Centrioles The paired **centrioles** (sen′tre-ōlz) lie close to the nucleus (see Figure 3.4). They are rod-shaped bodies that lie at right angles to each other; internally they are made up of fine microtubules. During cell division, the centrioles direct the formation of the *mitotic spindle* (see Figure 3.15, p. 81).

In addition to the cell structures described above, some cells have projections called **cilia** (sil′e-ah; "eyelashes"), whiplike cellular extensions that move substances along the cell surface. For example, the ciliated cells of the respiratory system lining move mucus up and away from the lungs. Where cilia appear, there are usually many of them projecting from the exposed cell surface. When a cell is about to make cilia, its centrioles multiply and then line up beneath the plasma membrane at the free cell surface. Microtubules then begin to "sprout" from the centrioles and put pressure on the membrane, forming the projections. If the projections formed by the centrioles are substantially longer, they are called **flagella** (flah-jel′ah). The only example of a flagellated cell in the human body is the sperm, which has a single propulsive flagellum called its *tail* (Figure 3.8g). *Notice that cilia propel other substances across a cell's surface, whereas a flagellum propels the cell itself.*

Cell Diversity

So far in this chapter, we have focused on an average human cell. However, the trillions of cells in the human body are made up of some 200 different cell types that vary greatly in size, shape, and function. They include sphere-shaped fat cells, disk-shaped red blood cells, branching nerve cells, and cube-shaped cells of kidney tubules. Figure 3.8 illustrates how the shapes of cells and the relative numbers of the various organelles they contain relate to specialized cell functions. Let's take a look at some of these cell specialists.

1. **Cells that connect body parts:**
   - *Fibroblast.* The elongated shape of this cell lies along the cable-like fibers that it secretes. It also has an abundant rough ER and

