Johns Hopkins Engineering

Molecular Biology

Transport Across Membranes: Overcoming the Permeability Barrier

Part 1

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Module 6 / Lecture 1

JOHNS HOPKINS WHITING SCHOOL of ENGINEERING

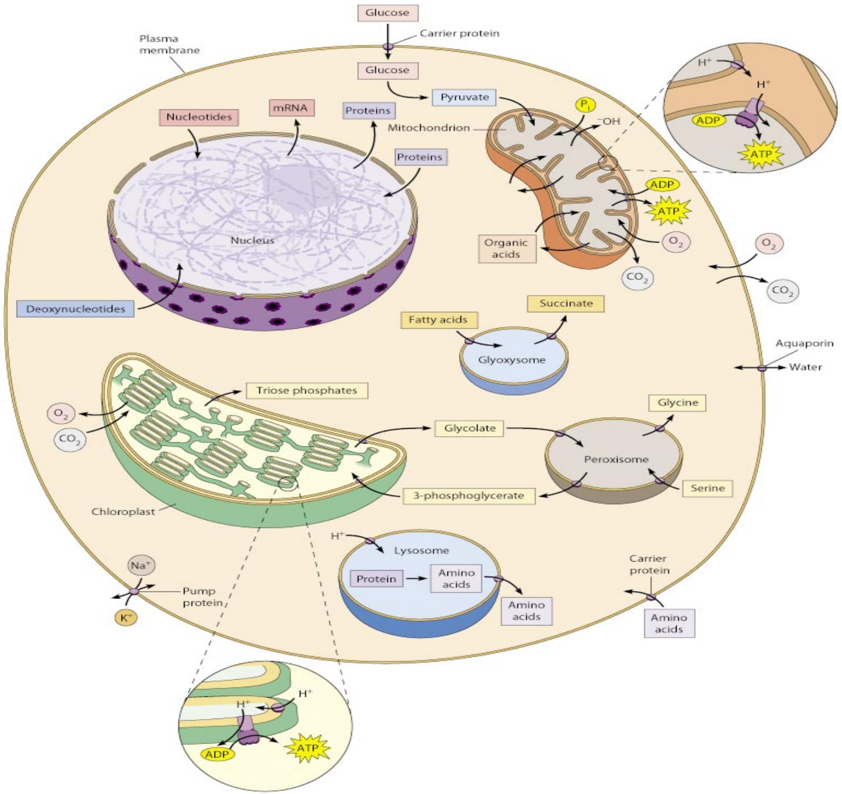
Cell transport

Cell Transport is the ability to move ions and organic molecules across membranes selectively.

The importance of membrane ~ 20% of the genes identified in the bacterium *Escherichia* coli are involved in some aspect of cell transport.

Figure 8-1 illustrates some of the many transport processes that occur within eukaryotic cells.

Transport processes within a composite cell



Transport Processes Within a Composite Eukaryotic Cell

The molecules and ions shown in this composite plant/animal cell are some of the many kinds of solutes that are transported across the membranes of eukaryotic cells.

Figure 8-1

Cells and transport processes

Every cell and subcellular compartment has the ability to accumulate a variety of substances at concentrations that are often strikingly different from those in the surrounding area.

Some of these substances are **proteins** and other **macromolecules**, which are moved into and out of cells and organelles.

Most substances that move across membranes are not **macromolecules** or **fluids**, but **dissolved ions** and **small organic molecules-solutes**.

These solutes cross membranes by a single file, one ion or molecule at a time.

Common ions transported across membranes include: **sodium, potassium, calcium, chloride, and hydrogen**.

Most of the small organic molecules are **metabolites-substrates, intermediates, and products** in the various metabolic pathways that take place within cells or specific organelles: **sugars, amino acids, and nucleotides**.

For most solutes, the concentration inside the cell or organelle is markedly higher than outside.

