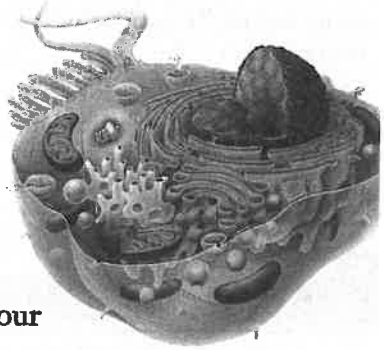
chapter 3 CELLS



did you know?

Why is it so important to eat a variety of fruits and vegetables? Because your parents wouldn't let you have dessert unless you did? Another good reason to eat plenty of fruits and vegetables is that these foods contain important compounds, known as phytochemicals (literally, "plant chemicals"), which help to keep cells healthy. Some phytochemicals block chemicals that can cause damage to cells. Others enhance your body's production of enzymes that render potentially cancer-causing substances harmless. Collectively, the actions of phytochemicals promote healthy cellular function, and prevent the types of cellular damage associated with cancer, aging, and heart disease.

Focus on Wellness, page 64

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About 200 different types of cells compose your body. Each ***cell*** is a living structural and functional unit that is enclosed by a membrane. All cells arise from existing cells by the proc of ***cell division***, in which one cell divides into two new cells. In your body, different types of cells fulfill uniqu roles that support homeostasis and contribute to the many functional capabilities of the human organism. ***Cell biology*** is the study of cellular structure and function. As you study the various parts of a cell and their relationships to each other, you will learn that cell structure and function are intimately related.

looking back to move ahead . . .

- **Levels of Organization and Body Systems (page 2)**
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A GENERALIZED VIEW OF THE CELL

OBJECTIVE • Name and describe the three main parts of a cell.

Figure 3.1 is a generalized view of a cell that shows the main cellular components. Though some body cells lack some cellular structures shown in this diagram, many body cells include most of these components. For ease of study, we can divide a cell into 3 main parts: the plasma membrane, cytoplasm, and nucleus.

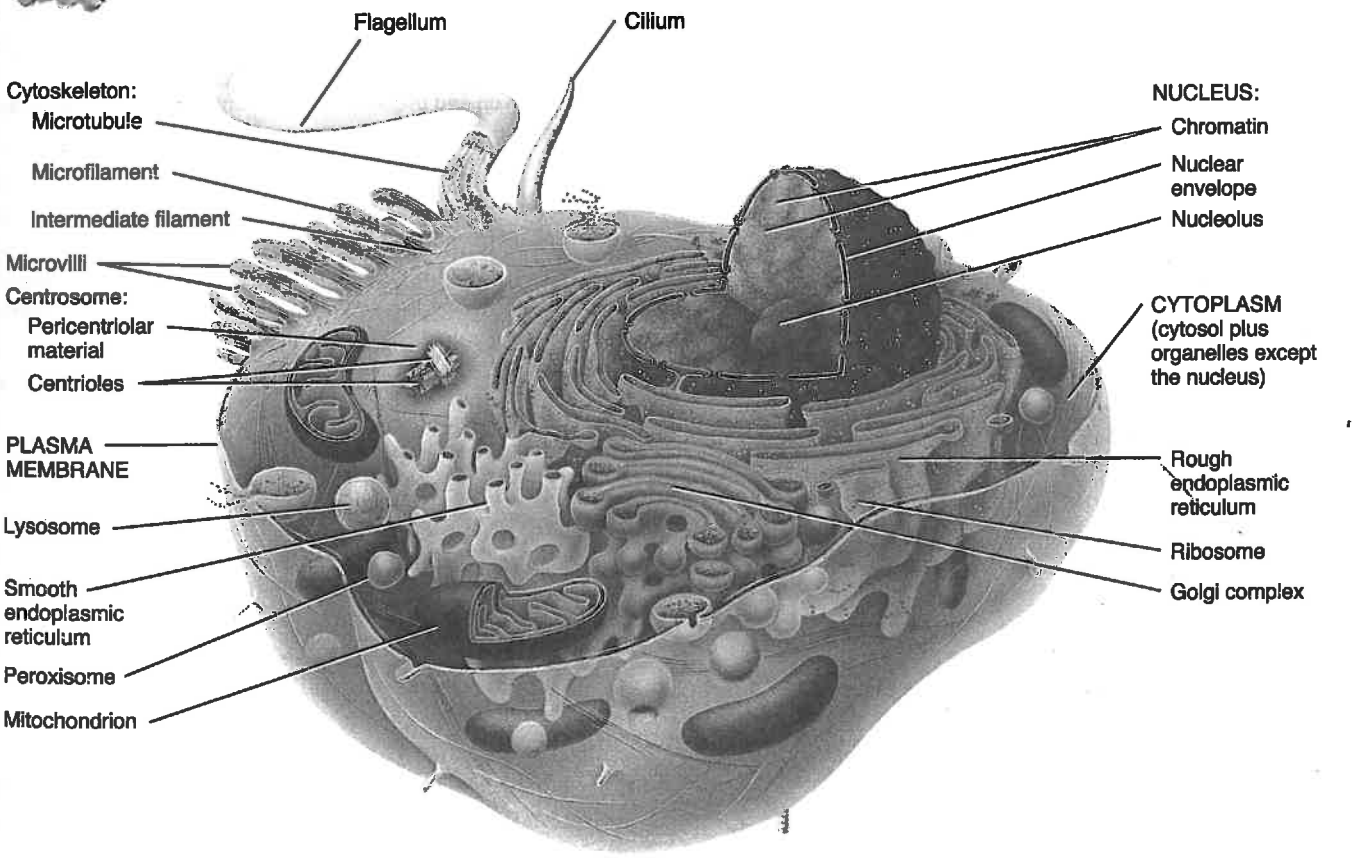
- The ***plasma membrane*** forms a cell's outer surface, separating the cell's internal environment (inside the cell) from its external environment (outside the cell). It regulates the flow of materials into and out of a cell to maintain the appropriate environment for normal cellular activities. The plasma membrane also plays a key role in communication among cells and between cells and their external environment.
- The ***cytoplasm*** (SĪ-tō-plazm; *-plasm* = formed or molded) consists of all the cellular contents between the plasma membrane and the nucleus. This compartment can be divided into two components: cytosol and organelles. ***Cytosol*** (SĪ-tō-sol) is the fluid portion of cytoplasm that consists mostly of water plus dissolved solutes and suspended particles. Within the cytosol are several different types of ***organelles*** (or-ga-NELZ = little organs), each of which has a characteristic structure and specific functions.
- The ***nucleus*** (NOO-klē-us = nut kernel) is the largest organelle of a cell. The nucleus acts as the control center for a cell because it contains the genes, which control cellular structure and most cellular activities.

CHECKPOINT

1. What are the general functions of the three main parts of a cell?

Figure 3.1 Generalized view of a body cell.

The cell is the basic, living, structural and functional unit of the body.



Sectional view

What are the three principal parts of a cell?

THE PLASMA MEMBRANE

OBJECTIVE • Describe the structure and functions of the plasma membrane.

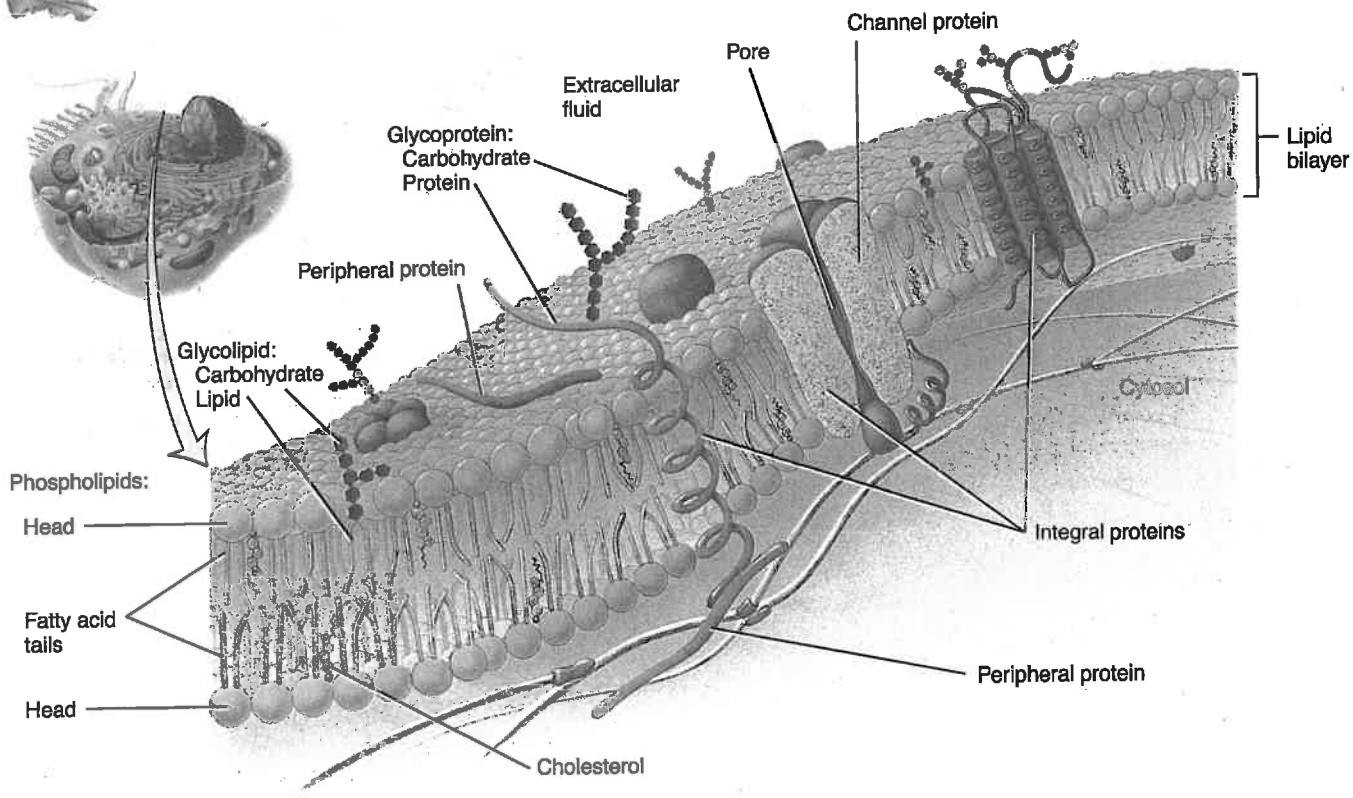
The ***plasma membrane*** is a flexible yet sturdy barrier that consists mostly of phospholipids (lipids that contain phosphorus) and proteins. Virtually all membrane proteins are ***glycoproteins***, proteins with attached carbohydrates. Other molecules present in lesser amounts in the plasma membrane are cholesterol and glycolipids (lipids with attached carbohydrates). The basic framework of the plasma membrane is the ***lipid bilayer***, two back-to-back layers made up of three types of lipid molecules: phospholipids, cholesterol, and glycolipids (Figure 3.2). The proteins in a membrane are of two types—integral and peripheral (Figure 3.2). ***Integral proteins*** extend into or through the lipid bilayer among the fatty acid tails. ***Peripheral proteins*** are loosely attached to the exterior or interior surface of the membrane. Although many of the proteins can float laterally in the lipid bilayer, each individual protein has a specific orientation with respect to the "inside" and "outside" faces of the membrane.