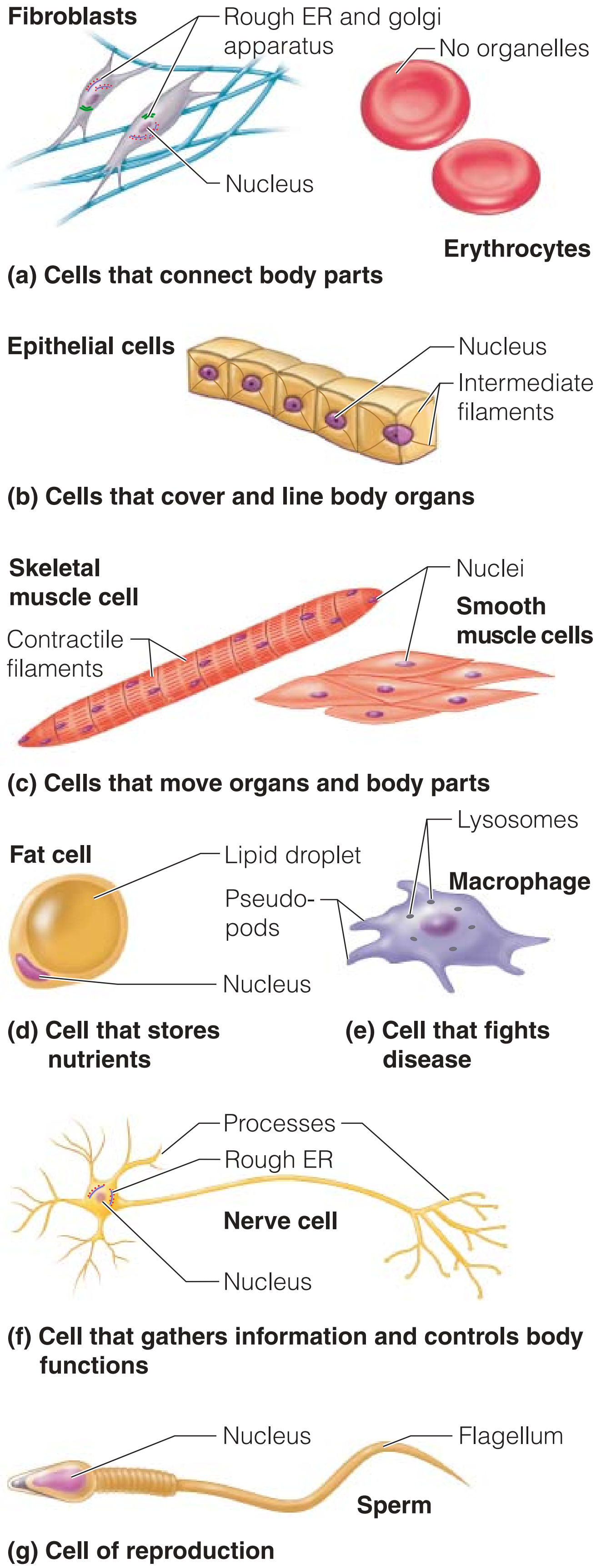

FIGURE 3.8 Cell diversity. The shape of human cells and the relative abundances of their various organelles relate to their function in the body.

a large Golgi apparatus, to make and secrete the protein building blocks of these fibers.

- *Erythrocyte (red blood cell).* This cell carries oxygen in the bloodstream. Its concave disk shape provides extra surface area for the uptake of oxygen and streamlines the cell so it flows easily through the bloodstream. So much oxygen-carrying pigment is packed in erythrocytes that all other organelles have been shed to make room.

2. **Cell that covers and lines body organs:**
    - *Epithelial cell.* The hexagonal shape of this cell is exactly like a "cell" in a honeycomb of a beehive. This shape allows epithelial cells to pack together in sheets. An epithelial cell has abundant intermediate filaments that resist tearing when the epithelium is rubbed or pulled.
3. **Cells that move organs and body parts:**
    - *Skeletal muscle* and *smooth muscle cells.* These cells are elongated and filled with abundant contractile filaments, so they can shorten forcefully and move the bones or change the size of internal organs.
4. **Cell that stores nutrients:**
    - *Fat cell.* The huge spherical shape of a fat cell is produced by a large lipid droplet in its cytoplasm.
5. **Cell that fights disease:**
    - *Macrophage (a phagocytic cell).* This cell extends long pseudopods ("false feet") to crawl through tissue to reach infection sites. The many lysosomes within the cell digest the infectious microorganisms it takes up.
6. **Cell that gathers information and controls body functions:**
    - *Nerve cell (neuron).* This cell has long processes for receiving messages and transmitting them to other structures in the body. The processes are covered with an extensive plasma membrane, and a plentiful rough ER is present to synthesize membrane components.
7. **Cells of reproduction:**
    - *Oocyte (female).* The largest cell in the body, this egg cell contains many copies of all organelles, for distribution to the daughter cells that arise when the fertilized egg divides to become an embryo.
    - *Sperm (male).* This cell is long and streamlined, built for swimming to the egg for fertilization. Its flagellum acts as a motile whip to propel the sperm.

Cell Physiology

As mentioned earlier, each of the cell's internal parts is designed to perform a specific function for the cell. Most cells have the ability to *metabolize* (use nutrients to build new cell material, break down substances, and make ATP), *digest foods, dispose of wastes, reproduce, grow, move,* and *respond to a stimulus* (irritability). Most of these functions are considered in detail in later chapters. For example, metabolism is covered in Chapter 14, and the ability to react to a stimulus is covered in Chapter 7. Here, we will consider only the functions of membrane transport (the means by which substances get through plasma membranes), protein synthesis, and cell reproduction (cell division).

Membrane Transport

The fluid environment on both sides of the plasma membrane is an example of a solution. It is important that you really understand solutions before we dive into an explanation of membrane transport. In the most basic sense, a **solution** is a homogeneous mixture of two or more components. Examples include the air we breathe (a mixture of gases), seawater (a mixture of water and salts), and rubbing alcohol (a mixture of water and alcohol). The substance present in the largest amount in a solution is called the **solvent** (or dissolving medium). Water is the body's chief solvent. Components or substances present in smaller amounts are called **solutes.** The solutes in a solution are so tiny; they do not settle out.

