Note: For the past several years, I've been puzzling how to integrate new discoveries on the nature of water movement through cell membranes into Chapter 7. The Section below is a draft of my first efforts to integrate the role of aquaporin, the water channel protein, into a discussion of passive transport and osmosis. Comments and criticisms are most welcome.

- Ken Miller (July, 2007)

Section 7-3 Cell Boundaries

Key Questions (One for each B-head in Lesson)

- *What is the function of the cell membrane?*
- *How does diffusion allow materials to cross cell membranes?*
- *Can cells actively take in the materials they need??*
- *How do cells communicate with each other??*

THINK ABOUT IT When you first study a country, you may begin by examining a map of the country's borders. Before you can learn anything about a nation, it's important to understand where it begins and where it ends. The same principle applies to cells. Among the most important parts of a cell are its borders, which separate the cell from its surroundings, and determine what comes in, and what goes out.

Cell Walls and Membranes

What are the functions of the cell membranes and cell walls?

All cells are surrounded by a thin, flexible barrier known as the **cell membrane**. The cell membrane is sometimes called the plasma membrane because many cells in the body are in direct contact with the fluid portion of the blood—the plasma. Many cells also produce a strong supporting layer around the membrane known as a cell wall.

Cell Membranes The composition of nearly all cell membranes is a double-layered sheet called a lipid bilayer.. The lipid bilayer gives cell membranes a flexible structure that forms a strong barrier between the cell and its surroundings. **The cell membrane regulates what enters and leaves the cell and also provides the cell with protection and support.**

In addition to lipids, most cell membranes contain protein molecules that are embedded in the lipid bilayer. Carbohydrate molecules are attached to many of these proteins. In fact, there are so many kinds of molecules in cell membranes that scientists describe their understanding of the membrane as the "fluid mosaic model" of membrane structure. As you will see, some of the proteins form channels and pumps that help to move material across the cell membrane. Many of the carbohydrates act like chemical identification cards, allowing individual cells to identify one another

Cell Walls
Cell walls are present in many organisms, including plants, algae, fungi, and many prokaryotes. Cell walls lie outside the cell membrane. Most cell walls are porous enough to allow water, oxygen, carbon dioxide, and certain other substances to pass through easily. **The main function of the cell wall is to provide support and protection for the cell.**

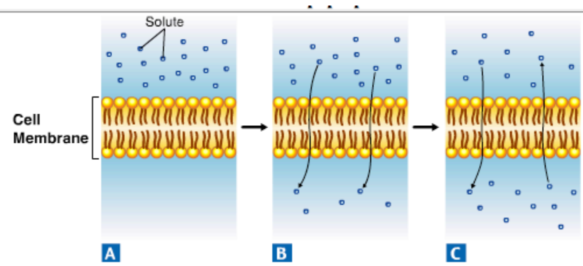
Most cell walls are made from fibers of carbohydrate and protein. These substances are produced within the cell and then released at the surface of the cell membrane where they are assembled to form the wall. Plant cell walls are composed mostly of cellulose, a tough carbohydrate fiber. Cellulose is the principal component of both wood and paper, so every time you pick up a sheet of paper, you are holding the stuff of cell walls in your hand

Passive Transport

How does diffusion allow materials to cross cell membranes?

Every living cell exists in a liquid environment. It may not always seem that way; yet even in the dust and heat of a desert, the cells of cactus plants, scorpions, and vultures are bathed in liquid. One of the most important functions of the cell membrane is to regulate the movement of dissolved molecules from the liquid on one side of the membrane to the liquid on the other side.

Diffusion
One of the principal ways in which molecules cross cell membranes is a process known as diffusion. The cytoplasm of a cell is a solution of many different substances dissolved in water. You should recall that a solution is a mixture of two or more substances, and that the substances dissolved in the solution are called solutes.



A There is a higher concentration of solute on one side of the membrane as compared to the other side of the membrane.

B Solute particles move from the side of the membrane with a higher concentration of solute to the side of the membrane with a lower concentration of solute. The solute particles will continue to diffuse across the membrane until equilibrium is reached.

C When equilibrium is reached, solute particles continue to diffuse across the membrane in both directions.

Diffusion Diffusion is the process by which molecules of a substance move from areas of higher concentration to areas of lower concentration. **Diffusion does not require the cell to use energy.**

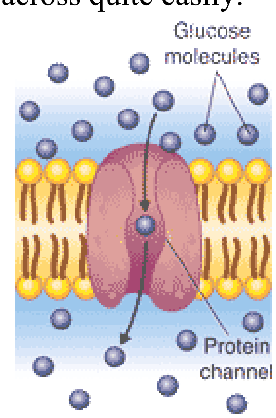
In any solution, solute particles move constantly. They collide with one another and tend to spread out randomly. As a result, the particles tend to move from an area where they are more concentrated to an area where they are less concentrated, a process known as diffusion (dih-FYOO-zhun). When the concentration of the solute is the same throughout a system, the system has reached equilibrium.