Very few cellular reactions or processes could occur at reasonable rates if they had to depend on *the concentrations* at which essential substrates are present in the cell's surroundings.

Solutes cross membranes by simple diffusion, facilitated diffusion, and active transport

More than **two-thirds of the energy your body expends in the resting state** is used to maintain gradients of ions such as H^{+}, K^{+}, Na^{+}, and Ca^{2+} across the membranes of your cells.

Because ions have an electrical charge, the transport process and resulting concentration gradient can produce an electrical voltage, or ***membrane potential,*** across the membrane.

The combined **concentration gradient** and associated **membrane potential** are referred to as an ***electrochemical gradient***.

The stored energy of gradients is used to drive a variety of processes, including uptake of other solutes and the synthesis of ATP during the processes of cellular respiration and photosynthesis.

In nerve cells, gradients of K^{+} and Na^{+} ions are responsible for the transmission of nerve impulses.

Simple diffusion

(a) Simple diffusion. Oxygen and carbon dioxide diffuse directly across the plasma membrane in response to their relative concentrations inside and outside the cell.

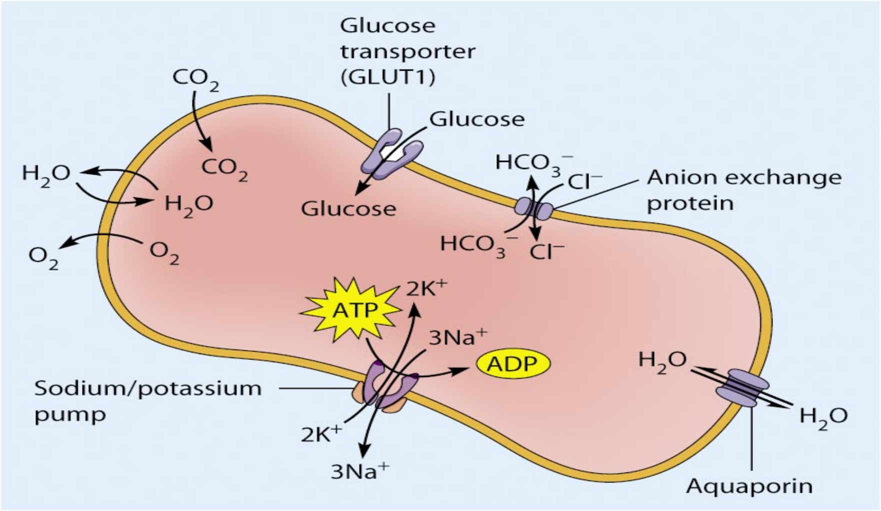


Figure 8-2a

Simple diffusion: unassisted movement down the gradient

Most straightforward way for a solute to get from one side of a membrane to the other is **simple diffusion,** which is the unassisted net movement of a solute from a region where its concentration is higher to a region where its concentration is lower (Figure 8-2a).

Because of the **hydrophobic** interior of the membrane, **simple diffusion** is a relevant means of transport only for **small, relatively nonpolar molecules**.

Facilitated diffusion mediated by carrier protein

(b) Facilitated diffusion mediated by carrier proteins. The movement of glucose across the plasma membrane is facilitated by a specific glucose transporter called GLUT1. An anion exchange protein facilitates the reciprocal transport of chloride (Cl^-) and bicarbonate (HCO_3^-).