Intracellular fluid (collectively, the nucleoplasm and the cytosol) is a solution containing small amounts of gases (oxygen and carbon dioxide), nutrients, and salts, dissolved in water. So too is **interstitial fluid,** the fluid that continuously bathes the exterior of our cells. Interstitial fluid can be thought of as a rich, nutritious, and rather unusual "soup." It contains thousands of ingredients, including nutrients (amino acids, sugars, fatty acids, vitamins), regulatory substances such as hormones and neurotransmitters, salts, and waste products. To remain healthy, each cell must extract a large Golgi apparatus, to make and secrete the protein building blocks of these fibers.

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The plasma membrane is a selectively permeable barrier. **Selective permeability** means that a barrier allows some substances to pass through it while excluding others. Thus, it allows nutrients to enter the cell but keeps many undesirable substances out. At the same time, valuable cell proteins and other substances are kept within the cell, and wastes are allowed to pass out of it.

Homeostatic Imbalance

The property of selective permeability is typical only of healthy, unharmed cells. When a cell dies or is badly damaged, its plasma membrane can no longer be selective and becomes permeable to nearly everything. This phenomenon is evident when someone has been severely burned. Precious fluids, proteins, and ions "weep" (leak out) from the dead and damaged cells of the burned areas.

Movement of substances through the plasma membrane happens in basically two ways—passively or actively. In **passive transport processes,** substances are transported across the membrane without any energy input from the cell. In **active transport processes,** the cell provides the metabolic energy (ATP) that drives the transport process.

Passive Transport Processes: Diffusion and Filtration

Diffusion (dĭ-fu′zhun) is an important means of passive membrane transport for every cell of the body. The other passive transport process, *filtration,* generally occurs only across capillary walls. Let us examine how these two types of passive transport differ.

Diffusion **Diffusion** is the process by which molecules (and ions) tend to scatter themselves throughout the available space. All molecules possess *kinetic energy* (energy of motion), as described in Chapter 2. As the molecules move about randomly at high speeds, they collide and change direction with each collision. Since the overall effect of this erratic movement is that molecules move away from a region where they are more concentrated (more numerous) to a region where they are less concentrated (fewer of them), we say that molecules move *down* their **concentration gradient.** Because the driving force (source of energy) is the kinetic energy of the molecules themselves, the speed of diffusion is affected by the size of the molecules (the smaller the faster) and temperature (the warmer the faster).