The plasma membrane allows some substances to move into and out of the cell but restricts the passage of other substances. This property of membranes is called ***selective permeability*** (per'-mē-a-BIL-i-tē). The lipid bilayer part of the membrane is permeable to water and to nonpolar (lipid-soluble) molecules, such as fatty acids, fat-soluble vitamins, steroids, oxygen, and carbon dioxide. The lipid bilayer is *not* permeable to ions and large, uncharged polar molecules such as glucose and amino acids. These small and medium-sized water-soluble materials may cross the membrane with the assistance of integral proteins. Some integral proteins form ***ion channels*** through which specific substances can move into and out of cells (Figure 3.2). Other membrane proteins act as ***transporters***, which change shape as they move a substance from one side of the membrane to the other. Large molecules such as proteins are unable to pass through the plasma membrane except by transport within vesicles (discussed later in this chapter).

Most functions of the plasma membrane depend on the types of proteins that are present. Integral proteins called ***receptors*** recognize and bind a specific molecule that governs some cellular function, for example, a hormone such as insulin. Some integral and peripheral proteins act as ***enzymes*** speeding up specific chemical reactions. Membrane glycoproteins and glycolipids often are ***cell identity markers***. They enable a cell to recognize other cells of its own kind during tissue formation, or to recognize and respond to potentially dangerous foreign cells.

Figure 3.2 Chemistry and structure of the plasma membrane.

The plasma membrane consists mostly of phospholipids, arranged in a bilayer, and proteins, most of which are glycoproteins.



Name several functions carried out by membrane proteins.

■ **CHECKPOINT**

2. What molecules make up the plasma membrane and what are their functions?
3. What is meant by selective permeability?

TRANSPORT ACROSS THE PLASMA MEMBRANE

OBJECTIVE • Describe the processes that transport substances across the plasma membrane.

Movement of materials across its plasma membrane is essential to the life of a cell. Certain substances must move into the cell to support metabolic reactions. Other materials must be moved out because they have been produced by the cell for export or are cellular waste products. Before discussing how materials move into and out of a cell, we need to understand what exactly is being moved as well as the form it needs to take to make its journey.

About two-thirds of the fluid in your body is contained inside body cells and is called ***intracellular fluid*** or ***ICF*** (*intra-* = within). ICF is actually the cytosol of a cell. Fluid outside body cells is called ***extracellular fluid*** or ***ECF*** (*extra-* = outside). The ECF in the microscopic spaces between the cells of tissues is ***interstitial fluid*** (in′-ter-STISH-al; *inter-* = between). The ECF in blood vessels is called ***plasma***, and that in lymphatic vessels is called ***lymph***.

Materials dissolved in body fluids include gases, nutrients, ions, and other substances needed to maintain life. Any material dissolved in a fluid is called a ***solute***, and the fluid in which it is dissolved is the ***solvent***. Body fluids are dilute solutions in which a variety of solutes are dissolved in a very familiar solvent, water. The amount of a solute in a solution is its ***concentration***. A ***concentration gradient*** is a difference in concentration between two different areas, for example, the ICF and ECF. Solutes moving from a high-concentration area (where there are more of them) to a low-concentration area (where there are fewer of them) are said to move *down* or *with* the concentration gradient. Solutes moving from a low-concentration area to a high-concentration area are said to move *up* or *against* the concentration gradient.

Substances move across cellular membranes by passive processes and active processes. ***Passive processes***, in which a substance moves down its concentration gradient through the membrane, using only its own energy of motion (kinetic energy), include simple diffusion and osmosis. In ***active processes***, cellular energy, usually in the form of ATP, is used to "push" the substance through the membrane "uphill" against its concentration gradient. An example is active transport. Another way that some substances may enter and leave cells is an active process in which tiny membrane sacs referred to as ***vesicles*** are used (see Figure 3.10).

Passive Processes

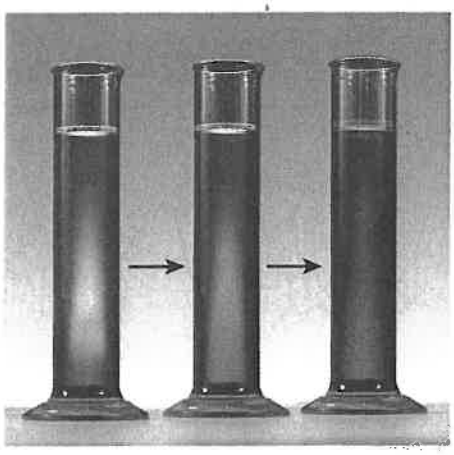
Diffusion: The Principle

Diffusion (di-FŪ-zhun; *diffus-* = spreading) is a passive process in which a substance moves from one place to another due to the substance's kinetic energy. If a particular substance is present in high concentration in one area and in low concentration in another area, more particles of the substance diffuse from the region of high concentration to the region of low concentration than diffuse in the opposite direction. The diffusion of more molecules in one direction than the other is called *net* diffusion. Substances undergoing net diffusion move from a high to a low concentration, or *down their concentration gradient*. After some time, ***equilibrium*** (ē′-kwi-LIB-rē-um) is reached: The substance becomes evenly distributed throughout the solution and the concentration gradient disappears.

Placing a crystal of dye in a water-filled container provides an example of diffusion (Figure 3.3). At the beginning, the color is most intense just next to the crystal because the crystal is dissolving and the dye concentration is greatest there. At increasing distances, the color is lighter and lighter because the dye concentration is lower and lower. The dye molecules undergo net diffusion, down their concentration gradient, until they are evenly mixed in the water. At equilibrium the solution has a uniform color. In the example of dye diffusion, no membrane was involved. Substances may also diffuse across a membrane, if the membrane is permeable to them.

Figure 3.3 Principle of diffusion. A crystal of dye placed in a cylinder of water dissolves (beginning), and there is net diffusion from the region of higher dye concentration to regions of lower dye concentration (intermediate). At equilibrium, dye concentration is uniform throughout the solution.

At equilibrium, net diffusion stops but random movements continue.



Beginning (a) Intermediate (b) Equilibrium (c)

How does simple diffusion differ from facilitated diffusion?

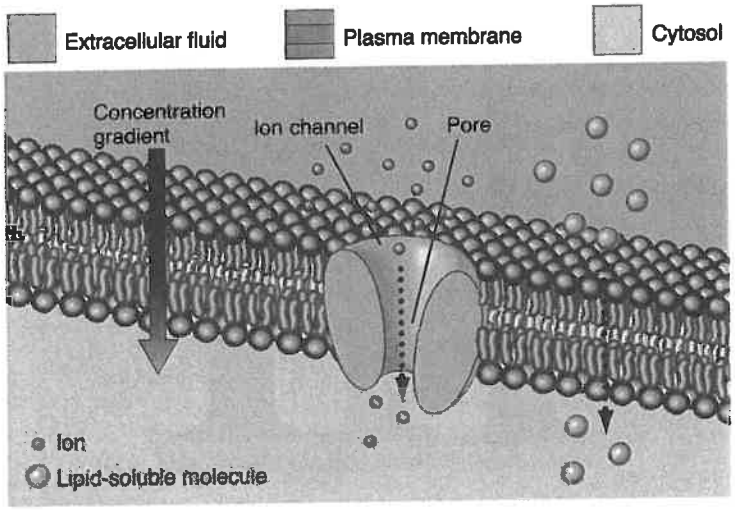
Now that you have a basic understanding of the nature of diffusion, we will consider two types of diffusion: simple diffusion and facilitated diffusion.

SIMPLE DIFFUSION In ***simple diffusion***, substances diffuse across a membrane in one of two ways: lipid-soluble substances diffuse through the lipid bilayer, and ions diffuse through pores of ion channels formed by integral proteins (Figure 3.4). Lipid-soluble substances that move across membranes by simple diffusion through the lipid bilayer include oxygen, carbon dioxide, and nitrogen gases; fatty acids; steroids; and fat-soluble vitamins (A, D, E, and K). Polar molecules such as water and urea also move through the lipid bilayer. Simple diffusion through the lipid bilayer is important in the exchange of oxygen and carbon dioxide between blood and body cells and between blood and air within the lungs during breathing. It also is the transport method for absorption of lipid-soluble nutrients and release of some wastes from body cells.

