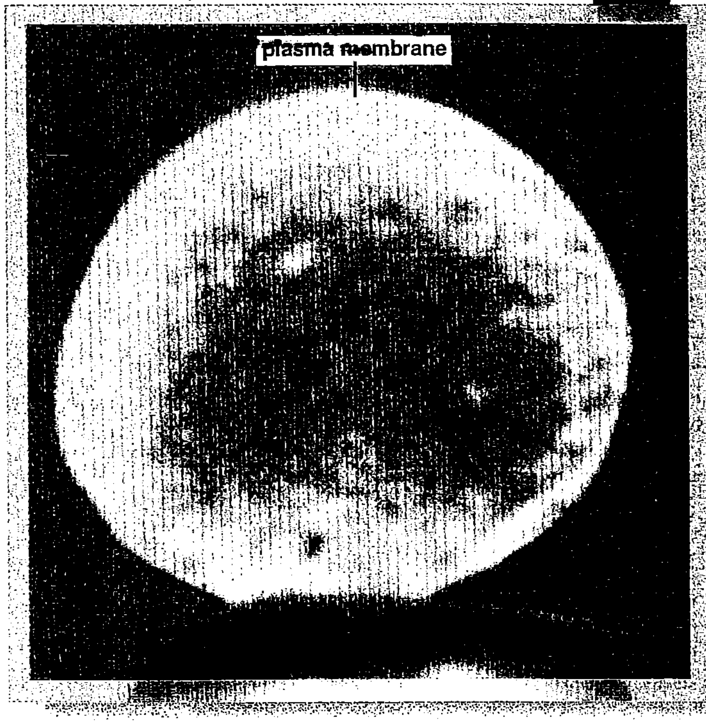
C H A P T E R 4

Membrane Structure and Function

Chapter Concepts



A plasma membrane is the outer boundary of the cell. It regulates the contents of the cell, and affects how the cell will function in the body.

Laura liked to hang out with her friends and do all the things they did—wear nail polish and makeup, listen to rock and roll, and go to parties. But something was wrong. Her parents took her to the doctor because she didn't get a monthly period like her friends did. The news was startling. Laura's cells bore X and Y chromosomes instead of two X chromosomes like females usually do. And she didn't have the internal organs of a female. Her condition was diagnosed as androgen insensitivity. There was plenty of the male sex hormone testosterone in her blood, but her cells were unable to respond to it. So, she had the external features of a female instead of a male.

Many medical conditions that we attribute to faulty organs are actually disorders of the cell, and specifically the plasma membrane. The plasma membrane controls what gets into and out of a cell, and Laura's receptor for testosterone was faulty—the hormone couldn't get into her cells. One form of diabetes is also a disorder of the plasma membrane; in this instance, the cells do not respond to the hormone insulin. And cystic fibrosis develops when NaCl can't get out of a cell.

A plasma membrane encloses every cell, and its proper functioning is important to the health of the cell, and therefore the organism.

4.1 Plasma Membrane Structure and Function

The plasma membrane separates the internal environment of the cell from the external environment. It regulates the entrance and exit of molecules into and out of the cell. In this way, it helps the cell and the organism maintain a steady internal environment. The plasma membrane is a phospholipid bilayer in which protein molecules are either partially or wholly embedded (Fig. 4.1). The phospholipid bilayer has a *fluid* consistency, comparable to that of light oil. The proteins are scattered either just outside or within the membrane; therefore, they form a *mosaic* pattern. This description of the plasma membrane is called the **fluid-mosaic model** of membrane structure.

The hydrophilic (water-loving) polar heads of the phospholipid molecules face the outside and inside of the cell where water is found, and the hydrophobic (water-fearing) nonpolar tails face each other (Fig. 4.1). Cholesterol is another lipid found in animal plasma membranes; related steroids are found in the plasma membranes of plants. Cholesterol stiffens and strengthens the membrane, thereby helping to regulate its fluidity.

The proteins in a membrane may be peripheral proteins or integral proteins. The peripheral proteins on the inside surface of the membrane are often held in place by cytoskeletal filaments. Integral proteins are embedded in the membrane, but they can move laterally back and forth. Some integral proteins protrude from only one surface of the bilayer. Most span the membrane, with a hydrophobic region within the membrane and hydrophilic regions that protrude from both surfaces of the bilayer.