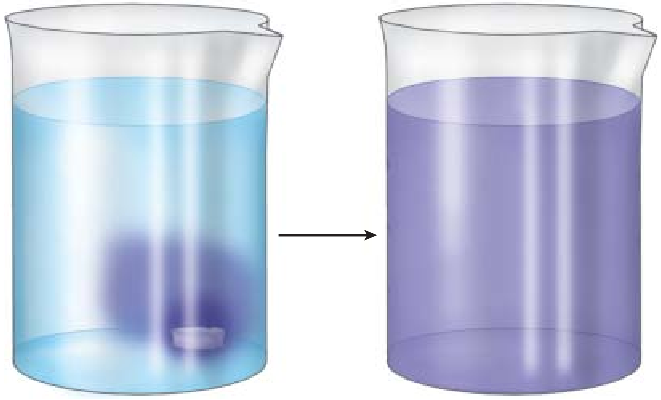
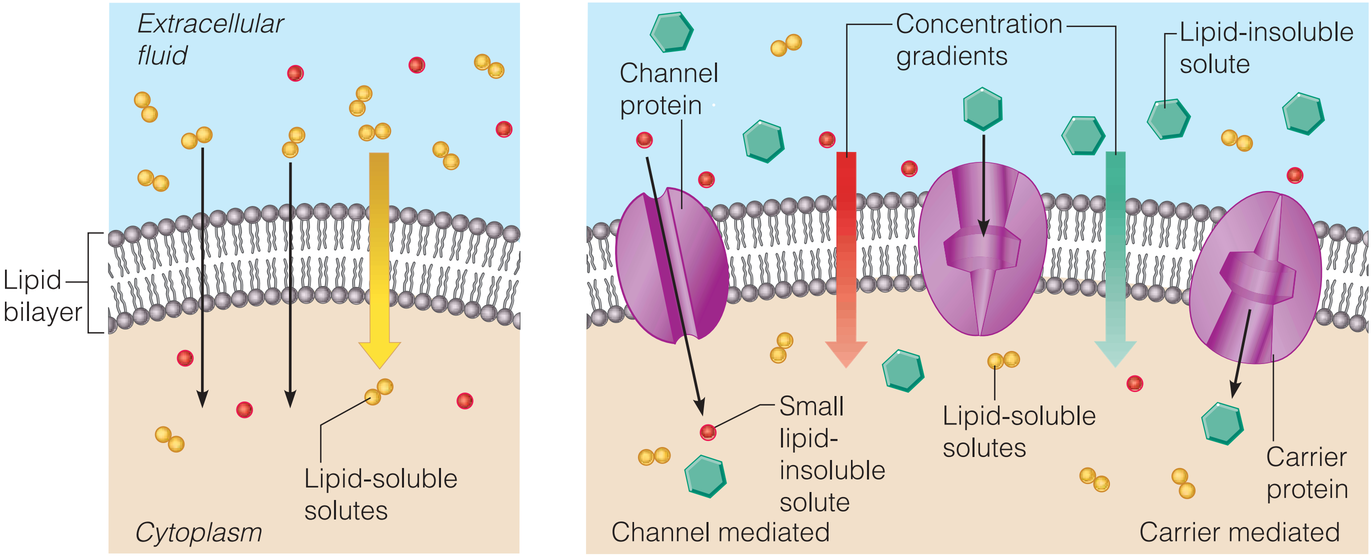


FIGURE 3.9 **Diffusion.** Particles in solution move continuously and collide constantly with other particles. As a result, particles tend to move away from areas where they are most highly concentrated and to become evenly distributed, as illustrated by the diffusion of dye molecules in a beaker of water.

An example should help you understand diffusion. Picture yourself pouring a cup of coffee, and then adding a cube of sugar (but not stirring the cup). After adding the sugar, the phone rings, and you are called in to work. You never do get to drink the coffee. Upon returning that evening, you find that the coffee tastes sweet even though it was never stirred. This is because the sugar molecules moved around all day and eventually, as a result of their activity, became sufficiently distributed throughout the coffee to sweeten the entire cup. A laboratory example that might be familiar to some students is illustrated in Figure 3.9.

The plasma membrane is a physical barrier to diffusion. Molecules will move *passively* through the plasma membrane by diffusion if (1) they are small enough to pass through its pores or (2) they can dissolve in the fatty portion of the membrane (Figure 3.10). The unassisted diffusion of solutes through the plasma membrane (or any selectively permeable membrane) is called **simple diffusion** (Figure 3.10a). Solutes transported this way are either lipid-soluble (fats, fat-soluble vitamins, oxygen, carbon dioxide) or small enough to pass through the membrane pores (some small ions such as chloride ions, for example).

Q *What "facilitates" facilitated diffusion?*



(a) Simple diffusion **(b) Facilitated diffusion**

FIGURE 3.10 Diffusion through the plasma membrane. (a) Simple diffusion. Lipid-soluble molecules diffuse directly through the lipid bilayer of the plasma membrane, in which they can dissolve. **(b)** Facilitated diffusion. On the left, small lipid-insoluble substances (water molecules or small ions) are shown diffusing through channels constructed by membrane proteins. On the right, facilitated diffusion moves large, lipid-insoluble molecules (e.g., glucose) across the membrane. The substance to be transported binds to a transmembrane protein carrier in this example.

Diffusion of water through a selectively permeable membrane such as the plasma membrane is specifically called **osmosis** (oz-mo′sis). Because water is highly polar, it is repelled by the (nonpolar) lipid core of the plasma membrane, but it can and does pass easily through special pores called *aquaporins* ("water pores") created by the proteins in the membrane. Osmosis into and out of cells is occurring all the time as water moves down its concentration gradient.

