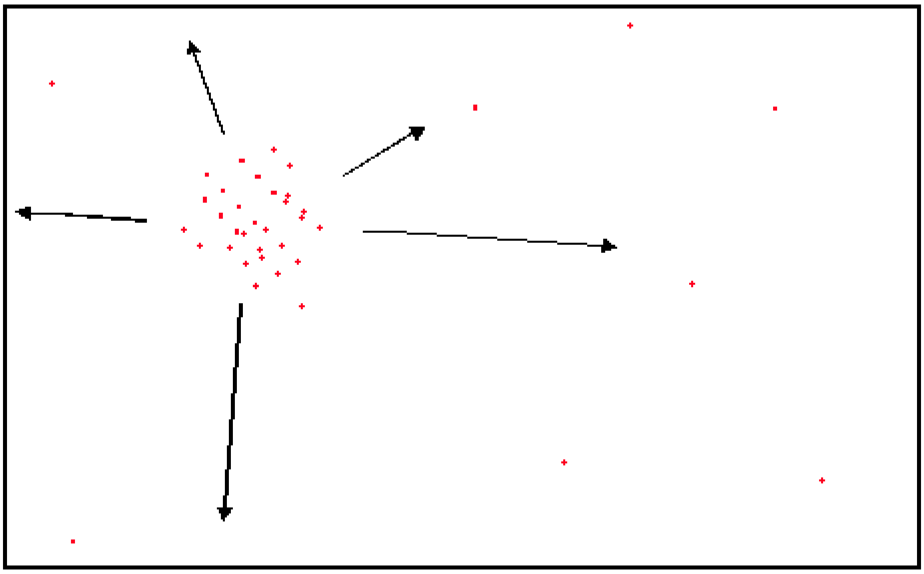
Hydrophilic (polar) regions of the protein project from the inner or outer surface. Hydrophobic (nonpolar) regions are embedded within the membrane.



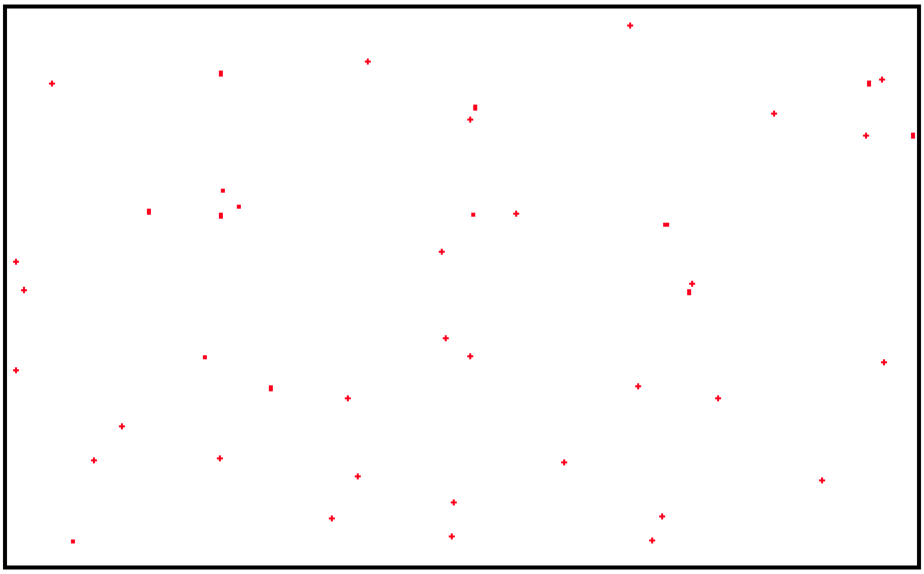
Membrane proteins are capable of lateral movement.

Diffusion

Diffusion is the movement of particles from an area of higher concentration to an area of lower concentration. The movement is due to collisions, which occur more frequently in areas of higher concentration.



The dots on the diagram above represent molecules or ions. After a period of time, the particles becoming dispersed (below). Overall, the movement is from the area of initial high concentration to areas that have a lower concentration.



Membranes are Differentially Permeable

The plasma membrane is differentially permeable because some particles can pass through, others cannot. It can control the extent to which certain substances pass through.