Both phospholipids and proteins can have attached carbohydrate (sugar) chains. If so, these molecules are called **glycolipids** and **glycoproteins** respectively. Since

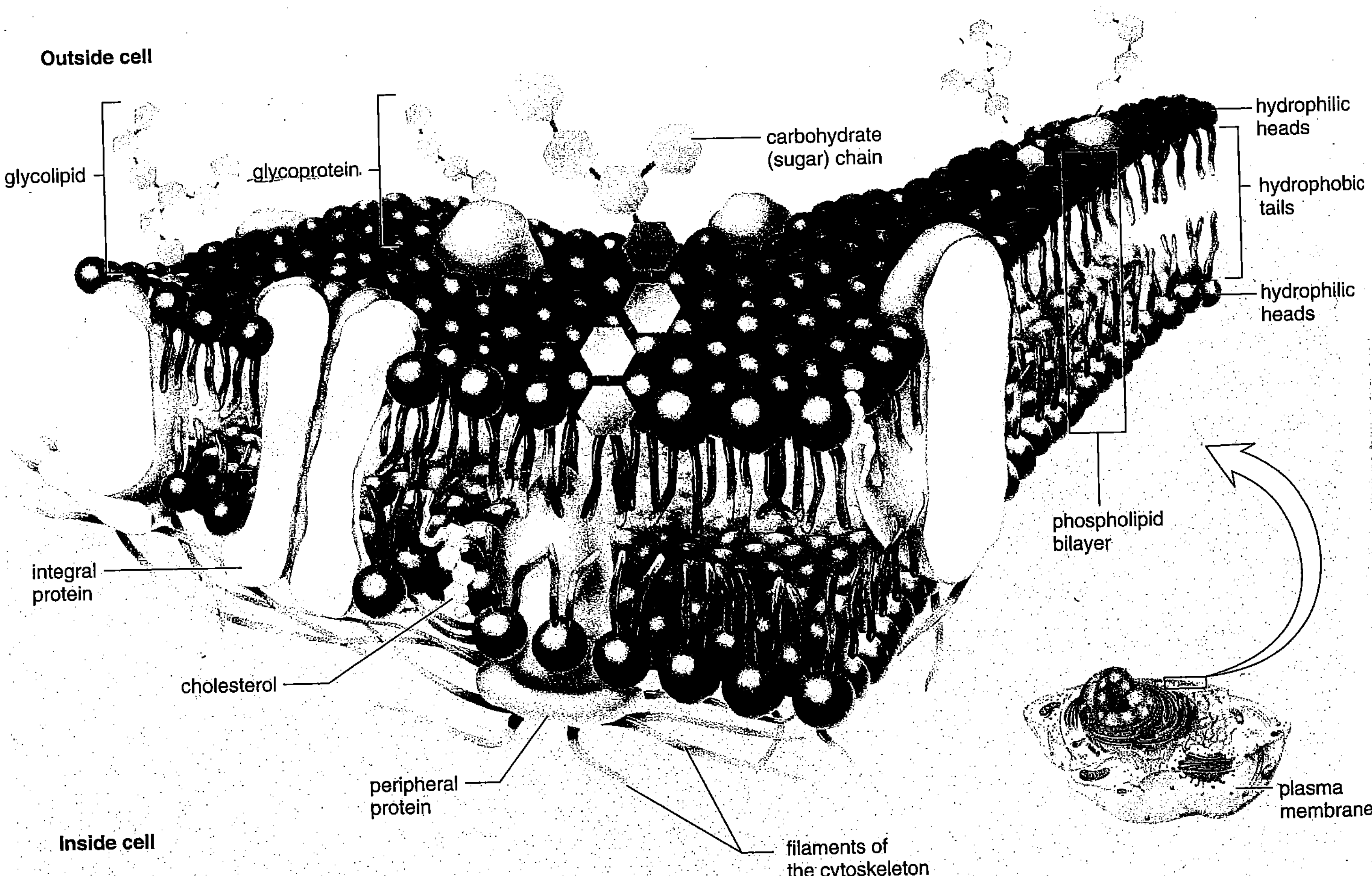


Figure 4.1 Fluid-mosaic model of plasma membrane structure.
The membrane is composed of a phospholipid bilayer in which proteins are embedded. The hydrophilic heads of phospholipids are part of both the outside surface and the inside surface of the membrane. The hydrophobic tails make up the interior of the membrane. Note the plasma membrane's asymmetry—carbohydrate chains are attached to the outside surface, and cytoskeleton filaments are attached to the inside surface.

the carbohydrate chains occur only on the outside surface and peripheral proteins occur asymmetrically on one surface or the other, the two halves of the membrane are not identical.