Still another example of diffusion is **facilitated diffusion** (see Figure 3.10b). Facilitated diffusion provides passage for certain needed substances (notably glucose) that are both lipid-insoluble and too large to pass through the membrane pores. Although facilitated diffusion follows the laws of diffusion—that is, the substances move down their own concentration gradient—a protein membrane channel is used or a protein molecule that acts as a carrier is needed as a transport vehicle. Hence, some of the proteins in the plasma membrane form channels or act as carriers to move glucose and certain other solutes passively across the membrane and make it available for cell use.

Substances that pass into and out of cells by diffusion save the cell a great deal of energy. When you consider how vitally important water, glucose, and oxygen are to cells, it becomes apparent just how necessary these passive transport processes really are. Glucose and oxygen continually move into the cells (where they are in lower concentration because the cells keep using them up), and carbon dioxide (a waste product of cellular activity) continually moves out of the cells into the blood (where it is in lower concentration).

A *Carrier proteins or protein channels.*

A Closer Look

IV Therapy and Cellular "Tonics"

WHY is it essential that medical personnel give only the proper *intravenous (IV)*, or into-the-vein, *solutions* to patients?

Consider that there is a steady traffic of small molecules across the plasma membrane. Although diffusion of solutes across the membrane is rather slow, osmosis, which moves water across the membrane, occurs very quickly. Anyone administering an IV must use the correct solution to protect the patient's cells from life-threatening dehydration or rupture due to excessive water entry.

The tendency of a solution to hold water or "pull" water into it is called osmotic pressure. Osmotic pressure is directly related to the concentration of solutes in the solution. The higher the solute concentration, the greater the osmotic pressure and the greater the tendency of water to move into the solution. Many molecules, particularly proteins and some ions, are prevented from diffusing through the plasma membrane. Consequently, any change in their concentration on one side of the membrane forces water to move from one side of the membrane to the other, causing cells to lose or gain water. The ability of a solution to change the size and shape of cells by altering the amount of water they contain is called *tonicity* (ton-is′i-te; *ton* = strength).

Isotonic (i″so-ton′ik; "same tonicity") solutions (such as Ringer's lactate, 5 percent dextrose, and 0.9 percent saline) have the same solute and water concentrations as cells do. Isotonic solutions cause no visible changes in cells, and when such solutions are infused into the bloodstream, red blood cells retain their normal size and disclike shape

(a) (b) (c)

The effect of IV solutions of varying tonicity on living red blood cells.

IV Therapy and Cellular "Tonics" *(continued)*

(Photo a). As you might guess, interstitial fluid and most intravenous solutions are isotonic solutions.

If red blood cells are exposed to a *hypertonic* (hi″per-ton′ik) solution—a solution that contains more solutes, or dissolved substances, than there are inside the cells—the cells will begin to shrink, or *crenate* (kre′nāt). This is because water is in higher concentration inside the cell than outside, so it follows its concentration gradient and leaves the cell (Photo b). Hypertonic solutions are sometimes given to patients who have *edema* (swollen feet and hands because of fluid retention). Such solutions draw water out of the tissue spaces into the bloodstream so that excess fluid can be eliminated by the kidneys.

When a solution contains fewer solutes (and therefore more water) than the cell does, it is said to be *hypotonic* (hi″po-ton′ik) to the cell. Cells placed in hypotonic solutions plump up rapidly as water rushes into them (Photo c). Distilled water represents the most extreme example of a hypotonic fluid. Since it contains no solutes at all, water will enter cells until they finally burst, or *lyse*. Hypotonic solutions are sometimes infused intravenously (slowly and with care) to rehydrate the tissues of extremely dehydrated patients. In less extreme cases, drinking hypotonic fluids usually does the trick. (Many fluids that humans tend to drink regularly, such as tea, colas, apple juice, and sport drinks, are hypotonic.)