Most membrane channels are *ion channels*, which allow a specific type of ion to move across the membrane by simple diffusion through the channel's pore. In typical plasma membranes, the most common ion channels are selective for K^+ (potassium ions) or Cl^- (chloride ions); fewer channels are available for Na^+ (sodium ions) or Ca^{2+} (calcium ions). Many ion channels are gated; that is, a portion of the channel protein acts as a "gate," moving in one direction to open the pore and in another direction to close it (Figure 3.5). When the gates are open, ions diffuse into or out of cells, down their concentration gradient. Gated channels are important for the production of electrical signals by body cells.

Figure 3.4 Simple diffusion. Lipid-soluble molecules may diffuse through the lipid bilayer, and ions may diffuse through pores of ion channels in integral proteins. Plasma membranes have channels, formed by integral proteins, that are selective for potassium ions (K^+), sodium ions (Na^+), calcium ions (Ca^{2+}), and chloride ions (Cl^-).

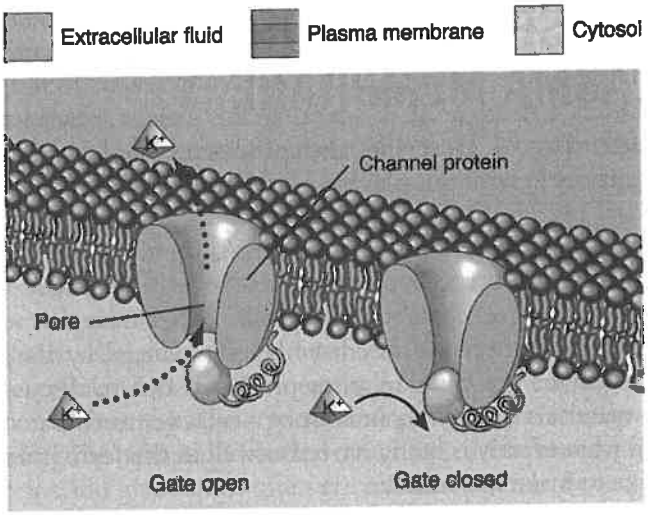
In simple diffusion there is a net (greater) movement of substances from a region of their higher concentration to a region of their lower concentration.



What are some examples of substances that diffuse through the lipid bilayer?

Figure 3.5 Diffusion of potassium ions (K^+) through a gated K^+ channel. A gated channel is one in which a portion of the channel protein acts as a gate to open or close the channel's pore to the passage of ions.

Channels are integral membrane proteins that allow specific small, inorganic ions to pass across the membrane by simple diffusion.



Details of the K^+ channel

Is the concentration of K^+ in body cells higher in the cytosol or in the extracellular fluid?

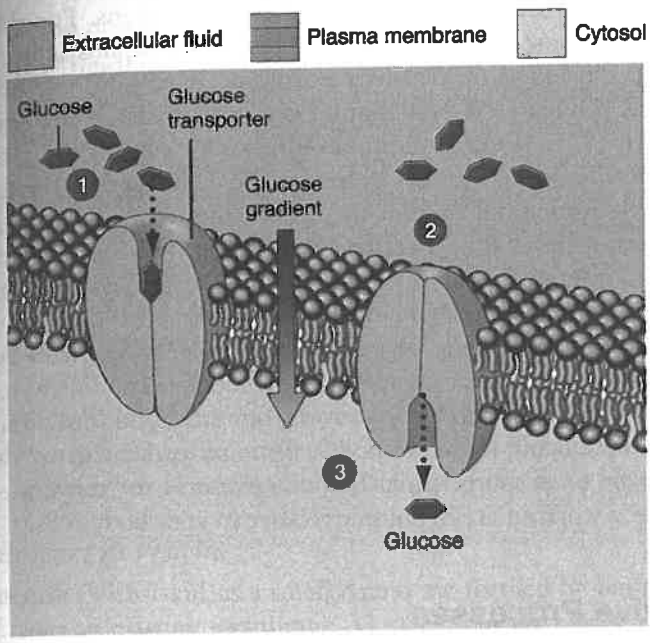
FACILITATED DIFFUSION Some substances that cannot diffuse through the lipid bilayer or through ion channels do cross the plasma membrane by a passive process called ***facilitated diffusion***. In this process, an integral membrane protein assists a specific substance across the membrane. The substance binds to a specific *transporter* on one side of the membrane and is released on the other side after the transporter undergoes a change in shape. As is true for simple diffusion, facilitated diffusion moves a substance down a concentration gradient—from a region of higher concentration to a region of lower concentration—and does not require cellular energy in the form of ATP.

Substances that move across plasma membranes by facilitated diffusion include glucose, fructose, galactose, and some vitamins. Glucose enters many body cells by facilitated diffusion as follows (Figure 3.6):

1. Glucose binds to a glucose transporter protein on the outside surface of the membrane.
2. As the transporter undergoes a change in shape, glucose passes through the membrane.
3. The transporter releases glucose on the other side of the membrane.

Figure 3.6 Facilitated diffusion of glucose across a plasma membrane. The transporter protein binds to glucose in the extracellular fluid and releases it into the cytosol.

Facilitated diffusion across a membrane requires a transporter protein but does not use ATP.



How does insulin alter glucose transport by facilitated diffusion?

The selective permeability of the plasma membrane is often regulated to achieve homeostasis. For example, the hormone insulin promotes the insertion of glucose transporters into the plasma membranes of certain cells. Thus, the effect of insulin is to increase entry of glucose into body cells by means of facilitated diffusion.

Osmosis

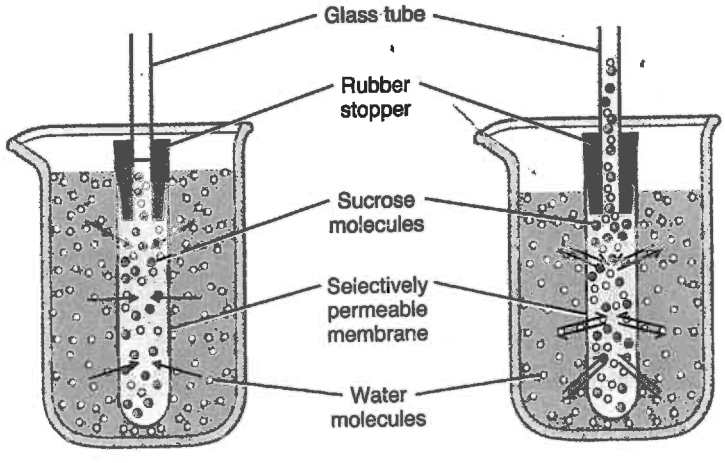
Osmosis (oz-MŌ-sis) is a passive process in which there is a net movement of water through a selectively permeable membrane. Water moves by osmosis from an area of *higher water concentration* to an area of *lower water concentration* (or from an area of *lower solute concentration* to an area of *higher solute concentration*). Water molecules pass through plasma membranes in two places: through the lipid bilayer and through integral membrane proteins that function as water channels.

The device in Figure 3.7 demonstrates osmosis. A sac made of cellophane, a selectively permeable membrane that permits water but not sucrose (sugar) molecules to pass, is filled with a solution that is 20% sucrose and 80% water. The upper part of the cellophane sac is wrapped tightly about a stopper through which a glass tube is fitted. The sac is then placed into a beaker containing pure (100%) water (Figure 3.7a). Notice that the cellophane now separates two fluids having different water concentrations. As a result, water begins to move by osmosis from the region where its concentration is higher (100% water in the beaker) through the cellophane to where its concentration is lower (80% water inside the sac). Because the cellophane is not permeable to sucrose, however, all the sucrose molecules remain inside the sac. As water moves into the sac, the volume of the sucrose solution increases and the fluid rises into the glass tube (Figure 3.7b). As the fluid rises in the tube, its water pressure forces some water molecules from the sac back into the beaker. At equilibrium, just as many water molecules are moving into the beaker due to the water pressure as are moving into the sac due to osmosis.

A solution containing solute particles that cannot pass through a membrane exerts a pressure on the membrane, called ***osmotic pressure***. The osmotic pressure of a solution depends on the concentration of its solute particles—the higher the solute concentration, the higher the solution's osmotic pressure. Because the osmotic pressure of cytosol and

Figure 3.7 Principle of osmosis. (a) At the start of the experiment, a cellophane sac—a selectively permeable membrane that permits water but not sucrose molecules to pass—containing a 20% sucrose solution is immersed in a beaker of pure (100%) water. Osmosis begins (arrows) as water moves down its concentration gradient into the sac. (b) As the volume of the sucrose solution increases, the solution moves up the glass tubing. The added fluid in the tube exerts a pressure that drives some water molecules back into the beaker. At equilibrium, osmosis has stopped because the number of water molecules entering and the number leaving the cellophane sac are equal.

Osmosis is the net movement of water molecules through a selectively permeable membrane.



Will the fluid level in the tube continue to rise until the sucrose concentrations are the same in the beaker and in the sac?

interstitial fluid is the same, cell volume remains constant. Cells neither shrink due to water loss by osmosis nor swell due to water gain by osmosis.

Any solution in which cells maintain their normal shape and volume is called an ***isotonic solution*** (*iso-* = same; *tonic-* = tension) (Figure 3.8). This is a solution in which the concentrations of solutes are the *same* on both sides. For example, a 0.9% NaCl (sodium chloride, or table salt) solution, called a *normal saline solution*, is isotonic for red blood cells. When red blood cells are bathed in 0.9% NaCl, water molecules enter and exit the cells at the same rate, allowing the red blood cells to maintain their normal shape and volume.

If red blood cells are placed in a ***hypotonic solution*** (*hypo-* = less than), a solution that has a *lower* concentration of solutes (higher concentration of water) than the cytosol inside the red blood cells (Figure 3.8), water molecules enter the cells by osmosis faster than they leave. This situation causes the red blood cells to swell and eventually to burst. Rupture of red blood cells is called ***hemolysis*** (hē-MOL-i-sis). A ***hypertonic solution*** (*hyper-* = greater than) has a *higher* concentration of solutes (lower concentration of water) than does the cytosol inside red blood cells (Figure 3.8). When cells are placed in a hypertonic solution, water molecules move out of the cells by osmosis faster than they enter, causing the cells to shrink. Such shrinkage of red blood cells is called ***crenation*** (kre-NĀ-shun).