Functions of the Proteins

The plasma membranes of various cells and the membranes of various organelles each have their own unique collections of proteins. The integral proteins largely determine a membrane's specific functions. The plasma membrane of a red blood cell contains over 50 different types of proteins, and each has a specific function.

As we will discuss in more detail, certain plasma membrane proteins are involved in the passage of molecules through the membrane. Some of these are **channel proteins** through which a substance can simply move across the membrane; others are **carrier proteins** that combine with a substance and help it move across the membrane. Still others are receptors; each type of **receptor protein** has a shape that allows a specific molecule to bind to it. The binding of a molecule, such as a hormone (or other signal molecule), can cause the protein to change its shape and bring about a cellular response. Some plasma membrane proteins are **enzymatic proteins** that carry out metabolic reactions directly. The peripheral proteins associated with the membrane often have a structural role in that they help stabilize and shape the plasma membrane.

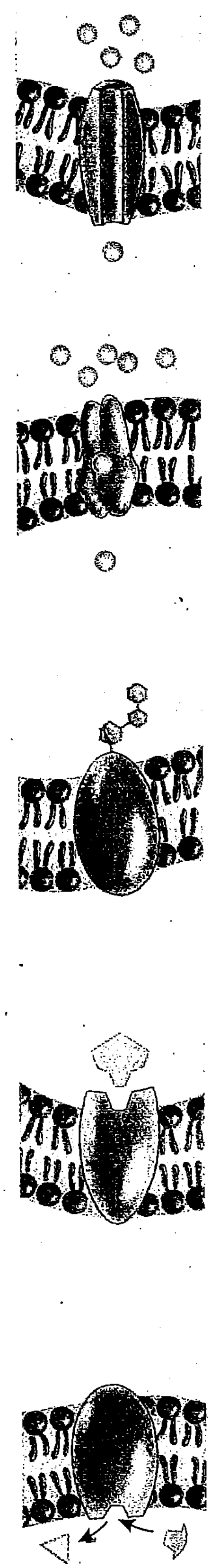
Figure 4.2 depicts the various functions of membrane proteins.

The Carbohydrate Chains

In animal cells, the carbohydrate chains of **cell recognition proteins** give the cell a "sugar coat," more properly called the glycocalyx. The glycocalyx protects the cell and has various other functions. For example, it facilitates adhesion between cells, reception of signal molecules, and cell-to-cell recognition.

The possible diversity of the carbohydrate (sugar) chains is enormous. The chains can vary by the number (15 is usual, but there can be several hundred) and sequence of sugars and by whether the chain is branched. Each cell within the individual has its own particular "fingerprint" because of these chains. As you probably know, transplanted tissues are often rejected by the recipient. This is because the immune system is able to recognize that the foreign tissue's cells do not have the appropriate carbohydrate chains. In humans, carbohydrate chains are also the basis for the A, B, and O blood groups.

The plasma membrane consists of a fluid phospholipid bilayer in which embedded proteins form a mosaic pattern. Carbohydrate chains project outward from the membrane.



Channel Protein
Allows a particular molecule or ion to cross the plasma membrane freely. Cystic fibrosis, an inherited disorder, is caused by a faulty chloride (Cl^-) channel; a thick mucus collects in airways and in pancreatic and liver ducts.

Carrier Protein
Selectively interacts with a specific molecule or ion so that it can cross the plasma membrane. A faulty carrier for glucose may be the cause of diabetes mellitus in some persons. The cells starve in the midst of plenty, and glucose spills over into the urine.

Cell Recognition Protein
The MHC (major histocompatibility complex) glycoproteins are different for each person, so organ transplants are difficult to achieve. Cells with foreign MHC glycoproteins are attacked by blood cells responsible for immunity.

Receptor Protein
Is shaped in such a way that a specific molecule can bind to it. Pygmies are short, not because they do not produce enough growth hormone, but because their plasma membrane growth hormone receptors are faulty and cannot interact with growth hormone.