Filtration **Filtration** is the process by which water and solutes are forced through a membrane (or capillary wall) by *fluid,* or *hydrostatic, pressure*. In the body, hydrostatic pressure is usually exerted by the blood. Like diffusion, filtration is a passive process, and a gradient is involved. In filtration, however, the gradient is a **pressure gradient** that actually pushes solute-containing fluid *(filtrate)* from the higher-pressure area to the lower-pressure area. Filtration is necessary for the kidneys to do their job properly. In the kidneys, water and small solutes filter out of the capillaries into the kidney tubules because the blood pressure in the capillaries is greater than the fluid pressure in the tubules. Part of the filtrate formed in this way eventually becomes urine. Filtration is not very selective. For the most part, only blood cells and protein molecules too large to pass through the membrane pores are held back.

Active Transport Processes

Whenever a cell uses some of its ATP supply to move substances across the membrane, the process is referred to as *active*. Substances moved actively are usually unable to pass in the desired direction by diffusion. They may be too large to pass through membrane channels or the membrane lacks special protein carriers for their transport, they may not be able to dissolve in the fat core, or they may have to move "uphill" *against* their concentration gradients. The two most important examples of active transport mechanisms, *solute pumping* and *bulk transport,* are described next.

Solute Pumping *Solute pumping* (more simply called *active transport* by some) is similar to the carrier-mediated facilitated diffusion described earlier in that both processes require protein carriers