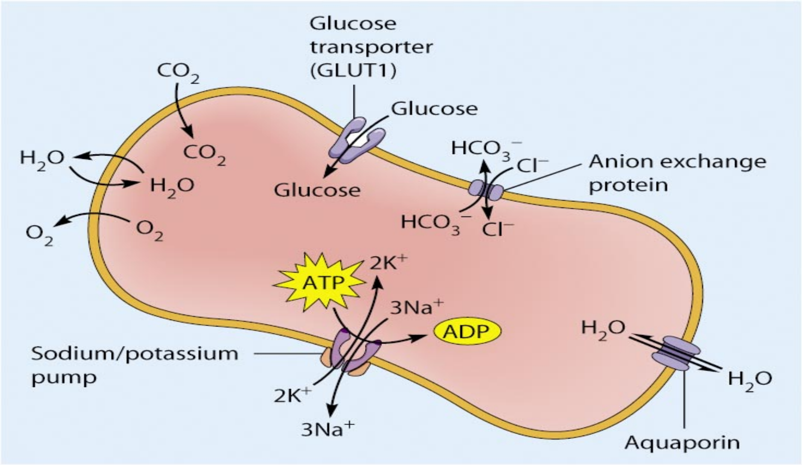
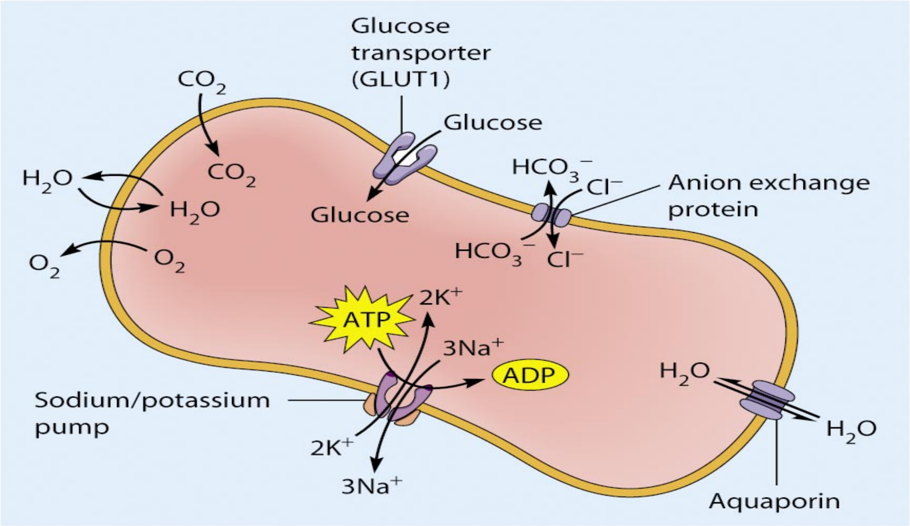


Figure 8-2b

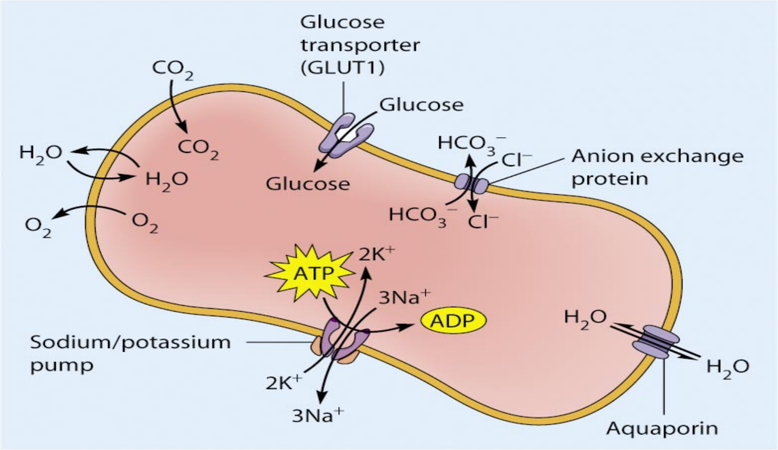
Facilitated diffusion mediated by channel protein



(c) Facilitated diffusion mediated by channel proteins. Aquaporin channel proteins can facilitate the rapid inward or outward movement of water molecules.

Figure 8-2c

Active transport



(d) Active transport. Driven by the hydrolysis of ATP, the Na^+/K^+ pump moves three sodium ions outward for every two potassium ions moved inward, establishing an electrochemical potential across the plasma membrane for both ions.