Nonpolar molecules pass through cell membranes more readily than polar molecules because the center of the lipid bilayer (the fatty acid tails) is nonpolar and does not readily interact with polar molecules.

The following substances can pass through the cell membrane:

Nonpolar molecules (example: lipids)

Small polar molecules such as water

The following substances cannot pass through the cell membrane:

Ions and charged molecules (example: salts dissolved in water)

Large polar molecules (example: glucose)

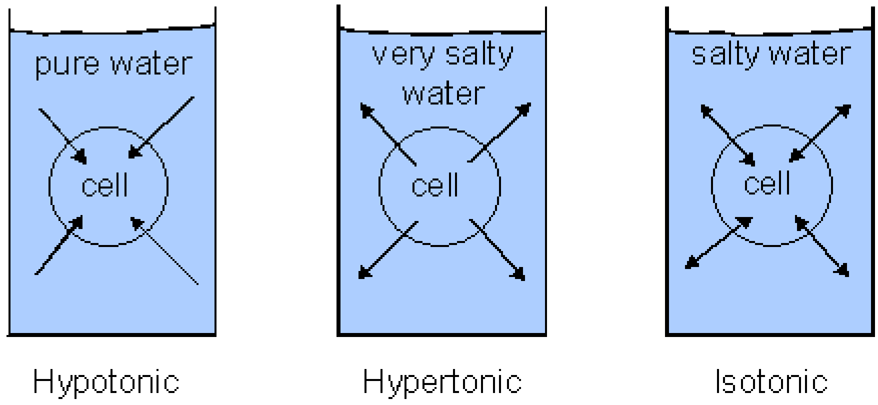
Macromolecules

Osmosis

Osmosis is the diffusion of water across a differentially permeable membrane (see "Diffusion" above).

It occurs when a solute (example: salt, sugar, protein, etc.) cannot pass through a membrane but the solvent (water) can. Water always moves from where it is most concentrated (has less solute) to where it is less concentrated.

In general, water moves toward the area with a higher solute concentration because it has a lower water concentration.



In the container on the left side of the diagram, water will enter the cell because it is more concentrated on the outside. In the center drawing, water is more concentrated inside the cell, so it will move out. If the solute concentration is the same inside as it is out, the amount of water that moves out will be approximately to the amount that moves in.

Osmotic pressure is the force of osmosis. In the diagram above, the cell on the left will swell. The pressure within the cell is osmotic pressure.

Tonicity

Tonicity refers to the relative concentration of solute on either side of a membrane.

Isotonic

In an isotonic solution, the concentration of solute is the same on both sides of the membrane (inside the cell and outside). A cell placed in an isotonic solution neither gains or loses water. Most cells in the body are in an isotonic solution.

Hypotonic

A hypotonic solution is one that has less solute (more water). Cells in hypotonic solution tend to gain water.

Animal cells can ***lyse*** (rupture) in a hypotonic solution due to the osmotic pressure.

Freshwater organisms live in a hypotonic solution and have a tendency to gain water. The contractile vacuole in freshwater protozoans removes water that enters the cell.

The cell wall of plant cells prevents the cell from rupturing. The osmotic pressure, called ***turgor pressure***, helps support the cell. A cell in which the contents are under pressure is ***turgid***.

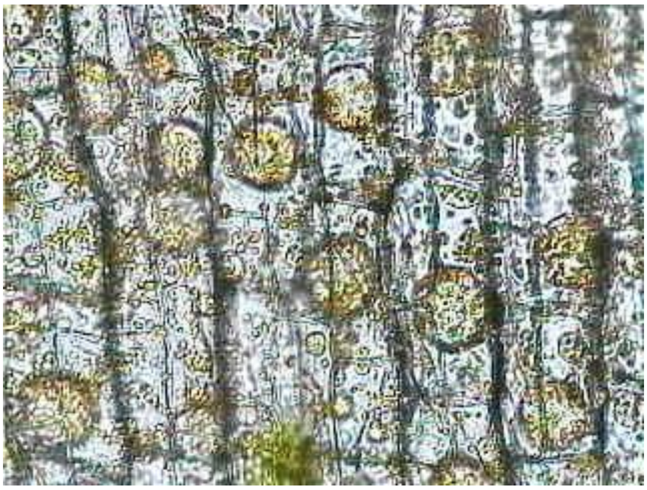
Hypertonic solution

A hypertonic solution is one that has a high solute concentration. Cells in a hypertonic solution will lose water.