Enzymatic Protein
Catalyzes a specific reaction. Cholera bacteria release a toxin that interferes with the functioning of an enzyme that helps regulate the sodium content of cells. Sodium ions and water leave intestinal cells, and the individual may die from severe diarrhea.

Figure 4.2 Membrane protein diversity.
These are some of the functions performed by proteins found in the plasma membrane.

Table 4.1 Passage of Molecules into and out of Cells

	Name	Direction	Requirement	Examples
PASSIVE TRANSPORT	Diffusion	Toward lower concentration	Concentration gradient	Lipid-soluble molecules, water, and gases
	Facilitated Transport	Toward lower concentration	Channels or carrier and concentration gradient	Water, some sugars, and amino acids
ACTIVE TRANSPORT	Active Transport	Toward higher concentration	Carrier plus energy	Sugars, amino acids, and ions
	Exocytosis	Toward outside	Vesicle fuses with plasma membrane	Macromolecules
	Endocytosis	Toward inside	Vesicle formation	Macromolecules

4.2 The Permeability of the Plasma Membrane

The plasma membrane is **differentially** (selectively) **permeable.** This means that some substances can move across the membrane, and some cannot (Fig. 4.3). The ways of crossing a plasma membrane are classified as passive or active (Table 4.1). Passive transport, which does not use chemical energy, involves diffusion or facilitated transport. Diffusion occurs without benefit of a carrier protein whereas facilitated transport does require a carrier protein.

Active transport not only requires a carrier protein, it also requires chemical energy, i.e., ATP. There are other means of actively getting ions and molecules into and out of cells. Vesicle formation can take a molecule out of a cell (called exocytosis) or into a cell (called endocytosis).

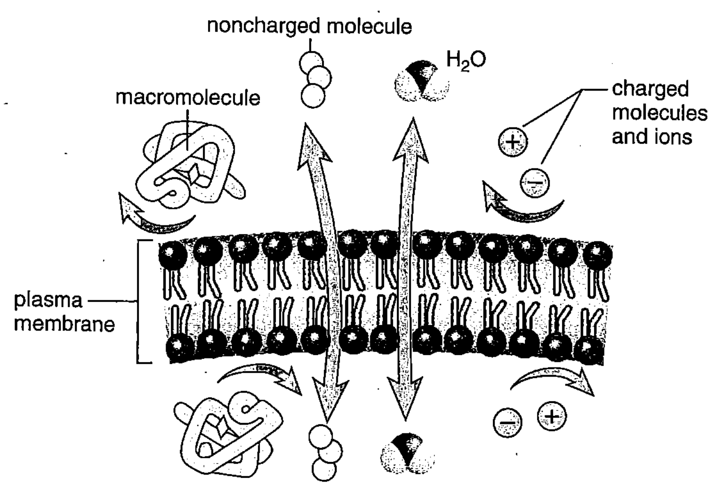


Figure 4.3 How molecules cross the plasma membrane. The small, curved arrows indicate that these substances cannot cross the plasma membrane, and the two large arrows indicate that these substances can cross the plasma membrane.

The last column of Table 4.1 gives examples of molecules that cross the membrane passively or actively. Small, noncharged molecules, such as carbon dioxide, oxygen, glycerol, water, and alcohol, can diffuse across the membrane. They can diffuse because they are able to slip between the hydrophilic heads of the phospholipids and pass through the hydrophobic tails of the membrane. These molecules are said to follow their **concentration gradient** as they move from an area where their concentration is high to an area where their concentration is low. Consider that a cell is always using oxygen when it carries on cellular respiration. Therefore, the concentration of oxygen is always higher outside a cell and oxygen follows a concentration gradient when it enters a cell. Carbon dioxide, on the other hand, is produced when a cell carries on cellular respiration. Therefore carbon dioxide is also following a concentration gradient when it moves from inside the cell to outside the cell.

Ions and polar molecules such as glucose and amino acids are often assisted across the plasma membrane by either facilitated or active transport. Both of these means of crossing a membrane involve carrier proteins. The carrier protein must combine with an ion, such as Na^+, or a molecule, such as glucose, before transporting it across the membrane. Therefore, carrier proteins are specific for the substances they transport across the plasma membrane.