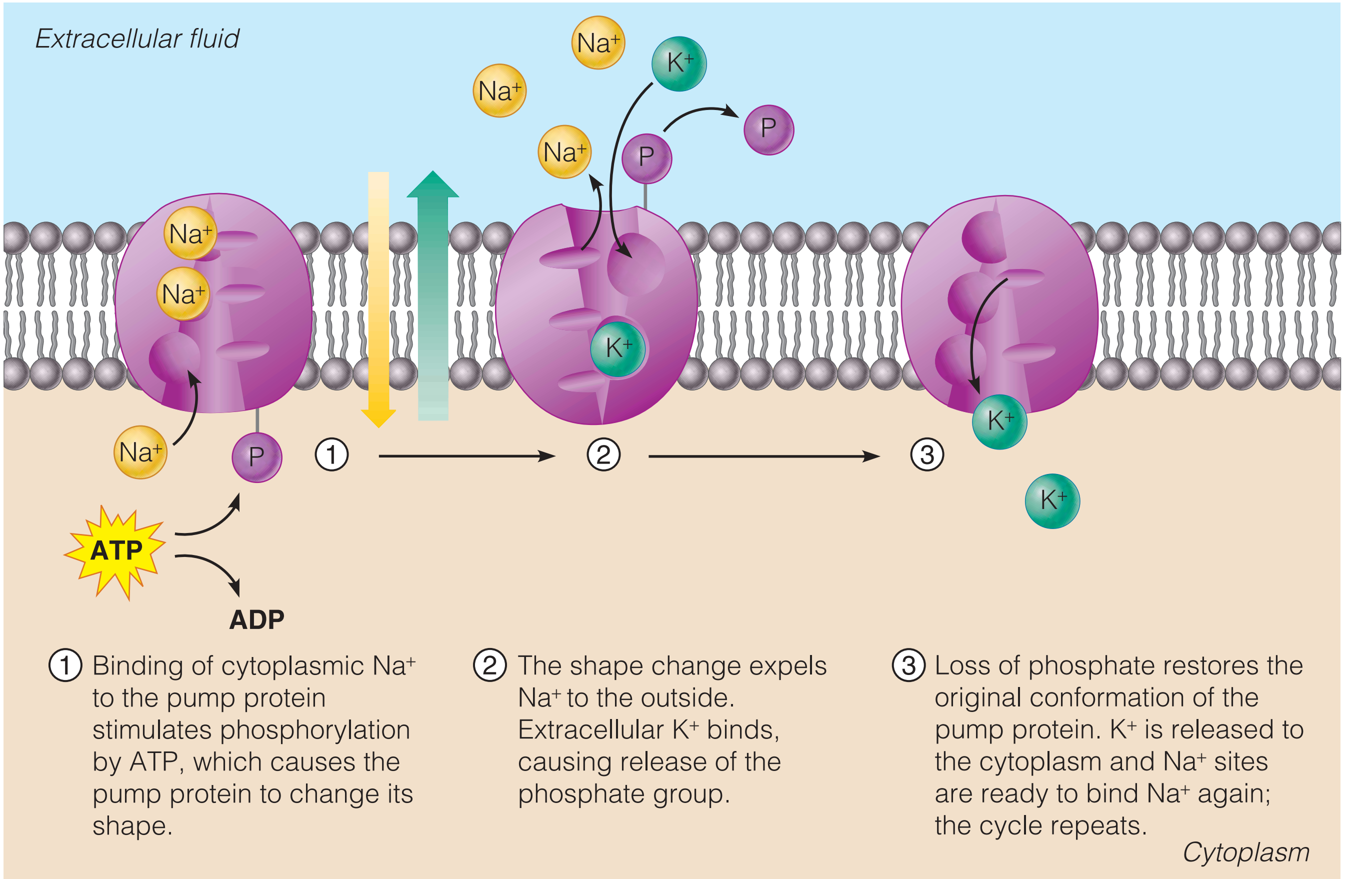


FIGURE 3.11 Operation of the sodium-potassium pump, a solute pump. ATP provides the energy for a "pump" protein to move three sodium ions out of the cell and two potassium ions into the cell. Both ions are moved against their concentration gradients.

that combine reversibly with the substances to be transported across the membrane. However, facilitated diffusion is driven by the kinetic energy of the diffusing molecules, whereas solute pumping uses ATP to energize its protein carriers, which are called **solute pumps.** Amino acids, some sugars, and most ions are transported by solute pumps, and in most cases these substances move *against* concentration (or electrical) gradients. This is opposite to the direction in which substances would naturally flow by diffusion, which explains the need for energy in the form of ATP. Amino acids are needed to build cellular proteins but are too large to pass through the membrane channels and are not lipid-soluble. The **sodium-potassium pump** that simultaneously carries sodium ions out of and potassium ions into the cell is absolutely necessary for normal transmission of impulses by nerve cells. Sodium ions (Na^+) are moved out of cells by solute pumps (Figure 3.11). There are more sodium ions outside the cells than inside, so they tend to remain in the cell unless the cell uses ATP to force, or "pump," them out. Likewise, there are relatively more potassium ions inside cells than in the interstitial (extracellular) fluid, and potassium ions that leak out of cells must be actively pumped back inside. Since each of the pumps in the plasma membrane transports only specific substances, solute pumping provides a way for the cell to be very selective in cases where substances cannot pass by diffusion. (No pump—no transport.)

Bulk Transport Some substances that cannot get through the plasma membrane in any other way are transported with the help of ATP out of or into cells by *bulk transport*. The two types of bulk transport are *exocytosis* and *endocytosis*.