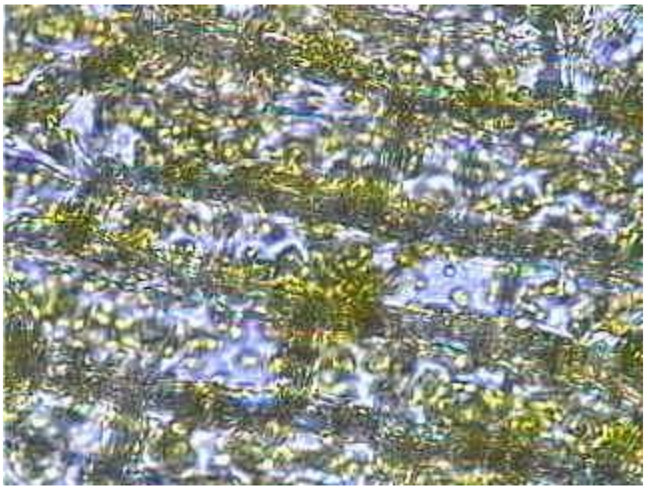
The marine environment is a hypertonic solution for many organisms. They often have mechanisms to prevent dehydration or to replace lost water.

Animal cells placed in a hypertonic solution will undergo crenation, a condition where the cell shrivels up as it loses water.

Plant cells placed in a hypertonic solution will undergo ***plasmolysis***, a condition where the plasma membrane pulls away from the cell wall as the cell shrinks. The cell wall is rigid and does not shrink.



Left: The *Elodea* cells below (X 200) have been placed in a 10% NaCl solution. The contents of the cells have been reduced to the spherical structures shown. Compare these cells to normal cells in the second photograph.

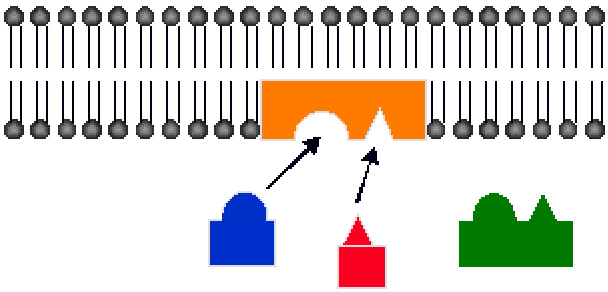


Left: Normal *Elodea* cells X 400

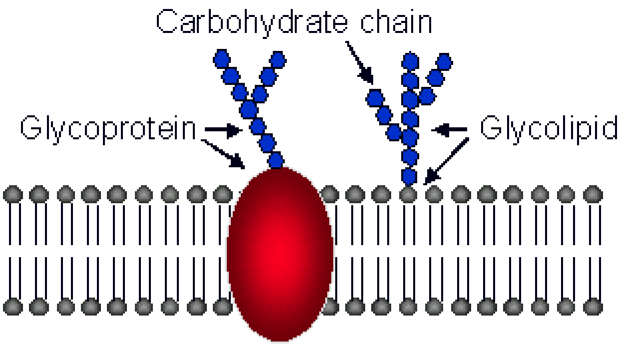
Functions of Membrane Proteins

Enzymes

Some enzymes are embedded within membranes.