Figure 8-2d

Simple diffusion: unassisted movement down a gradient

Oxygen is example of a molecule that moves across membranes by simple diffusion.

Oxygen enables erythrocytes in the circulatory system to take up oxygen in the lungs and release it again in body tissues.

In capillaries of body tissues, where oxygen concentration is low, oxygen is released from hemoglobin and diffuses passively from the cytoplasm of the erythrocyte into the blood plasma and from there into the cells that line the capillaries (**Figure 8-3a**).

In the capillaries of lungs, the opposite occurs: oxygen diffuses from the inhaled air in the lungs, where its concentration is higher, into the cytoplasm of the erythrocytes, where its concentration is lower.

Carbon dioxide is also able to cross membranes by simple diffusion; however, most CO_2 is actually transported in the form of bicarbonate ion (HCO_3^-).

Carbon dioxide and oxygen move across the erythrocyte (red blood cell) membrane in opposite directions, with carbon dioxide diffusing inward in body tissues and outward in the lungs.

Capillary action of body tissue

(a) In the capillaries of body tissues (low [O_2] and high [CO_2] relative to the erythrocytes), O_2 is released by hemoglobin within the erythrocytes and diffuses outward to meet tissue needs. CO_2 diffuses inward and is converted to bicarbonate by carbonic anhydrase in the cytosol. Bicarbonate ions are transported outward by the anion exchange protein, accompanied by the inward movement of chloride ions to maintain charge balance. Carbon dioxide therefore returns to the lungs as bicarbonate ions.

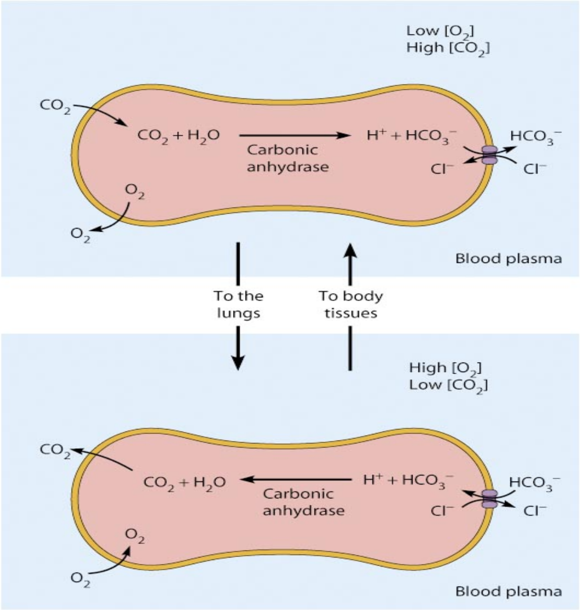
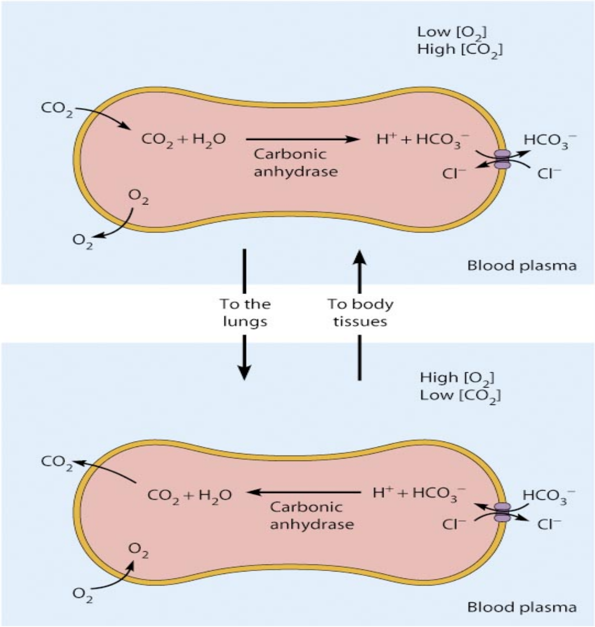