RBCs and other body cells may be damaged or destroyed if exposed to hypertonic or hypotonic solutions. For this reason, most **intravenous (IV) solutions**, liquids infused into the blood of a vein, are isotonic. Examples are isotonic saline (0.9% NaCl) and D5W, which stands for dextrose 5% in water. Sometimes infusion of a hypertonic solution is useful to treat patients who have *cerebral edema*, excess interstitial fluid in the brain. Infusion of such a solution relieves fluid overload by causing osmosis of water from interstitial fluid into the blood. The kidneys then excrete the excess water from the blood into the urine. Hypotonic solutions, given either orally or through an IV, can be used to treat people who are dehydrated. The water in the hypotonic solution moves from the blood into interstitial fluid and then into body cells to rehydrate them. Water and most sports drinks that you consume to "rehydrate" after a workout are hypotonic relative to your body cells.

Active Processes

Active Transport

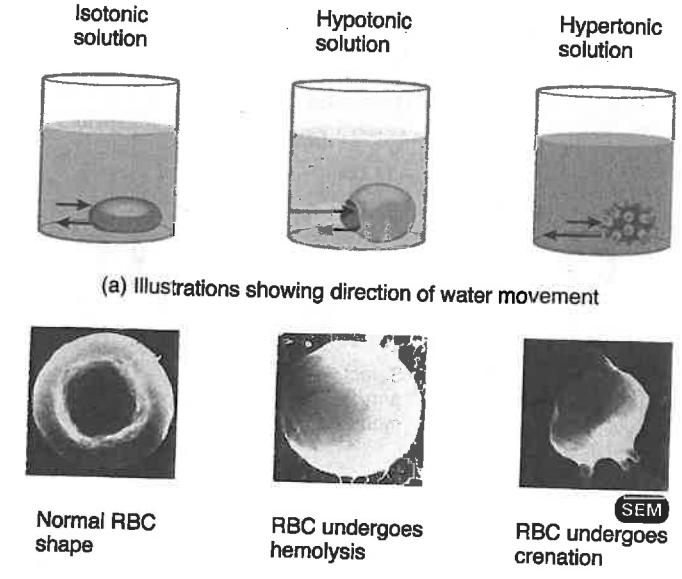
Active transport is an active process in which cellular energy is used to transport substances across the membrane against a concentration gradient (from an area of low to an area of high concentration).

Energy derived from splitting ATP changes the shape of a transporter protein, called a ***pump***, which moves a substance across a cellular membrane against its concentration gradient. A typical body cell expends about 40% of its ATP on active transport. Drugs that turn off ATP production, such as the poison cyanide, are lethal because they shut down active transport in cells throughout the body. Substances transported across the plasma membrane by active transport are mainly ions, primarily Na^+, K^+, H^+, Ca^{2+}, I^-, and Cl^-.

The most important active transport pump expels sodium ions (Na^+) from cells and brings in potassium ions (K^+). The pump protein also acts as an enzyme to split ATP. Because of the ions it moves, this pump is called the ***sodium-potassium*** (Na^+/K^+) ***pump***. All cells have thousands of sodium-potassium pumps in their plasma membranes. These pumps maintain a low concentration of sodium ions in the cytosol by pumping Na^+ into the extracellular fluid against the Na^+ concentration gradient. At the same time, the pump moves potassium ions into cells against the K^+ concentration gradient. Because K^+ and Na^+ slowly leak back across the plasma membrane down their gradients, the sodium-potassium pumps must operate continually to maintain a low concentration of Na^+ and a high concentration of K^+ in the cytosol. These differing concentrations are crucial for osmotic

Figure 3.8 Principle of osmosis applied to red blood cells (RBCs). The arrows indicate the direction and degree of water movement into and out of the cells. One example of an isotonic solution for RBCs is 0.9% NaCl.

An isotonic solution is one in which cells maintain their normal shape and volume.



Will a 2% solution of NaCl cause hemolysis or crenation of RBCs?

balance of the two fluids and also for the ability of some cells to generate electrical signals such as action potentials.

Figure 3.9 shows how the sodium-potassium pump operates.

1. Three sodium ions (Na^+) in the cytosol bind to the pump protein.
2. Na^+ binding triggers the splitting of ATP into ADP plus a phosphate group (Ⓟ), which also becomes attached to the pump protein. This chemical reaction changes the shape of the pump protein, expelling the three Na^+ into the extracellular fluid. The changed shape of the pump protein then favors binding of two potassium ions (K^+) in the extracellular fluid to the pump protein.
3. The binding of K^+ causes the pump protein to release the phosphate group, which causes the pump protein to return to its original shape.
4. As the pump protein returns to its original shape, it releases the two K^+ into the cytosol. At this point, the pump is ready again to bind Na^+, and the cycle repeats.

Transport in Vesicles

A ***vesicle*** (VES-i-kul) is a small round sac formed by budding off from an existing membrane. Vesicles transport substances from one structure to another within cells, take in substances from extracellular fluid, and release substances into extracellular fluid. Movement of vesicles requires energy supplied by ATP and is therefore an active process. The two main types of transport in vesicles between a cell and the extracellular fluid that surrounds it are (1) ***endocytosis*** (*endo-* = within), in which materials move *into* a cell in a vesicle formed from the plasma membrane, and (2) ***exocytosis*** (*exo-* = out), in which materials move *out of* a cell by the fusion of a vesicle formed inside a cell with the plasma membrane.

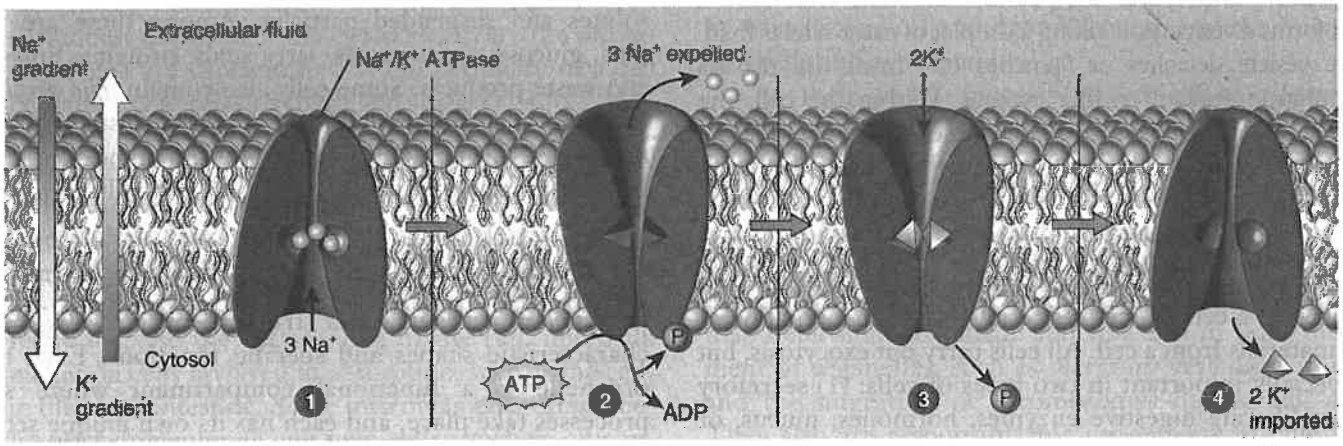
ENDOCYTOSIS Substances brought into the cell by endocytosis are surrounded by a piece of the plasma membrane, which buds off inside the cell to form a vesicle containing the ingested substances. The two types of endocytosis we will consider are phagocytosis and bulk-phase endocytosis.

1. **Phagocytosis.** In ***phagocytosis*** (fag′-ō-sī-TŌ-sis; *phago-* = to eat), large solid particles, such as whole bacteria or viruses or aged or dead cells, are taken in by the cell (Figure 3.10). Phagocytosis begins as the particle binds to a plasma membrane receptor, causing the cell to extend projections of its plasma membrane and cytoplasm, called ***pseudopods*** (SOO-dō-pods; *pseudo-* = false; *-pods* = feet). Two or more pseudopods surround the particle, and portions of their membranes fuse to form a vesicle that enters the cytoplasm. The vesicle fuses with one or more lysosomes, and lysosomal enzymes break down the ingested material. In most cases, any undigested materials remain indefinitely in a vesicle called a ***residual body***.

   Phagocytosis occurs only in ***phagocytes***, cells that are specialized to engulf and destroy bacteria and other foreign substances. Phagocytes include certain types of white blood cells and macrophages, which are present in most body tissues. The process of phagocytosis is a vital defense mechanism that helps protect the body from disease.

Figure 3.9 Operation of the sodium-potassium pump. Sodium ions (Na^+) are expelled from the cell, and potassium ions (K^+) are imported into the cell. The pump does not work unless Na^+ and ATP are present in the cytosol and K^+ is present in the extracellular fluid.