The concentration of a solute is usually expressed as the amount dissolved in a certain volume of solvent. For example, if you dissolved 12 grams of salt in 3 liters of water, the concentration of the solution would be 12 g/3 L, or 4 g/L (grams per liter). If you had 12 grams of salt in 6 liters of water, the concentration would be 12 g/6 L, or 2 g/L. The first solution would be twice as concentrated as the second solution.

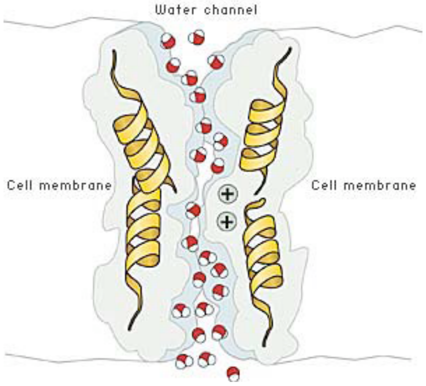
What do solute concentration, diffusion, and equilibrium have to do with cell membranes? Suppose a substance is present in unequal concentrations on either side of a cell membrane. If the substance can cross the cell membrane, its particles will tend to move toward the area where it is less concentrated until equilibrium is reached. At that point, the concentration of the substance on both sides of the cell membrane will be the same.

Because diffusion depends upon random particle movements, substances diffuse across membranes without requiring the cell to use additional energy. Even when equilibrium is reached, particles of a solution will continue to move across the membrane in both directions. However, because almost equal numbers of particles move in each direction, there is no further change in the concentration on either side.

Facilitated Diffusion Some molecules, such as the sugar glucose, seem to pass through the cell membrane much more quickly than they should. One might think that these molecules are too large or too strongly charged to cross the membrane, and yet they diffuse across quite easily.



How does this happen? Cell membranes have protein channels that act as carriers, making it easy for certain molecules to cross. Red blood cells, for example, have membrane proteins with carrier channels that allow glucose to pass through them. Only glucose can pass through this protein carrier, and it can move through in either direction. This is sometimes known as carrier-facilitated diffusion. These cell membrane channels are also said to facilitate, or help, the diffusion of glucose across the membrane. The process, shown in Figure 7–x, is known as **facilitated diffusion.** Hundreds of different protein channels have been found that allow particular substances to cross cell membranes.



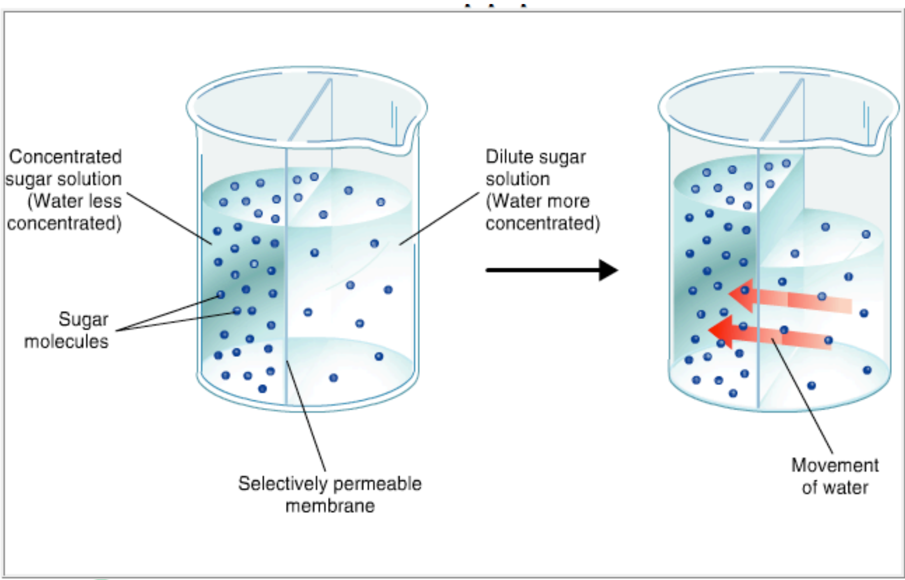
Surprising new research has added water to the list of molecules that enter cells by facilitated diffusion. Water molecules have a tough time crossing the cell membrane's lipid bilayer, and therefore water diffuses in and out of many cells very slowly. However, many cells contain huge numbers of water channel proteins, known as **aquaporins**, that allow water to pass right through them (Figure 7-x). As we will see in a moment, the movement of water through cell membranes by facilitated diffusion is an extremely important biological process[1].