Figure 8-3a

Cells and transport processes



(b) In the capillaries of the lungs (high [O_2] and low [CO_2] relative to the erythrocytes), O_2 diffuses inward and binds to hemoglobin. Bicarbonate moves inward from the blood plasma, accompanied by an outward movement of chloride ions. Incoming bicarbonate is converted into CO_2, which diffuses out of the erythrocytes and into the cells lining the capillaries of the lungs. The CO_2 is now ready to be expelled from the body.

Figure 8-3b

Summary of capillary action of body tissue

(a) In the capillaries of body tissues (low [O_2] and high [CO_2] relative to the erythrocytes), O_2 is released by hemoglobin within the erythrocytes and diffuses outward to meet tissue needs. CO_2 diffuses inward and is converted to bicarbonate by carbonic anhydrase in the cytosol. Bicarbonate ions are transported outward by the anion exchange protein, accompanied by the inward movement of chloride ions to maintain charge balance. Carbon dioxide therefore returns to the lungs as bicarbonate ions.

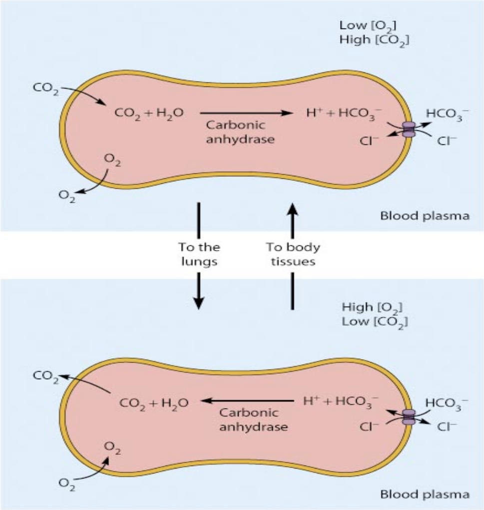


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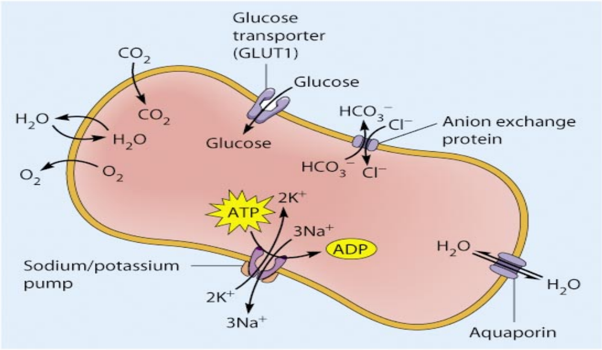
Figure 8-3

Summary of cell transport processes

(a) Simple diffusion. Oxygen and carbon dioxide diffuse directly across the plasma membrane in response to their relative concentrations inside and outside the cell.

(b) Facilitated diffusion mediated by carrier proteins. The movement of glucose across the plasma membrane is facilitated by a specific glucose transporter called GLUT1. An anion exchange protein facilitates the reciprocal transport of chloride (Cl^-) and bicarbonate (HCO_3^-).



(d) Active transport. Driven by the hydrolysis of ATP, the Na^+/K^+ pump moves three sodium ions outward for every two potassium ions moved inward, establishing an electrochemical potential across the plasma membrane for both ions.

(c) Facilitated diffusion mediated by channel proteins. Aquaporin channel proteins can facilitate the rapid inward or outward movement of water molecules.

Figure 8-2

Osmosis of water across a membrane

Osmosis Is the Diffusion of Water Across a Differentially Permeable Membrane

Properties of water that cause it to behave in a special way:

1. Water molecules are not charged, so they are not affected by membrane potential.
2. Water concentration is not appreciably different on opposite sides of a membrane.