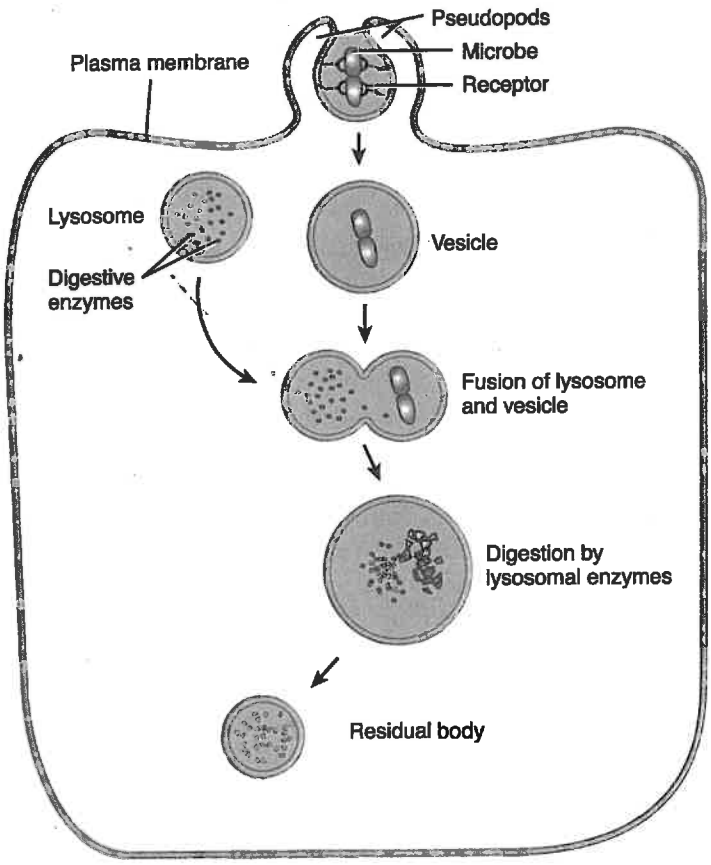
The sodium-potassium pump maintains a low intracellular concentration of Na^+.



What is the role of ATP in the operation of this pump?

Figure 3.10 Phagocytosis.

Phagocytosis is a vital defense mechanism that helps protect the body from disease.



What triggers pseudopod formation?

2. **Bulk-phase Endocytosis.** In ***bulk-phase endocytosis (pinocytosis)***, cells take up tiny droplets of extracellular fluid. The process occurs in most body cells and takes in any and all solutes dissolved in the extracellular fluid. During bulk-phase endocytosis the plasma membrane folds inward and forms a vesicle containing a droplet of extracellular fluid. The vesicle detaches or "pinches off" from the plasma membrane and enters the cytosol. Within the cell, the vesicle fuses with a lysosome, where enzymes degrade the engulfed solutes. The resulting smaller molecules, such as amino acids and fatty acids, leave the lysosome to be used elsewhere in the cell.

EXOCYTOSIS In contrast with endocytosis, which brings materials into a cell, exocytosis results in *secretion*, the liberation of materials from a cell. All cells carry out exocytosis, but it is especially important in two types of cells: (1) secretory cells that liberate digestive enzymes, hormones, mucus, or other secretions; (2) nerve cells that release substances called *neurotransmitters* via exocytosis (see Figure 9.7 on page 235). During exocytosis, membrane-enclosed vesicles called *secretory vesicles* form inside the cell, fuse with the plasma membrane, and release their contents into the extracellular fluid.

Segments of the plasma membrane lost through endocytosis are recovered or recycled by exocytosis. The balance between endocytosis and exocytosis keeps the surface area of a cell's plasma membrane relatively constant.

Table 3.1 summarizes the processes by which materials move into and out of cells.

■ CHECKPOINT

4. What is the key difference between passive and active processes?
5. How does diffusion through membrane channels compare to facilitated diffusion?
6. In what ways are endocytosis and exocytosis similar and different?

CYTOPLASM

OBJECTIVE • Describe the structure and functions of cytoplasm, cytosol, and organelles.

Cytoplasm consists of all of the cellular contents between the plasma membrane and the nucleus and includes both cytosol and organelles.

Cytosol

The ***cytosol*** (***intracellular fluid***) is the fluid portion of the cytoplasm that surrounds organelles and accounts for about 55% of the total cell volume. Although cytosol varies in composition and consistency from one part of a cell to another, typically it is 75% to 90% water plus various dissolved solutes and suspended particles. Among these are various ions, glucose, amino acids, fatty acids, proteins, lipids, ATP, and waste products. Some cells also contain *lipid droplets* that contain triglycerides and *glycogen granules*, clusters of glycogen molecules. The cytosol is the site of many of the chemical reactions that maintain cell structures and allow cellular growth.

Organelles

Organelles are specialized structures inside cells that have characteristic shapes and specific functions. Each type of organelle is a functional compartment where specific processes take place, and each has its own unique set of enzymes.

Table 3.1 Transport of Materials Into and Out of Cells

Transport Process	Description	Substances Transported
Passive Processes	Movement of substances down a concentration gradient until equilibrium is reached; do not require cellular energy in the form of ATP.	
Diffusion		
Simple diffusion		
Diffusion through the lipid bilayer	Passive movement of a substance through the lipid bilayer of the plasma membrane.	Lipid-soluble molecules: oxygen, carbon dioxide, and nitrogen gases; fatty acids, steroids, and fat-soluble vitamins (A, D, E, K). Polar molecules: water and urea.
Diffusion through membrane channels	Passive movement of a substance down its gradient through channels that span a lipid bilayer; some channels are gated.	Mainly ions: K^+, Cl^-, Na^+, and Ca^{2+}. Water.
Facilitated diffusion	Passive movement of a substance down its concentration gradient aided by membrane proteins known as transporters.	Glucose, fructose, galactose, and some vitamins.
Osmosis	Movement of water molecules across a selectively permeable membrane from an area of higher water concentration to an area of lower water concentration.	Water.
Active Processes	Movement of substances against a concentration gradient; requires cellular energy in the form of ATP.	
Active Transport	Transport in which cell expends energy to move a substance across the membrane against its concentration gradient aided by membrane proteins that act as pumps; these integral membrane proteins use energy supplied by ATP.	Na^+, K^+, Ca^{2+}, H^+, I^-, Cl^-, and other ions.
Transport in Vesicles	Movement of substances into or out of a cell in vesicles that bud from the plasma membrane; requires energy supplied by ATP.	
Endocytosis	Movement of substances into a cell in vesicles.	
Phagocytosis	"Cell eating"; movement of a solid particle into a cell after pseudopods engulf it.	Bacteria, viruses, and aged or dead cells.
Bulk-phase endocytosis	"Cell drinking"; movement of extracellular fluid into a cell by infolding of plasma membrane.	Solutes in extracellular fluid.
Exocytosis	Movement of substances out of a cell in secretory vesicles that fuse with the plasma membrane and release their contents into the extracellular fluid.	Neurotransmitters, hormones, and digestive enzymes.

The Cytoskeleton

Extending throughout the cytosol, the ***cytoskeleton*** is a network of three different types of protein filaments: microfilaments, intermediate filaments, and microtubules (Figure 3.11).

The thinnest elements of the cytoskeleton are the ***microfilaments***, which are concentrated at the periphery of a cell and contribute to the cell's strength and shape (Figure 3.11a). Microfilaments have two general functions: providing mechanical support and helping generate movements. They also anchor the cytoskeleton to integral proteins in the plasma membrane and provide support for microscopic, fingerlike projections of the plasma membrane called ***microvilli*** (*micro-* = small; *-villi* = tufts of hair; singular is *microvillus*). Because they greatly increase the surface area of the cell, microvilli are abundant on cells involved in absorption, such as the cells that line the small intestine. Some microfilaments extend beyond the plasma membrane and help cells attach to one another or to extracellular materials.

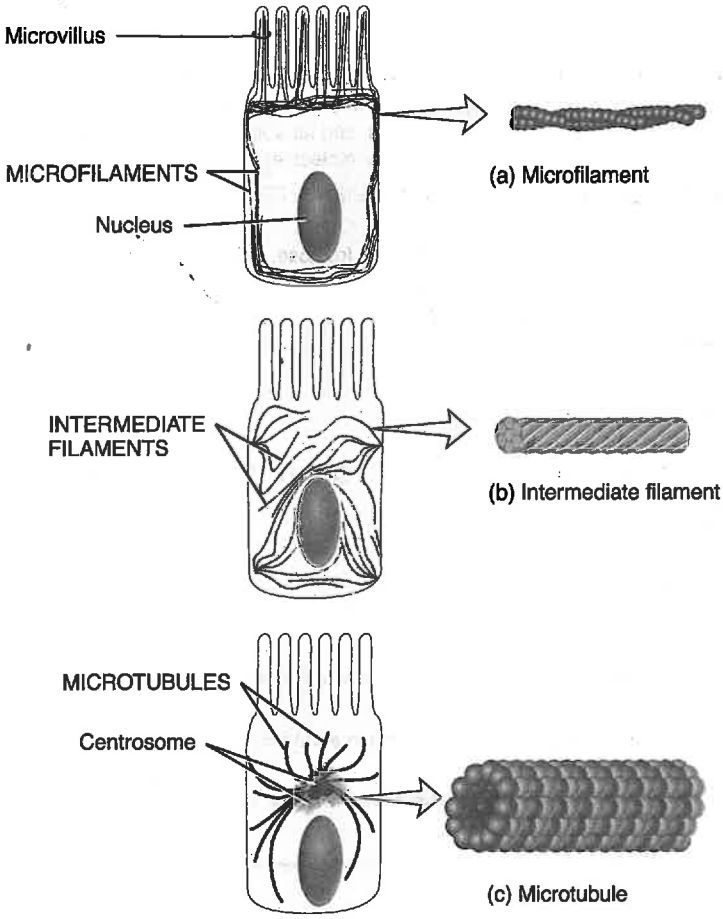
With respect to movement, microfilaments are involved in muscle contraction, cell division, and cell locomotion. Microfilament-assisted movements include the migration of embryonic cells during development, the invasion of tissues by white blood cells to fight infection, and the migration of skin cells during wound healing.

As their name suggests, ***intermediate filaments*** are thicker than microfilaments but thinner than microtubules (Figure 3.11b). They are found in parts of cells subject to tension (such as stretching), help hold organelles such as the nucleus in place, and help attach cells to one another.

The largest of the cytoskeletal components, ***microtubules*** are long, hollow tubes (Figure 3.11c). Microtubules help determine cell shape and function in both the movement of organelles, such as secretory vesicles, within a cell and the migration of chromosomes during cell division. They also are responsible for movements of cilia and flagella.

Figure 3.11 Cytoskeleton.

Extending throughout the cytoplasm, the cytoskeleton is a network of three kinds of protein filaments: microfilaments, intermediate filaments, and microtubules.



Which cytoskeletal components help form the structure of centrioles, cilia, and flagella?