Water moves much faster through the membrane when it utilizes a channel protein. Our discussion in this chapter, however, is largely restricted to the use of carrier proteins which help molecules cross a membrane.

> The plasma membrane is differentially permeable. Certain substances can freely pass through the membrane, and others must be transported across by carrier proteins.

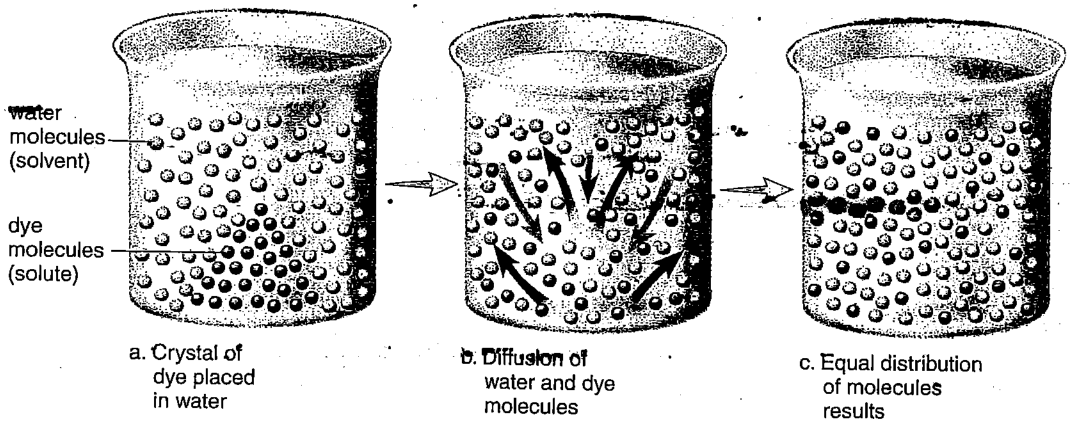


Figure 4.4 **Process of diffusion.**
Diffusion is spontaneous, and no chemical energy is required to bring it about. **a.** When dye crystals are placed in water, they are concentrated in one area. **b.** The dye dissolves in the water, and there is a net movement of dye molecules from higher to lower concentration. There is also a net movement of water molecules from higher to lower concentration. **c.** Eventually, the water and the dye molecules are equally distributed throughout the container.

4.3 Diffusion and Osmosis

Diffusion is the movement of molecules from a higher to a lower concentration—that is, down their concentration gradient—until equilibrium is achieved and they are distributed equally. Diffusion is a physical process that can be observed with any type of molecule. For example, when a crystal of dye is placed in water (Fig. 4.4), the dye and water molecules move in various directions, but their net movement, which is the sum of their motion, is toward the region of lower concentration. Eventually, the dye is dissolved in the water, resulting in a colored solution.

A solution contains both a solute, usually a solid, and a solvent, usually a liquid. In this case, the **solute** is the dye and the **solvent** is the water molecules. Once the solute and solvent are evenly distributed, they continue to move about, but there is no net movement of either one in any direction.

As discussed, the chemical and physical properties of the plasma membrane allow only a few types of molecules to enter and exit a cell simply by diffusion. Gases can diffuse through the lipid bilayer; this is the mechanism by which oxygen enters cells and carbon dioxide exits cells. Also, consider the movement of oxygen from the alveoli (air sacs) of the lungs to the blood in the lung capillaries (Fig. 4.5). After inhalation (breathing in), the concentration of oxygen in the alveoli is higher than that in the blood; therefore, oxygen diffuses into the blood.

Molecules diffuse down their concentration gradients. A few types of small molecules can simply diffuse through the plasma membrane.