Although facilitated diffusion is fast and specific, it is still diffusion. Therefore, a net movement of molecules across a cell membrane will occur only if there is a higher concentration of the particular molecules on one side than on the other side. This means that the movement of molecules by facilitated diffusion does not require any additional use of the cell's energy.

Osmosis Although many substances can diffuse across biological membranes, some are too large or too strongly charged to cross the lipid bilayer. If a substance is able to diffuse across a membrane, the membrane is said to be **permeable** to it. A membrane is **impermeable** to substances that cannot pass across it. Most biological membranes are selectively permeable, meaning that some substances can pass across them and others cannot. Selectively permeable membranes are also called semipermeable membranes.

Water moves quite easily through the aquaporin water channels in many cells, even though many solute molecules cannot. An important process known as osmosis is the result. Osmosis is the diffusion of water through a selectively permeable membrane.

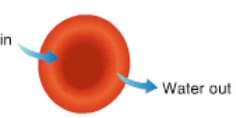
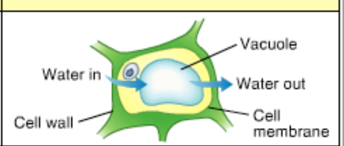
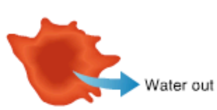
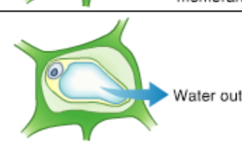
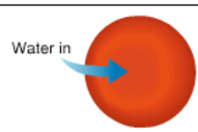
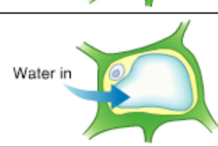
[1] Note: The 1994 discovery of Aquaporin by Peter Agre should be placed on the timeline.



Osmosis **Osmosis is the diffusion of water through a selectively permeable membrane.** In the first beaker, water is more concentrated on the right side of the membrane. As a result, the water diffuses (as shown in the second beaker) to the area of lower concentration.

How Osmosis Works Look at the beaker on the left in Figure 7–15. There are more sugar molecules on the left side of the membrane than on the right side. That means that the concentration of water is lower on the left than it is on the right. The membrane is permeable to water but not to sugar. This means that water can cross the membrane in both directions, but sugar cannot. As a result, there is a net movement of water from the area of high concentration to the area of low concentration.

The Effects of Osmosis on Cells

Solution	Animal Cell	Plant Cell
Isotonic: The concentration of solutes is the same inside and outside the cell.		
Hypertonic: Solution has a higher solute concentration than the cell.		
Hypotonic: Solution has a lower solute concentration than the cell.		

Effects of Osmosis Cells placed in an isotonic solution neither gain nor lose water. In a hypertonic solution, animal cells shrink, and plant cell vacuoles collapse. In a hypotonic solution, animal cells swell and burst. The vacuoles of plant cells swell, pushing the cell contents out against the cell wall. **Predicting** ***What would happen to the animal cell in the isotonic solution if it were placed in pure water?***

Water will tend to move across the membrane until equilibrium is reached. At that point, the concentrations of water and sugar will be the same on both sides of the membrane. When this happens, the two solutions will be **isotonic,** which means "same strength." When the experiment began, the more concentrated sugar solution was **hypertonic,** which means "above strength," as compared to the dilute sugar solution. The dilute sugar solution was **hypotonic,** or "below strength."

Word Origins

Hypotonic comes from the Greek word *hupo,* meaning "under," and the New Latin word *tonicus*, meaning "tension" or "strength." So a hypotonic solution is less strong, or less concentrated, than another solution of the same type

If *derma* means "skin," how would you describe a hypodermic injection?

Osmotic Pressure For organisms to survive, they must have a way to balance the intake and loss of water. Osmosis exerts a pressure known as osmotic pressure on the hypertonic side of a selectively permeable membrane. Osmotic pressure can cause serious problems for a cell. Because the cell is filled with salts, sugars, proteins, and other molecules, it will almost always be hypertonic to fresh water. This means that osmotic pressure should produce a net movement of water into a typical cell that is surrounded by fresh water. If that happens, the volume of a cell will increase until the cell becomes swollen. Eventually, the cell may burst like an overinflated balloon. Fortunately, cells in large organisms are not in danger of bursting. Most cells in such organisms do not come in contact with fresh water. Instead, the cells are bathed in fluids, such as blood, that are isotonic. These isotonic fluids have concentrations of dissolved materials roughly equal to those in the cells themselves.