Centrosome

The ***centrosome***, located near the nucleus, has two components—a pair of centrioles and pericentriolar material (Figure 3.12). The two *centrioles* are cylindrical structures, each of which is composed of nine clusters of three microtubules (a triplet) arranged in a circular pattern. Surrounding the centrioles is the *pericentriolar material* (per′-ē-sen′-trē-Ō-lar), containing hundreds of ring-shaped proteins called *tubulins*. The tubulins are the organizing centers for growth of the mitotic spindle, which plays a critical role in cell division, and for microtubule formation in nondividing cells.

Cilia and Flagella

Microtubules are the main structural and functional components of cilia and flagella, both of which are motile projections of the cell surface. ***Cilia*** (SIL-ē-a; singular is *cilium* = eyelash) are numerous, short, hairlike projections that extend from the surface of the cell (see Figure 3.1). In the human body, cilia propel fluids across the surfaces of cells that are firmly anchored in place. The coordinated movement of many cilia on the surface of a cell causes a steady movement of fluid along the cell's surface. Many cells of the respiratory tract, for example, have hundreds of cilia that help sweep foreign particles trapped in mucus away from the lungs. Their movement is paralyzed by nicotine in cigarette smoke. For this reason, smokers cough often to remove foreign particles from their airways. Cells that line the uterine (fallopian) tubes also have cilia that sweep oocytes (egg cells) toward the uterus.

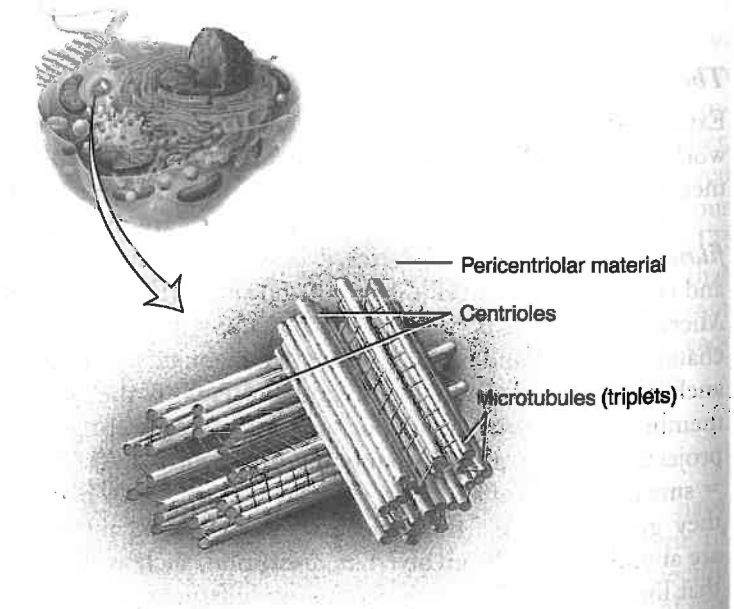
Flagella (fla-JEL-a; singular is *flagellum* = whip) are similar in structure to cilia but are much longer (see Figure 3.1). Flagella usually move an entire cell. The only example of a flagellum in the human body is a sperm cell's tail, which propels the sperm toward its possible union with an oocyte.

Ribosomes

Ribosomes (RĪ-bō-sōms; *-somes* = bodies) are the sites of protein synthesis. Ribosomes are named for their high content of *ribo*nucleic acid (RNA). Besides ribosomal RNA (rRNA), these tiny organelles contain ribosomal proteins. Structurally, a ribosome consists of two subunits, large and small, one about half the size of the other (Figure 3.13). The large and

Figure 3.12 Centrosome.

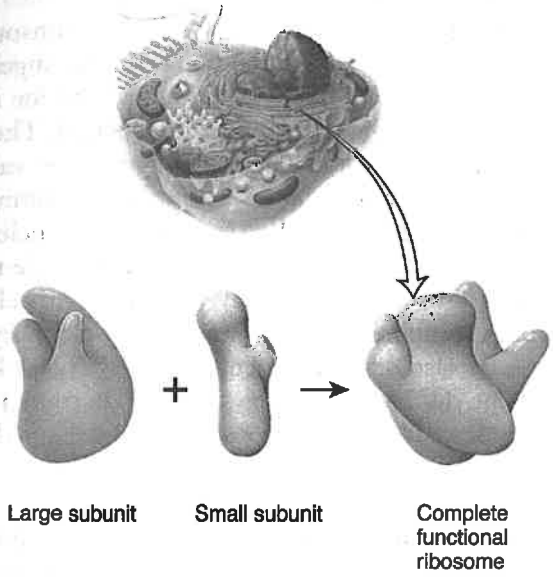
The pericentriolar material of a centrosome organizes the mitotic spindle during cell division.



What are the components of the centrosome?

Figure 3.13 Ribosomes.

Ribosomes, the sites of protein synthesis, consist of a large subunit and a small subunit.



Where are ribosomal subunits synthesized and assembled?

small subunits are made in the nucleolus of the nucleus. Later, they exit the nucleus and are assembled in the cytoplasm, where they form a functional ribosome.

Some ribosomes are attached to the outer surface of the nuclear membrane and to an extensively folded membrane called the endoplasmic reticulum. These ribosomes synthesize proteins destined for specific organelles, for insertion in the plasma membrane, or for export from the cell. Other ribosomes are "free" or unattached to other cytoplasmic structures. Free ribosomes synthesize proteins used in the cytosol. Ribosomes are also located within mitochondria, where they synthesize mitochondrial proteins.

Endoplasmic Reticulum

The ***endoplasmic reticulum*** (en′-dō-PLAS-mik re-TIK-ū-lum; *-plasmic* = cytoplasm; *reticulum* = network) or ***ER*** is a network of folded membranes (Figure 3.14). The ER extends throughout the cytoplasm and is so extensive that it constitutes more than half of the membranous surfaces within the cytoplasm of most cells.

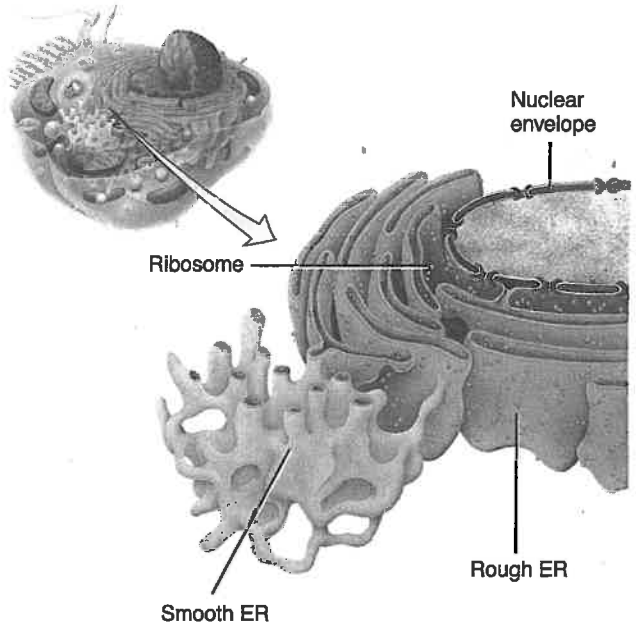
Cells contain two distinct forms of ER that differ in structure and function. ***Rough ER*** extends from the nuclear envelope (membrane around the nucleus) and appears "rough" because its outer surface is studded with ribosomes. Proteins synthesized by ribosomes attached to rough ER enter the spaces within the ER for processing and sorting. These molecules (glycoproteins and phospholipids) may be incorporated into organelle membranes or the plasma membrane. Thus, rough ER is a factory for synthesizing secretory proteins and membrane molecules.

Smooth ER extends from the rough ER to form a network of membranous tubules (Figure 3.14). As you may already have guessed, smooth ER appears "smooth" because it lacks ribosomes. Smooth ER is where fatty acids and steroids such as estrogens and testosterone are synthesized. In liver cells, enzymes of the smooth ER also help release glucose into the bloodstream and inactivate or detoxify a variety of drugs and potentially harmful substances, including alcohol, pesticides, and carcinogens (cancer-causing agents).

> One of the functions of smooth ER, as noted earlier, is to detoxify certain drugs. Individuals who repeatedly take such drugs, such as the sedative phenobarbital, develop changes in the smooth ER in their liver cells. Prolonged administration of phenobarbital results in increased tolerance to the drug; the same dose no longer produces the same degree of sedation. With repeated exposure to the drug, the amount of smooth ER and its enzymes increases to protect the cell from its toxic effects. As the amount of smooth ER increases, higher and higher dosages of the drug are needed to achieve the original effect.

Figure 3.14 Endoplasmic reticulum (ER).

The ER is a network of folded membranes that extend throughout the cytoplasm and connect to the nuclear envelope.



How do rough ER and smooth ER differ structurally and functionally?

Golgi Complex

After proteins are synthesized on a ribosome attached to rough ER, they usually are transported to another region of the cell. The first step in the transport pathway is through an organelle called the ***Golgi complex*** (GOL-jē). It consists of 3 to 20 ***cisterns*** (SIS-terns = cavities), flattened membranous sacs with bulging edges, piled on each other like a stack of pita bread (Figure 3.15). Most cells have several Golgi complexes. The Golgi complex is more extensive in cells that secrete proteins.

The main function of the Golgi complex is to modify and package proteins. Proteins synthesized by ribosomes on rough ER enter the Golgi complex and are modified to form glycoproteins and lipoproteins. Then, they are sorted and packaged. Some of the processed proteins are discharged from the cell by exocytosis. Certain cells of the pancreas release the hormone insulin this way. Other processed proteins become part of the plasma membrane as existing parts of the membrane are lost. Still other processed proteins become incorporated into organelles called lysosomes.