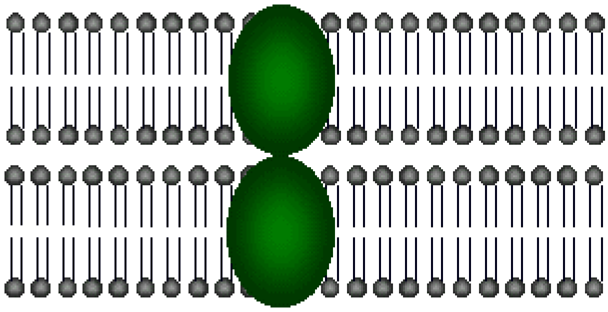
Cell Identification Markers



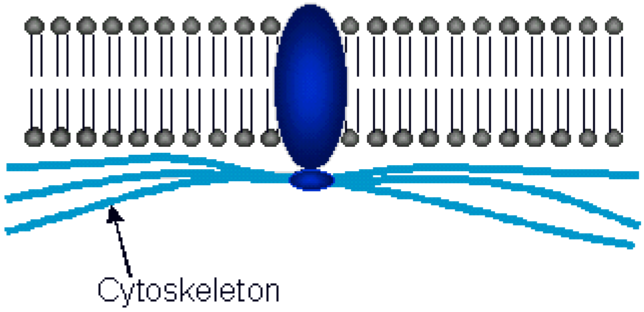
Lipids and proteins within the membrane may have a carbohydrate chain attached. These glycolipids and glycoproteins often function as cell identification markers, allowing cells to identify other cells. This is particularly important in the immune system where cells patrolling the body's tissues identify and destroy foreign invaders such as bacteria or viruses.

Cell Adhesion - Junctions

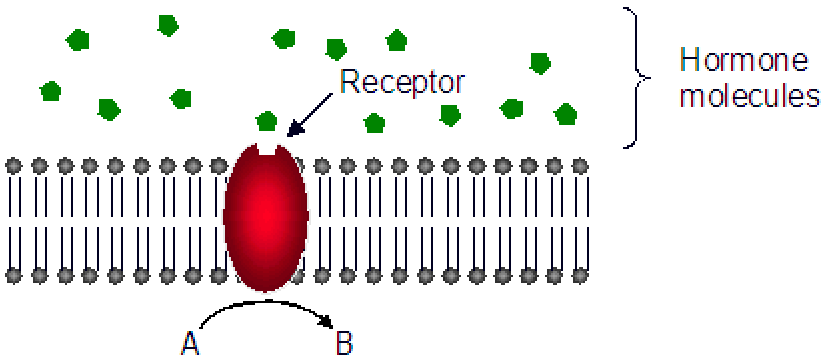
Proteins associated with the cell membranes of animal cells may bind to proteins of adjacent cells. These connections, called junctions may serve to bind cells together, to prevent the movement of material between the cells, or to allow cells to communicate with each other.



Attachment of the Cytoskeleton



Receptors



Receptors enable cells to detect hormones and a variety of other chemicals in their environment. The binding of a molecule and a receptor initiates a chemical change within the cell. In the diagram above, the binding of hormone and receptor initiates the conversion of chemical A to chemical B.

Hormones are molecules that cells use to communicate with one another. For example, cells in the pancreas produce the hormone insulin when glucose levels in the blood become elevated. The hormone travels within the blood to other parts of the body. It stimulates liver and muscle cells to begin removing the glucose and storing it as glycogen.

Vesicle Trafficking

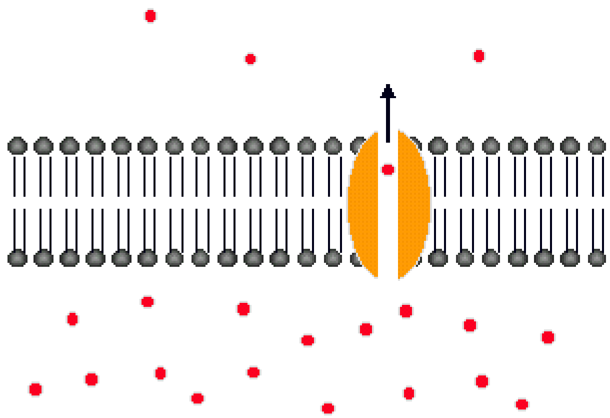
Vesicles may follow microtubules to their destination.

Proteins within the membrane of the vesicle recognize and attach to proteins in other membranes. This allows vesicles to attach to the membranes of other organelles such as the endoplasmic reticulum, golgi apparatus, or lysosomes.