What, then, determines the direction in which water molecules diffuse?

When a solute is dissolved in water, the solute molecules disrupt the ordered three dimensional interactions that normally occur between individual molecules of water.

Water tends to diffuse from areas where its free energy is higher to areas where its free energy is lower.

Water tends to move from regions of lower solute concentration (**higher free energy**) to regions of higher solute concentration (**lower free energy**).

Diffusion always moves solutes toward equilibrium

No matter how a population of molecules is distributed initially, diffusion always tends to create a random solution in which the concentration is the same everywhere.

Figure 8-4a, consists of two chambers separated by a membrane that is freely permeable to molecules of S, an uncharged solute represented by the black dots.

Initially, chamber A has a higher concentration of S than does chamber B.

Other conditions being equal, random movements of solute molecules back and forth through the membrane will lead to a net movement of solute S from chamber A to chamber B.

When the concentration of S is equal on both sides of the membrane, the system is at equilibrium; random back-and-forth movement of individual molecules continues, but no further net change in concentration occurs.

Thus, ***diffusion is always movement toward equilibrium***.

Osmosis of water across a membrane

Osmosis Is the diffusion of water across a differentially permeable membrane

Solutions of differing solute concentrations are placed in chambers A and B as in **Figure 8-4a**, but with the two chambers now separated by a *differentially permeable membrane* that is permeable to water but not to the dissolved solute.

Under these conditions, water moves, or diffuses, across the membrane from chamber B to chamber A.

Such movement of water in response to differences in solute concentration is **called osmosis.**

Osmotic movement of water across a membrane is always from the side with the higher free energy to the side with the lower free energy.

For most cells, water will move inward because the concentration of solutes is almost always higher inside a cell than outside.

If not controlled, the inward movement of water would cause cells to swell and perhaps to burst.

See Figure 8-4b.

Simple diffusion across a membrane

(a) Simple diffusion takes place when the membrane separating chambers A and B is permeable to molecules of dissolved solute, represented by the black dots. Net movement of solute molecules across the membrane is from chamber A to B (high to low solute concentration). Equilibrium is reached when the solute concentration is the same in both chambers.

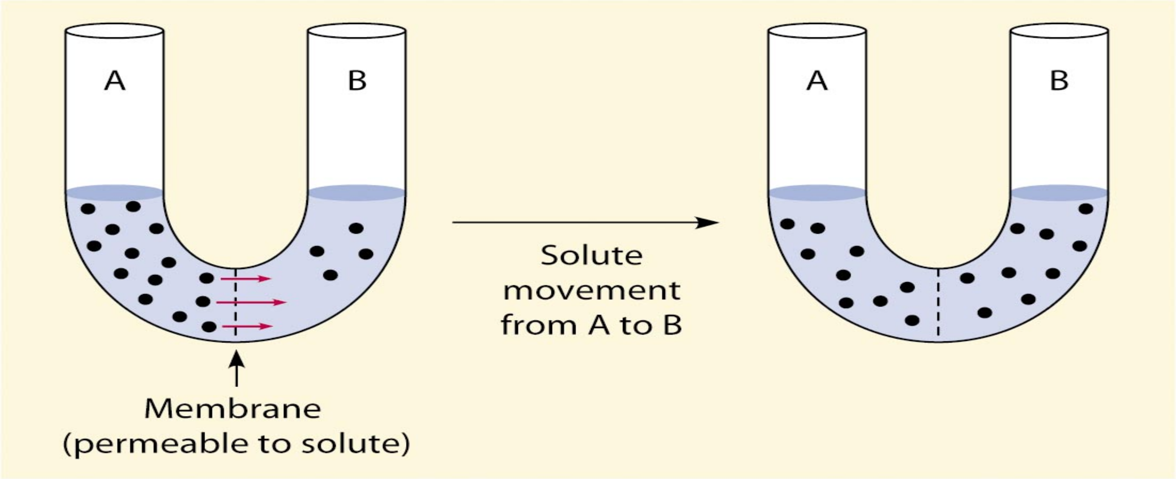


Figure 8-4a

Osmosis

(b) Osmosis occurs when the membrane between the two chambers is not permeable to the dissoved solute, represented by the black triangles. Because solute cannot cross the membrane, water diffuses from chamber B where the solute concentration is lower (more water) to chamber A where the solute concentration is higher (less water). At equilibrium, the solute concentration will be equal on both sides of the membrane.