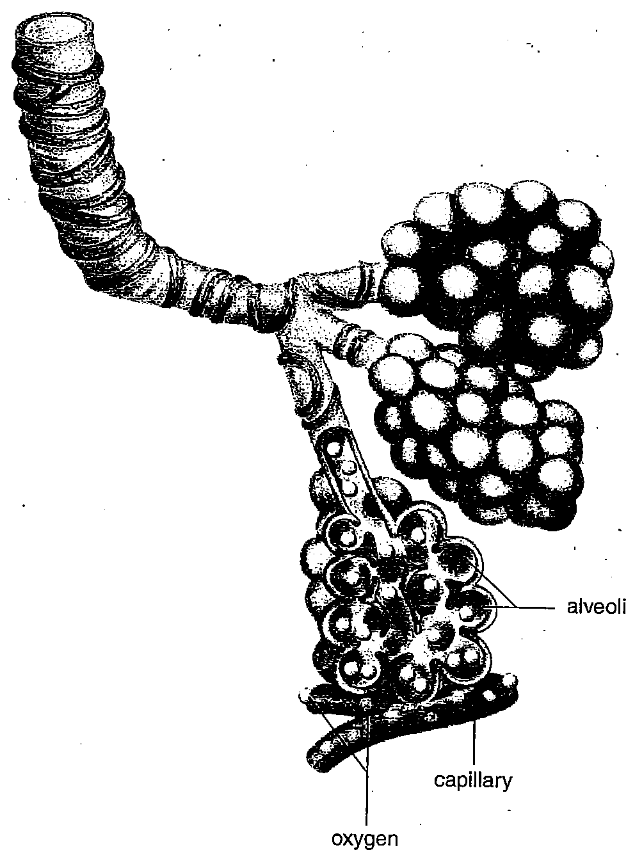


Figure 4.5 **Gas exchange in lungs.**
Oxygen (O_2) diffuses into the capillaries of the lungs because there is a higher concentration of oxygen in the alveoli (air sacs) than in the capillaries.

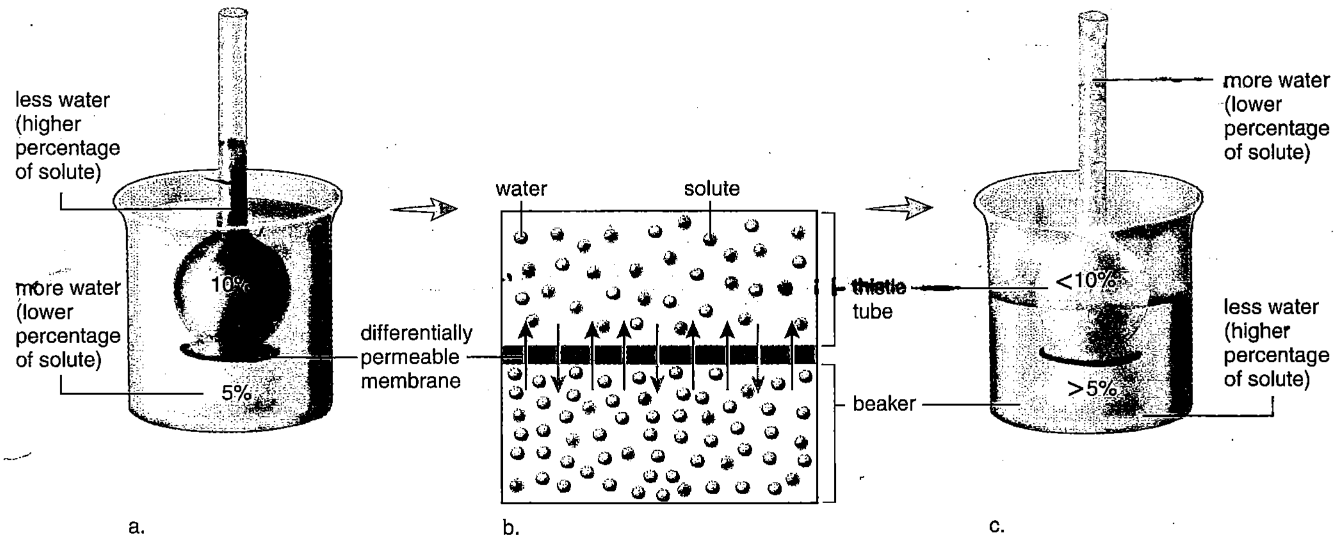


Figure 4.6 Osmosis demonstration.
a. A thistle tube, covered at the broad end by a differentially permeable membrane, contains a 10% sugar solution. The beaker contains a 5% sugar solution. **b.** The solute (gold circles) is unable to pass through the membrane, but the water (blue circles) passes through in both directions. There is a net movement of water toward the inside of the thistle tube, where there is a lower percentage of water molecules. **c.** Due to the incoming water molecules, the level of the solution rises in the thistle tube.