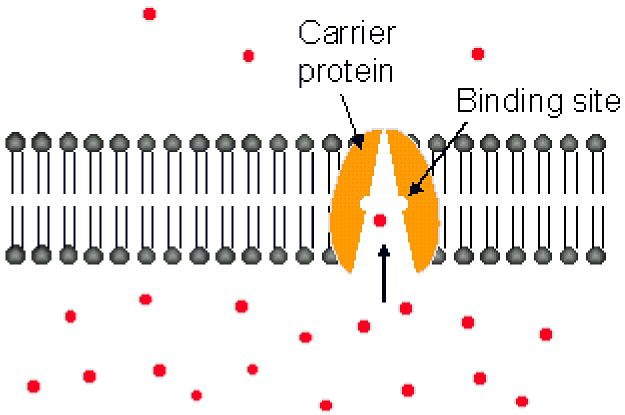
Transport of Materials Across Cell Membranes

Facilitated Diffusion

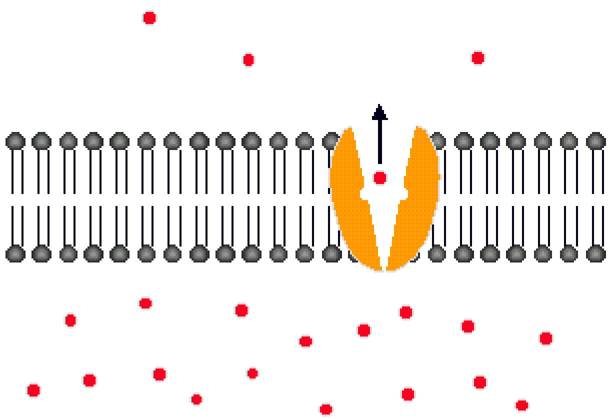
Facilitated diffusion involves the use of a protein to facilitate the movement of molecules across the membrane. In some cases, molecules pass through channels within the protein.



In other cases, the protein changes shape, allowing molecules to pass through.



As can be seen below, the protein changes shape and releases the molecule to the side of the membrane that has the lower concentration.



Additional energy is not required because the molecule is traveling down a concentration gradient (high concentration to low concentration). The energy of movement comes from the concentration gradient.

Active Transport

Active transport is used to move ions or molecules ***against*** a concentration gradient (low concentration to high concentration).

Active transport is like a water pump; it uses energy to pump water uphill where a siphon cannot. Facilitated diffusion (see above) is like a siphon in that additional energy is not required but it can only allow movement downhill.

Movement against a concentration gradient requires energy. The energy is supplied by ATP which is released by breaking a phosphate bond to produce ADP:

$ATP \rightarrow ADP + P_i + \text{energy}$

Cells that use a lot of active transport have many mitochondria to produce the ATP needed.

The Sodium-Potassium Pump

The sodium-potassium pump uses active transport to move 3 sodium ions to the outside of the cell for each 2 potassium ions that it moves in.

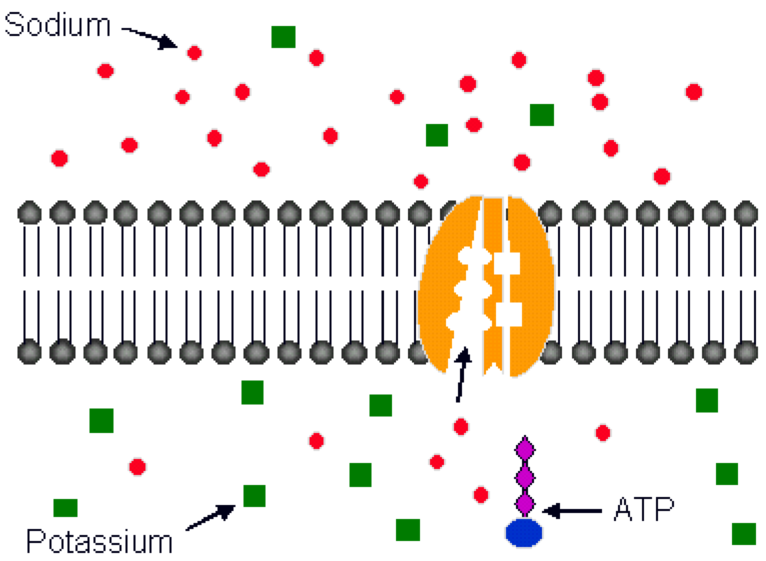
It is found in all human cells, especially nerve and muscle cells.