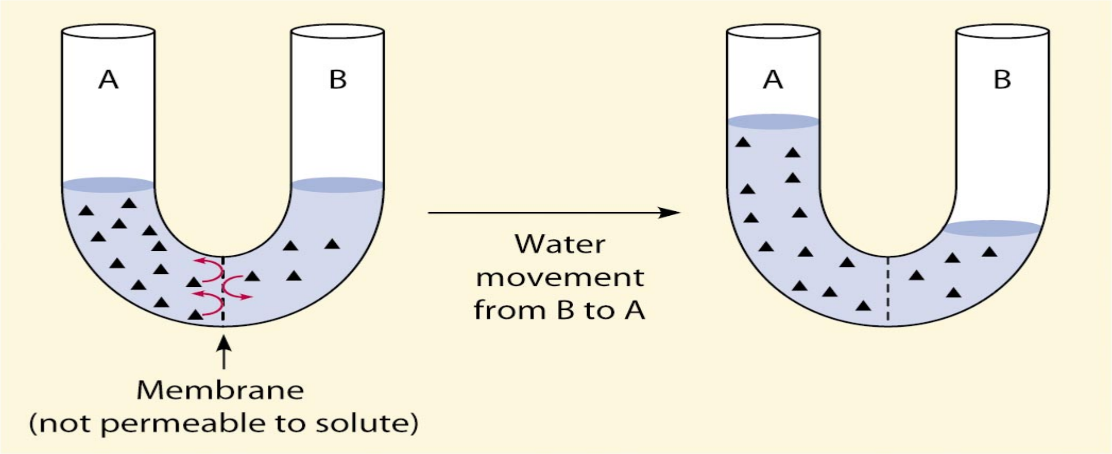


Figure 8-4b

Summary: simple diffusion and osmosis

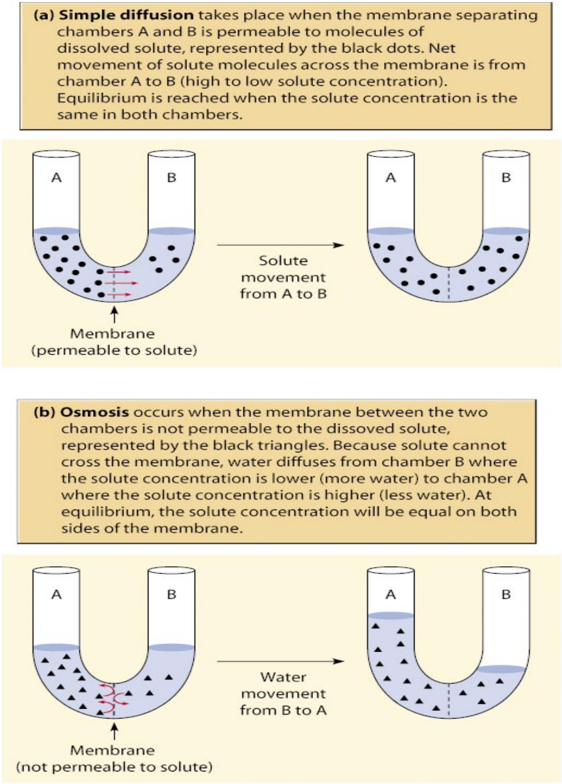


Figure 8-4