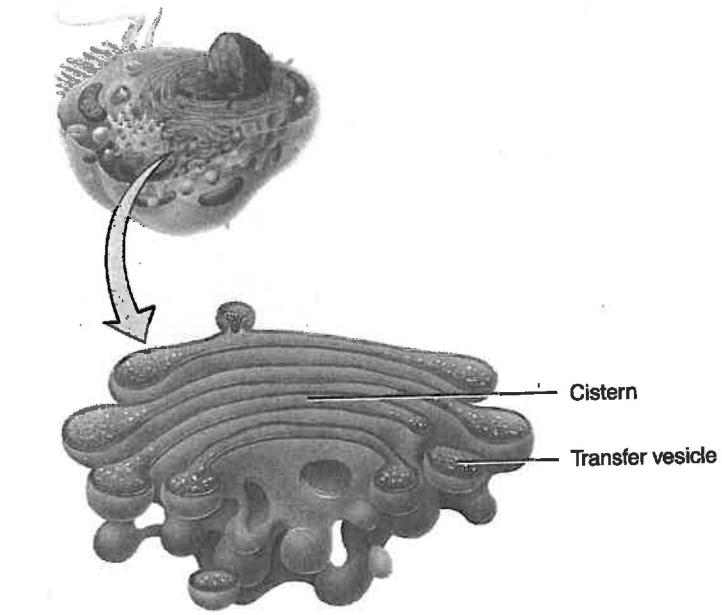
Lysosomes

Lysosomes (LĪ-sō-sōms; *lyso-* = dissolving; *-somes* = bodies) are membrane-enclosed vesicles (see Figure 3.1) that may contain as many as 60 different digestive enzymes; these enzymes can break down a wide variety of molecules once the lysosome fuses with vesicles formed during endocytosis. The lysosomal membrane allows the final products of digestion, such as monosaccharides, fatty acids, and amino acids, to be transported into the cytosol.

Lysosomal enzymes also help recycle worn-out structures. A lysosome can engulf another organelle, digest it, and return the digested components to the cytosol for reuse. In this way, old organelles are continually replaced. The process by which worn-out organelles are digested is called ***autophagy*** (aw-TOF-a-jē; *auto-* = self; *-phagy* = eating). During autophagy, the organelle to be digested is enclosed by a membrane derived from the ER to create a vesicle that then fuses with a lysosome. In this way, a human liver cell, for example, recycles about half its contents every week. Lysosomal enzymes may also destroy the entire cell, a process known as ***autolysis*** (aw-TOL-i-sis). Autolysis occurs in some pathological conditions and also is responsible for the tissue deterioration that occurs just after death.

Figure 3.15 Golgi complex.

Most proteins synthesized by ribosomes attached to rough ER pass through the Golgi complex for processing.



What types of body cells are likely to have extensive Golgi complexes?

Some disorders are caused by faulty or absent lysosomal enzymes. For instance, **Tay-Sachs disease**, which most often affects children of Ashkenazi (eastern European Jewish) descent, is an inherited condition characterized by the absence of a single lysosomal enzyme. This enzyme normally breaks down a membrane glycolipid called ganglioside G_{M2} that is especially prevalent in nerve cells. As the excess ganglioside G_{M2} accumulates, because it is not broken down, the nerve cells function less efficiently. Children with Tay-Sachs disease typically experience seizures and muscle rigidity. They gradually become blind, demented, and uncoordinated and usually die before the age of 5. Tests can now reveal whether an adult is a carrier of the defective gene.

Peroxisomes

Another group of organelles similar in structure to lysosomes, but smaller, are called ***peroxisomes*** (per-OK-si-sōms; *peroxi-* = peroxide; see Figure 3.1). Peroxisomes contain several *oxidases*, which are enzymes that can oxidize (remove hydrogen atoms from) various organic substances. For example, amino acids and fatty acids are oxidized in peroxisomes as part of normal metabolism. In addition, enzymes in peroxisomes oxidize toxic substances. Thus, peroxisomes are very abundant in the liver, where detoxification of alcohol and other damaging substances takes place. A byproduct of the oxidation reactions is hydrogen peroxide (H_2O_2), a potentially toxic compound. However, peroxisomes also contain an enzyme called *catalase* that decomposes the H_2O_2. Because the generation and degradation of H_2O_2 occurs within the same organelle, peroxisomes protect other parts of the cell from the toxic effects of H_2O_2.

Proteasomes

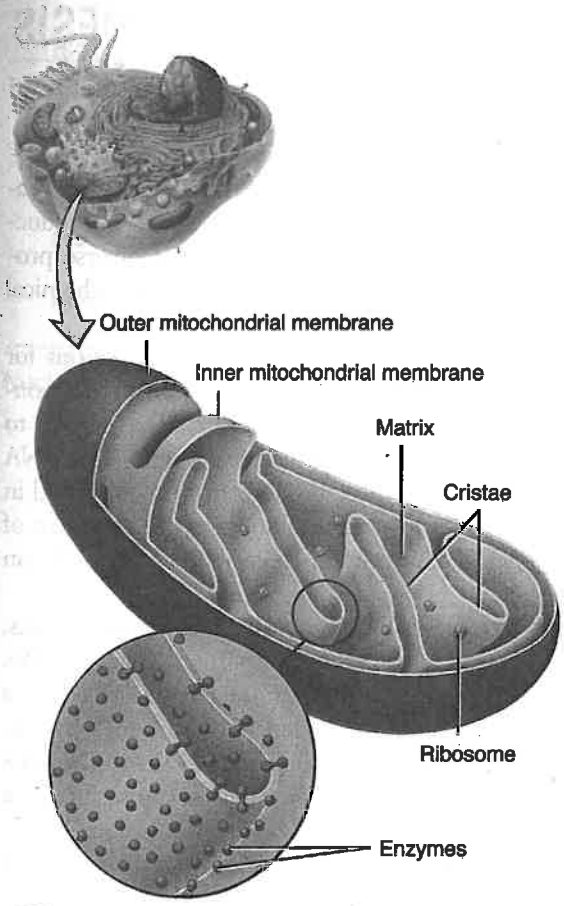
Although lysosomes degrade proteins delivered to them in vesicles, proteins in the cytosol also require disposal at certain times in the life of a cell. Continuous destruction of unneeded, damaged, or faulty proteins is the function of tiny barrel-shaped structures called ***proteasomes*** (PRŌ-tē-a-sōmes = protein bodies). A typical body cell contains many thousands of proteasomes, in both the cytosol and the nucleus. Proteasomes were so named because they contain myriad *proteases*, enzymes that cut proteins into small peptides. Once the enzymes of a proteasome have chopped up a protein into smaller chunks, other enzymes then break down the peptides into amino acids, which can be recycled into new proteins.

Mitochondria

Because they are the site of most ATP production, the "powerhouses" of a cell are its ***mitochondria*** (mī-tō-KON-drē-a; *mito-* = thread; *-chondria* = granules; singular is *mitochondrion*). A cell may have as few as one hundred or as many as several thousand mitochondria, depending on how active the cell is. For example, active cells such as those found in muscles, the liver, and kidneys use ATP at a high rate and have large numbers of mitochondria. A mitochondrion consists of two membranes, each of which is similar in structure to the plasma membrane (Figure 3.16). The *outer mitochondrial membrane* is smooth, but the *inner mitochondrial membrane* is arranged in a series of folds called ***cristae*** (KRIS-tē; singular is *crista* = ridge). The large central fluid-filled cavity of a mitochondrion, enclosed by the inner membrane and cristae, is the ***matrix***. The elaborate folds of the cristae provide an enormous surface area for a series of chemical reactions that provide most of a cell's ATP. Enzymes that catalyze these reactions are located in the matrix and on the cristae. Mitochondria also contain a small number of genes and a few ribosomes, enabling them to synthesize some proteins.

Figure 3.16 Mitochondrion.

Within mitochondria, chemical reactions generate most of a cell's ATP.



How do the cristae of a mitochondrion contribute to its ATP-producing function?

■ **CHECKPOINT**

7. What does cytoplasm have that cytosol does not?
8. What is an organelle?
9. Describe the structure and function of ribosomes, the Golgi complex, and mitochondria.

NUCLEUS

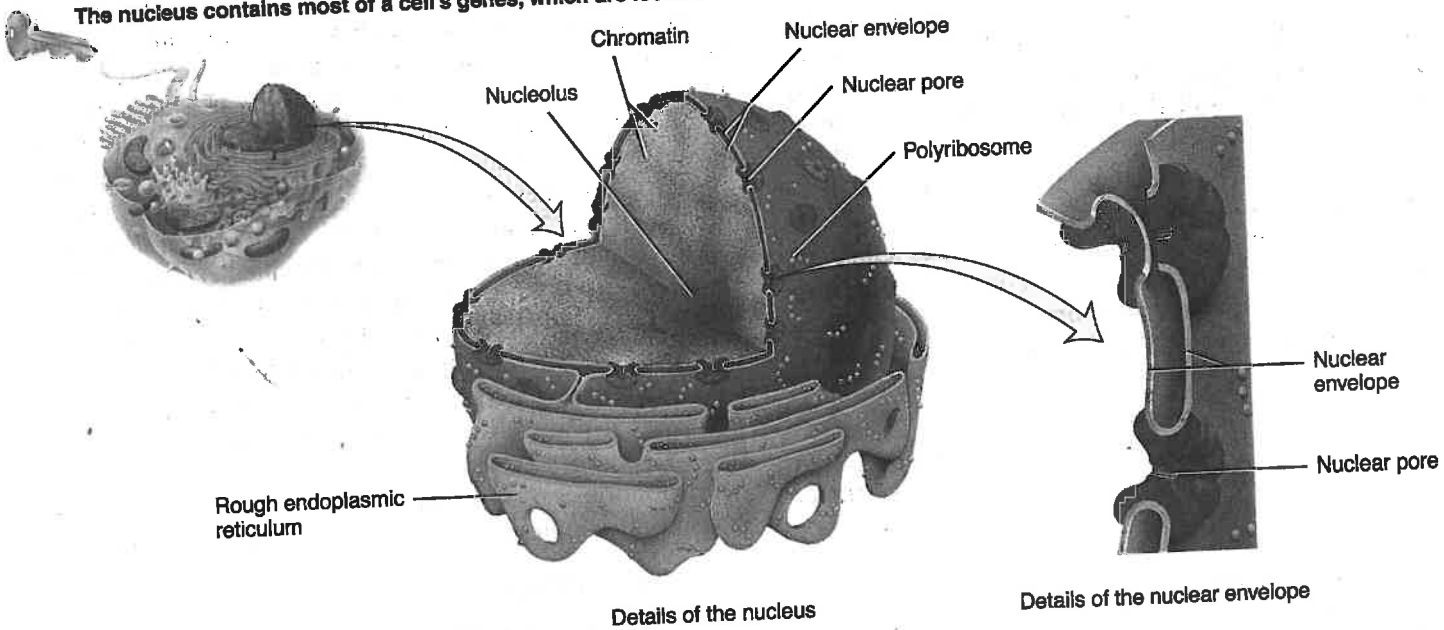
OBJECTIVE • Describe the structure and functions of the nucleus.