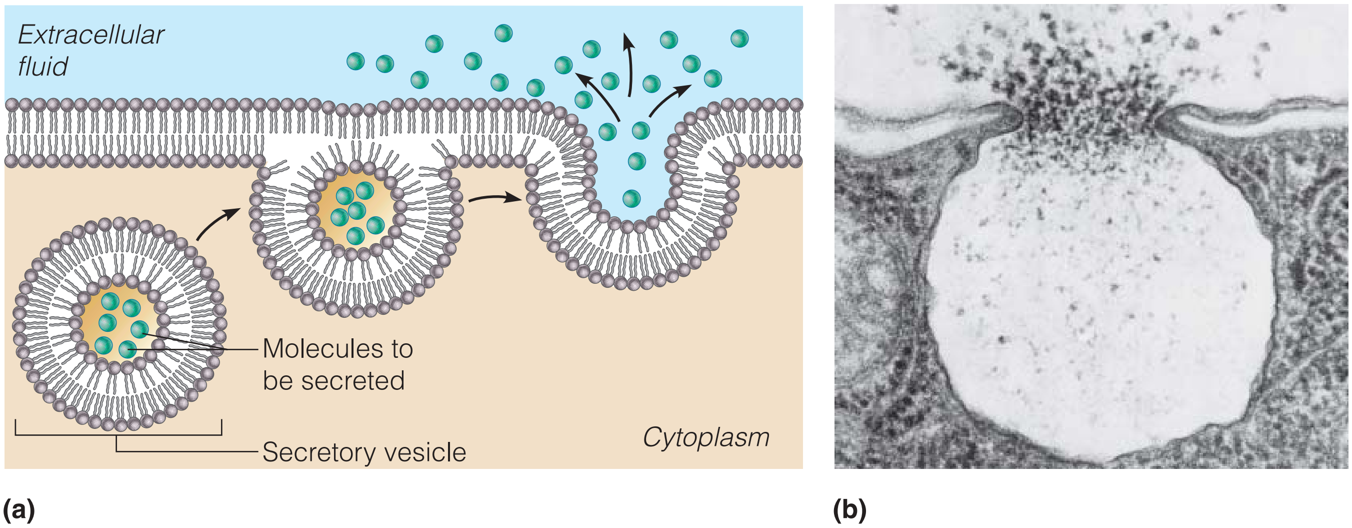


FIGURE 3.12 **Exocytosis. (a)** A secretory vesicle migrates to the plasma membrane, and the two membranes fuse. The fused site opens and releases the contents to the outside of the cell. **(b)** Electron micrograph of a vesicle in exocytosis (100,000×).

Exocytosis (ek″so-si-to′sis; "out of the cell") moves substances out of cells (Figure 3.12). It is the means by which cells actively secrete hormones, mucus, and other cell products or eject certain cellular wastes. The product to be released is first "packaged" (typically by the efforts of the Golgi apparatus) into a small membranous vesicle or sac. The sac migrates to the plasma membrane and fuses with it. The fused area then ruptures, spilling the sac contents out of the cell (also see Figure 3.6).

Endocytosis (en″do-si-to′sis; "into the cell") includes those ATP-requiring processes that take up, or engulf, extracellular substances by enclosing them in a small membranous vesicle (Figure 3.13). Once the vesicle, or sac, is formed, it detaches from the plasma membrane and moves into the cytoplasm, where it fuses with a lysosome and its contents are digested (by lysosomal enzymes). If the engulfed substances are relatively large particles such as bacteria or dead body cells, which are separated from the external environment by flowing cytoplasmic extensions called pseudopods, the endocytosis process is more specifically called **phagocytosis** (fag″o-si-to′sis), a term that means "cell eating" (Figure 3.13b). Certain white blood cells and other "professional" phagocytes of the body act as scavenger cells that police and protect the body by ingesting bacteria and other foreign debris as well as dead body cells. Hence, phagocytosis is a protective mechanism, not a means of getting nutrients.

If we say that cells can eat, we can also say that they can drink. This is **fluid-phase endocytosis,** also called **pinocytosis** (pi″no-si-to′sis; "cell drinking"). In this process the plasma membrane invaginates to form a tiny pit and then its edges fuse around the droplet of extracellular fluid containing dissolved proteins or fats (Figure 3.13a). Unlike phagocytosis, it is a routine activity of most cells. It is especially important in cells that function in absorption (for example, cells forming the lining of the small intestine and kidney tubule cells).

Receptor-mediated endocytosis is the main cellular mechanism for taking up specific target molecules (Figure 3.13c). In this process, plasma membrane receptor proteins bind only with certain substances, and both the receptors and high concentrations of the attached target molecules are internalized in a vesicle and then the contents of the vesicle are dealt with in one of the ways shown in Figure 3.13a. Although phagocytosis and pinocytosis are important, compared to receptor-mediated endocytosis, they are pretty unselective. Substances encytosed by receptor-mediated endocytosis include enzymes, some hormones, cholesterol, and iron. Unfortunately, flu viruses also use this route to enter and attack our cells.