Osmosis

The diffusion of water across a selectively permeable membrane due to concentration differences is called **osmosis.** To illustrate osmosis, a thistle tube containing a 10% solute solution[1] is covered at one end by a differentially permeable membrane and then placed in a beaker containing a 5% sugar solution (Fig. 4.6). The beaker has a higher concentration of water molecules (lower percentage of solute), and the thistle tube has a lower concentration of water molecules (higher percentage of solute). Diffusion always occurs from higher to lower concentration. Therefore, a net movement of water takes place across the membrane from the beaker to the inside of the thistle tube.

The solute does not diffuse out of the thistle tube. Why not? Because the membrane is not permeable to the solute. As water enters and the solute does not exit, the level of the solution within the thistle tube rises (Fig. 4.6*c*). In the end, the concentration of solute in the thistle tube is less than 10%. Why? Because there is now less solute per unit volume. And the concentration of solute in the beaker is greater than 5%. Why? Because there is now more solute per unit volume.

Water enters the thistle tube due to the osmotic pressure of the solution within the thistle tube. **Osmotic pressure** is the pressure that develops in a system due to osmosis.[2] In other words, the greater the possible osmotic pressure, the more likely it is that water will diffuse in that direction. Due to osmotic pressure, water is absorbed by the kidneys and taken up by capillaries from tissue fluid.

Osmosis in Cells

Osmosis also occurs across the plasma membrane, as we shall now see (Fig. 4.7).

Isotonic Solution In the laboratory, cells are normally placed in **isotonic solutions**—that is, the solute concentration and the water concentration both inside and outside the cell are equal, and therefore there is no net gain or loss of water. The prefix *iso* means the same as, and the term tonicity refers to the strength of the solution. A 0.9% solution of the salt sodium chloride (NaCl) is known to be isotonic to red blood cells. Therefore, intravenous solutions medically administered usually have this tonicity.

Hypotonic Solution Solutions that cause cells to swell, or even to burst, due to an intake of water are said to be **hypotonic solutions.** The prefix *hypo* means less than, and refers to a solution with a lower concentration of solute (higher concentration of water) than inside the cell. If a cell is placed in a hypotonic solution, water enters the cell; the net movement of water is from the outside to the inside of the cell.

Any concentration of a salt solution lower than 0.9% is hypotonic to red blood cells. Animal cells placed in such a solution expand and sometimes burst due to the buildup of pressure. The term *lysis* is used to refer to disrupted cells; hemolysis, then, is disrupted red blood cells.

The swelling of a plant cell in a hypotonic solution creates **turgor pressure.** When a plant cell is placed in a hypotonic solution, we observe expansion of the cytoplasm

[1] Percent solutions are grams of solute per 100 ml of solvent. Therefore, a 10% solution is 10 g of solute with water added to make up 100 ml of solution.

[2] Osmotic pressure is measured by placing a solution in an osmometer and then immersing the osmometer in pure water. The pressure that develops is the osmotic pressure of a solution.