Some cells, such as the eggs laid in fresh water by fish and frogs, lack water channels. As a result, water moves into them so slowly that osmotic pressure does not become a problem. Other cells, including those of plants and bacteria, which do come into contact with fresh water, are surrounded by tough cell walls. The cell walls prevent the cells from expanding, even under tremendous osmotic pressure. However, the increased osmotic pressure makes such cells extremely vulnerable to injuries to their cell walls.

Active Transport

Can cells actively take in the materials they need?

As powerful as diffusion is, cells sometimes must move materials in the opposite direction—against a concentration difference**.** **The movement of material against a concentration difference is known as active transport.** As its name implies, active transport requires energy. The active transport of small molecules or ions across a cell membrane is generally carried out by transport proteins or "pumps" that are found in the membrane itself. Larger molecules and clumps of material can also be actively transported across the cell membrane by processes known as endocytosis and exocytosis. The transport of these larger materials sometimes involves changes in the shape of the cell membrane.

Molecular Transport Small molecules and ions are carried across membranes by proteins in the membrane that act like energy-requiring pumps. Many cells use such proteins to move calcium, potassium, and sodium ions across cell membranes. Changes in protein shape, seem to play an important role in the pumping process. A considerable portion of the energy used by cells in their daily activities is devoted to providing the energy to keep this form of active transport working. The use of energy in these systems enables cells to concentrate substances in a particular location, even when the forces of diffusion might tend to move these substances in the opposite direction

Bulk Transport Larger molecules and even solid clumps of material may be transported by movements of the cell membrane known as bulk transport. Bulk transport may take several forms, depending upon the size and shape of the material taken into or out of the cell.

Endocytosis Endocytosis (en-doh-sy-TOH-sis) is the process of taking material into the cell by means of infoldings, or pockets, of the cell membrane. The pocket that results breaks loose from the outer portion of the cell membrane and forms a vacuole within the cytoplasm. Large molecules, clumps of food, and even whole cells can be taken up in this way. Two examples of endocytosis are phagocytosis (fag-oh-sy-TOH-sis) and pinocytosis (py-nuh-sy-TOH-sis).

Phagocytosis means "cell eating." In phagocytosis, extensions of cytoplasm surround a particle and package it within a food vacuole. The cell then engulfs it. Amoebas use this method of taking in food. Engulfing material in this way requires a considerable amount of energy and, therefore, is correctly considered a form of active transport.

In a process similar to endocytosis, many cells take up liquid from the surrounding environment. Tiny pockets form along the cell membrane, fill with liquid, and pinch off to form vacuoles within the cell. This process is known as pinocytosis.

Exocytosis Many cells also release large amounts of material from the cell, a process known as exocytosis (ek-soh-sy-TOH-sis). During exocytosis, the membrane of the vacuole surrounding the material fuses with the cell membrane, forcing the contents out of the cell. The removal of water by means of a contractile vacuole is one example of this kind of active transport.

Cellular Communication

How do cells communicate with each other?

For cells in a large organism to act together, they must be able to communicate with each other. **Cells communicate by means of chemical signals that are passed from one cell to another.** These chemical signals vary widely, and so do the ways in which cells respond to them.

Cellular Junctions

Many cells form cellular junctions that attach them to neighboring cells. Skin cells, for example, are joined by tough junctions that keep them from being pulled apart. The cells lining the digestive system have another type of junction that forms a tight seal between them. This helps to prevent material from leaking between cells, and enables layers of such cells to form a barrier. Junctions such as these help to keep the contents of the digestive system, including what you might have had for lunch today, from leaking out between the cells and into the rest of the body.

Other cells, including those in the heart and liver, form junctions that allow small molecules to pass directly from one cell to the next. These junctions mean that changes in the concentrations of small molecules and ions can spread very quickly from cell to cell. As a result, a chemical message or signal produced in one cell can travel to the next, allowing the cells joined by these kinds of junctions to act together. Such junctions are one of the principal reasons why the cells of the heart muscle are able to contract in a coordinated fashion.

Cellular Signaling

Many cells release molecules that can travel to other cells carrying chemical messages or signals. These cellular signals can speed up or slow down the activities of the cells that receive them, and can even cause a cell to change what it is doing in a most dramatic way. To respond to one of these chemical signals, a cell must have a **receptor** to which the signaling molecule can bind (Figure 7-x. Sometimes these receptors are on the cell membrane, although the receptors for certain types of signals are inside the cytoplasm. The chemical signals sent by various types of cells can cause important changes in cellular activity.