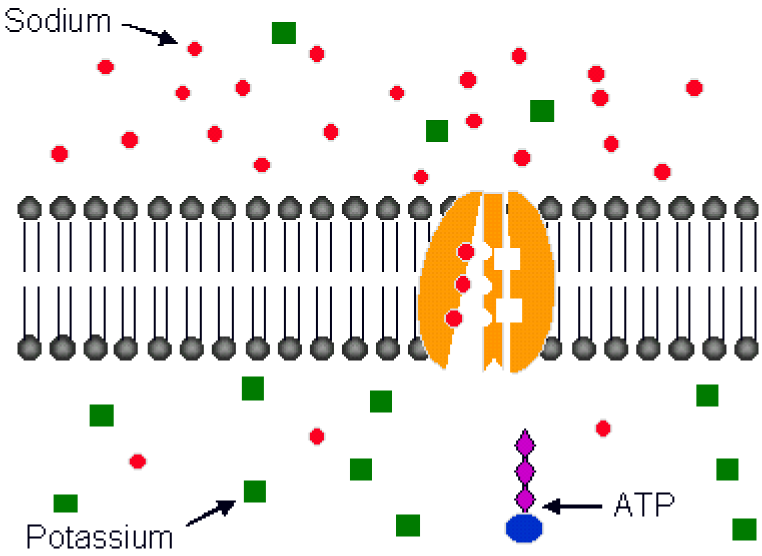
One third of the body's energy expenditure is used to operate the sodium-potassium pump.

Mechanism of operation of the Sodium-Potassium Pump

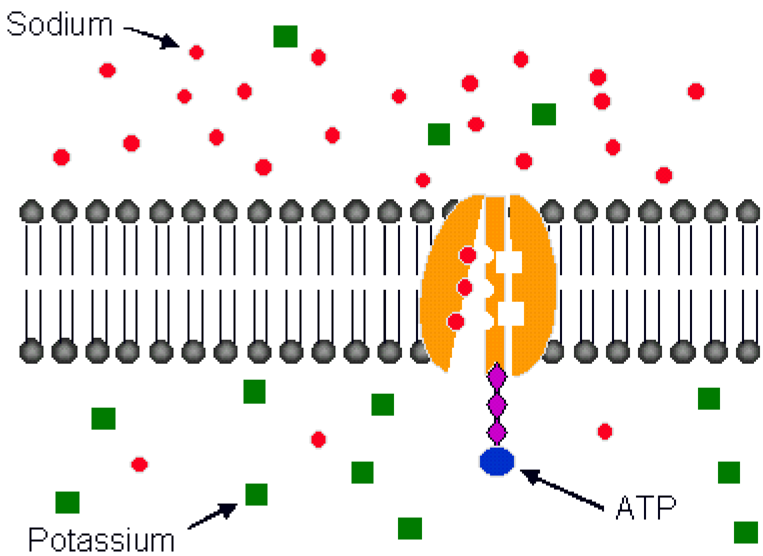
The diagrams below illustrate the mechanism of operation of the sodium-potassium pump. In these diagrams, orange is used to represent the pump protein. Circles are used to represent sodium ions and squares are used to represent potassium ions. Notice that the pump has three sodium binding sites and two potassium binding sites.

Three sodium ions enter the pump.