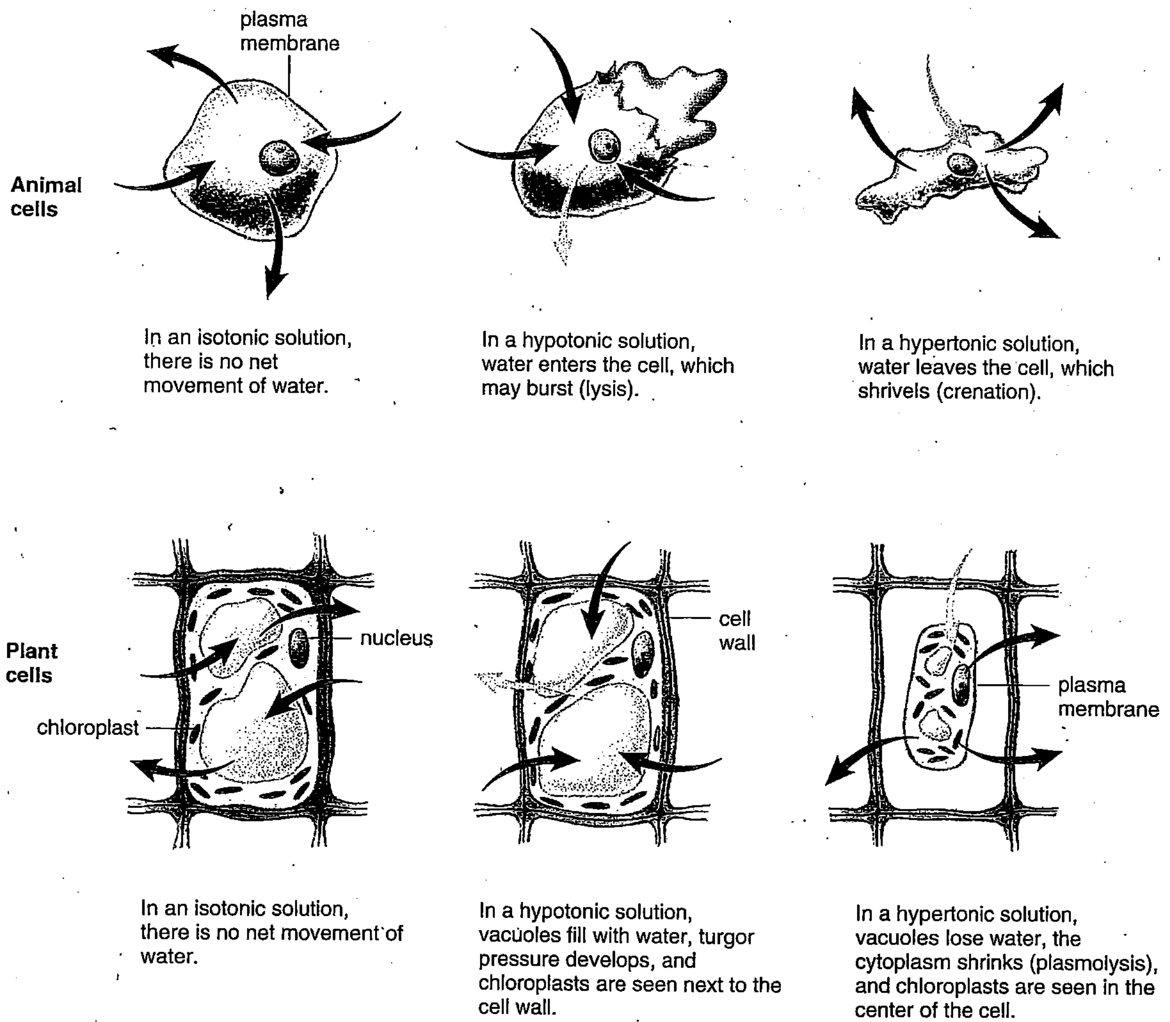


Figure 4.7 Osmosis in animal and plant cells.
The arrows indicate the movement of water molecules. To determine the net movement of water, compare the number of arrows that are taking water molecules into the cell versus the number that are taking water out of the cell. In an isotonic solution, a cell neither gains nor loses water; in a hypotonic solution, a cell gains water; and in a hypertonic solution, a cell loses water.

because the large central vacuole gains water and the plasma membrane pushes against the rigid cell wall. The plant cell does not burst because the cell wall does not give way. Turgor pressure in plant cells is extremely important to the maintenance of the plant's erect position. If you forget to water your plants, they wilt due to decreased turgor pressure.

Hypertonic Solution Solutions that cause cells to shrink or shrivel due to loss of water are said to be **hypertonic solutions.** The prefix *hyper* means more than, and refers to a solution with a higher percentage of solute (lower concentration of water) than the cell. If a cell is placed in a hypertonic solution, water leaves the cell; the net movement of water is from the inside to the outside of the cell.

Any solution with a concentration higher than 0.9% sodium chloride is hypertonic to red blood cells. If animal cells are placed in this solution, they shrink. The term *crenation* refers to red blood cells in this condition. Meats are sometimes preserved by salting them. The bacteria are not killed by the salt but by the lack of water in the meat.

When a plant cell is placed in a hypertonic solution, the plasma membrane pulls away from the cell wall as the large central vacuole loses water. This is an example of **plasmolysis,** a shrinking of the cytoplasm due to osmosis. The dead plants you may see along a salted roadside died because they were exposed to a hypertonic solution during the winter.

In an isotonic solution, a cell neither gains nor loses water. In a hypotonic solution, a cell gains water. In a hypertonic solution, a cell loses water and the cytoplasm shrinks.