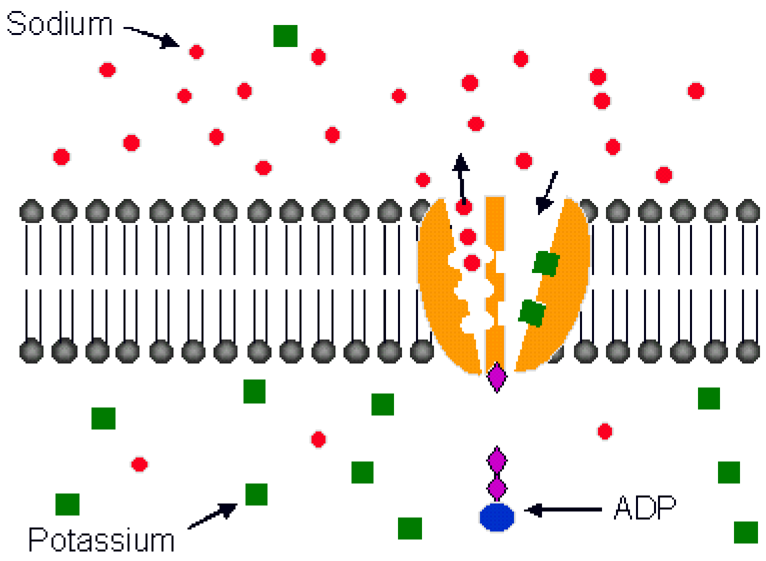




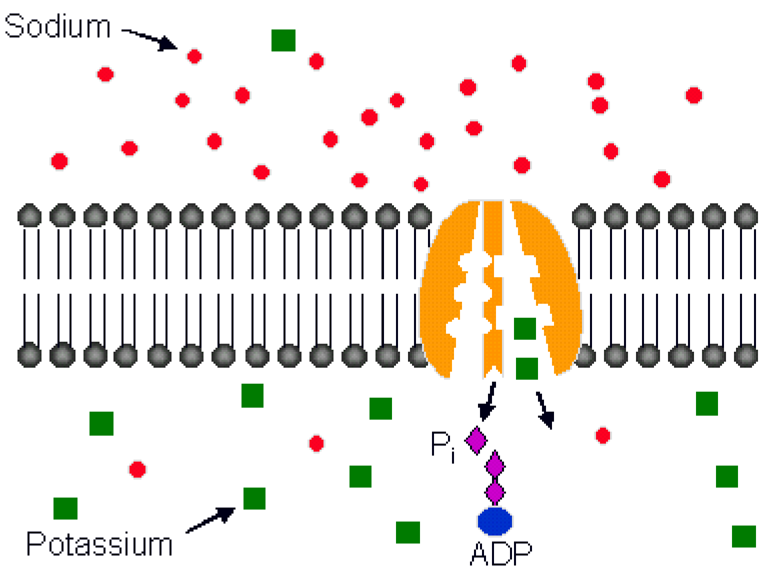
ATP bonds to the pump.



One phosphate bond in the ATP molecule breaks, releasing its energy to the pump protein. The pump protein changes shape, releasing the sodium ions to the outside. The two potassium binding sites are also exposed to the outside, allowing two potassium ions to enter the pump.



When the phosphate group detaches from the pump, the pump returns to its original shape. The two potassium ions leave and three sodium ions enter. The cycle then repeats itself.



Examples of Active Transport

Plants move minerals (inorganic ions) into their roots by active transport.

The gills of marine fish have cells that can remove salt from the body by pumping it into the salt water.

The thyroid gland cells bring in iodine for use in producing hormones.

Cells in the vertebrate kidney reabsorb sodium ions from urine.

Endocytosis and Exocytosis

These processes are used for materials that are too big to pass through the plasma membrane via protein transport.

Endocytosis

The process by which a cell engulfs material to bring it into the cell is called endocytosis. Two major forms of endocytosis described below.

Phagocytosis

Phagocytosis refers to the process of engulfing large particles.

A vacuole is formed that contains the material that has been engulfed.

Pinocytosis

Pinocytosis refers to engulfing macromolecules.

As in phagocytosis, a vesicle is formed which contains the molecules that were brought into the cell.

Vacuoles and vesicles produced by phagocytosis and pinocytosis can fuse with lysosomes (lysosomes are vesicles that contain digestive enzymes).

Phagocytosis and pinocytosis remove membrane from cell surface to form vacuoles that contain the engulfed material.

Receptor-Mediated endocytosis

Macromolecules bind to receptors on the surface of the cell.

Receptors with bound macromolecules aggregate in one area and are brought into the cell by endocytosis.

The vesicle containing the macromolecules can release the macromolecules into the cell directly or they can be processed by chemicals contained within lysosomes after fusing with the lysosomes.

The vesicle (and receptors) then returns to the cell surface.

Exocytosis

Exocytosis moves material to the outside. A vesicle fuses with the plasma membrane and discharges its contents outside. This allows cells to secrete molecules.

The fusion of vesicles to the plasma membrane adds membrane to the cell surface.