The ***nucleus*** is a spherical or oval structure that usually is the most prominent feature of a cell (Figure 3.17). Most body cells have a single nucleus, although some, such as mature red blood cells, have none. In contrast, skeletal muscle cells and a few other types of cells have several nuclei. A double membrane called the ***nuclear envelope*** separates the nucleus from the cytoplasm. Both layers of the nuclear envelope are lipid bilayers similar to the plasma membrane. The outer membrane of the nuclear envelope is continuous with the rough endoplasmic reticulum and resembles it in structure. Many openings called ***nuclear pores*** pierce the nuclear envelope. Nuclear pores control the movement of substances between the nucleus and the cytoplasm.

Inside the nucleus are one or more spherical bodies called ***nucleoli*** (noo′-KLĒ-ō-lī; singular is *nucleolus*). These clusters of protein, DNA, and RNA are the sites of assembly of ribosomes, which exit the nucleus through nuclear pores and participate in protein synthesis in the cytoplasm. Cells that synthesize large amounts of protein, such as muscle and liver cells, have prominent nucleoli.

Figure 3.17 Nucleus.

The nucleus contains most of a cell's genes, which are located on chromosomes.



What are the functions of nuclear genes?

Also within the nucleus are most of the cell's hereditary units, called ***genes***, which control cellular structure and direct most cellular activities. The nuclear genes are arranged along ***chromosomes*** (*chromo-* = colored) (see Figure 3.21). Human somatic (body) cells have 46 chromosomes, 23 inherited from each parent. In a cell that is not dividing, the 46 chromosomes appear as a diffuse, granular mass, which is called ***chromatin*** (Figure 3.17). The total genetic information carried in a cell or organism is called its ***genome***.

In the last decade of the twentieth century, the genomes of humans, mice, fruit flies, and more than 50 microbes were sequenced. As a result, research in the field of ***genomics***, the study of the relationships between the genome and the biological functions of an organism, has flourished. The Human Genome Project began in 1990 as an effort to sequence all of the nearly 3.2 billion nucleotides of our genome and was completed in April 2003. Scientists now know that the total number of genes in the human genome is about 30,000. Information regarding the human genome and how it is affected by the environment seeks to identify and discover the functions of the specific genes that play a role in genetic diseases. Genomic medicine also aims to design new drugs and to provide screening tests to enable physicians to provide more effective counseling and treatment for disorders with significant genetic components such as hypertension (high blood pressure), obesity, diabetes, and cancer.

The main parts of a cell and their functions are summarized in Table 3.2.

■ CHECKPOINT

10. Why is the nucleus so important in the life of a cell?

GENE ACTION: PROTEIN SYNTHESIS

OBJECTIVE • Outline the sequence of events involved in protein synthesis.

Although cells synthesize many chemicals to maintain homeostasis, much of the cellular machinery is devoted to protein production. Cells constantly synthesize large numbers of diverse proteins. The proteins, in turn, determine the physical and chemical characteristics of cells and, on a larger scale, of organisms.

The DNA contained in genes provides the instructions for making proteins. To synthesize a protein, the information contained in a specific region of DNA is first *transcribed* (copied) to produce a specific molecule of RNA (ribonucleic acid). The RNA then attaches to a ribosome, where the information contained in the RNA is *translated* into a corresponding specific sequence of amino acids to form a new protein molecule (Figure 3.18 on page 60).

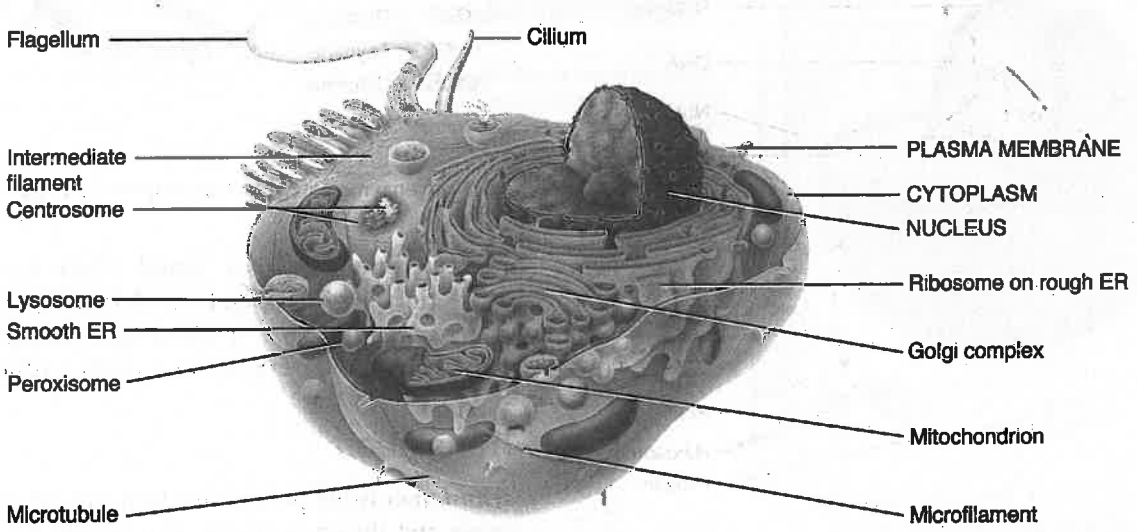
Information is stored in DNA in four types of nucleotides, the repeating units of nucleic acids (see Figure 2.15 on page 39). Each sequence of three DNA nucleotides is transcribed as a complementary (corresponding) sequence of three RNA nucleotides. Such a sequence of three successive DNA nucleotides is called a ***base triplet***. Each DNA base triplet is transcribed as a complementary sequence of three successive RNA nucleotides. The three successive RNA nucleotides are called a ***codon***. When translated, a given codon specifies a particular amino acid.

Transcription

During ***transcription***, which occurs in the nucleus, the genetic information in DNA base triplets is copied into a com-

Table 3.2 Cell Parts and Their Functions

Part	Structure	Functions
Plasma Membrane	Composed of a lipid bilayer consisting of phospholipids, cholesterol, and glycolipids with various proteins inserted; surrounds cytoplasm.	Protects cellular contents; makes contact with other cells; contains channels, transporters, receptors, enzymes, and cell-identity markers; mediates the entry and exit of substances.
Cytoplasm	Cellular contents between the plasma membrane and nucleus, including cytosol and organelles.	Site of all intracellular activities except those occurring in the nucleus.
Cytosol	Composed of water, solutes, suspended particles, lipid droplets, and glycogen granules.	Medium in which many of the cell's chemical reactions occur.
Organelles	Specialized cellular structures with characteristic shapes and specific functions.	Each organelle has one or more specific functions.
Cytoskeleton	Network composed of three protein filaments: microfilaments, intermediate filaments, and microtubules.	Maintains shape and general organization of cellular contents; responsible for cell movements.
Centrosome	Paired centrioles plus pericentriolar material.	Pericentriolar material is organizing center for microtubules and mitotic spindle.
Cilia and flagella	Motile cell surface projections with inner core of microtubules.	Cilia move fluids over a cell's surface; a flagellum moves an entire cell.
Ribosome	Composed of two subunits containing ribosomal RNA and proteins; may be free in cytosol or attached to rough ER.	Protein synthesis.
Endoplasmic reticulum (ER)	Membranous network of folded membranes. Rough ER is studded with ribosomes and is attached to the nuclear membrane; smooth ER lacks ribosomes.	Rough ER is the site of synthesis of glycoproteins and phospholipids; smooth ER is the site of fatty acid and steroid synthesis. Smooth ER also releases glucose into the bloodstream, inactivates or detoxifies drugs and potentially harmful substances, and stores calcium ions for muscle contraction.
Golgi complex	A stack of 3–20 flattened membranous sacs called cisterns.	Accepts proteins from rough ER, forms glycoproteins and lipoproteins; stores, packages, and exports proteins.
Lysosome	Vesicle formed from Golgi complex; contains digestive enzymes.	Fuses with and digests contents of vesicles; digests worn-out organelles (autophagy), entire cells (autolysis), and extracellular materials.
Peroxisome	Vesicle containing oxidative enzymes.	Detoxifies harmful substances.
Proteasome	Tiny structure that contains proteases, enzymes that cut proteins.	Degrades unneeded, damaged, or faulty proteins by cutting them into small peptides.
Mitochondrion	Consists of an outer and inner membranes, cristae, and matrix.	Site of reactions that produce most of a cell's ATP.
Nucleus	Consists of nuclear envelope with pores, nucleoli, and chromatin (or chromosomes).	Contains genes, which control cellular structure and direct most cellular activities.



plementary sequence of codons in a strand of RNA. Transcription of DNA is catalyzed by the enzyme *RNA polymerase*, which must be instructed where to start the transcription process and where to end it. The segment of DNA where RNA polymerase attaches to it is a special sequence of nucleotides called a ***promoter***, located near the beginning of a gene (Figure 3.19a). Three kinds of RNA are made from DNA:

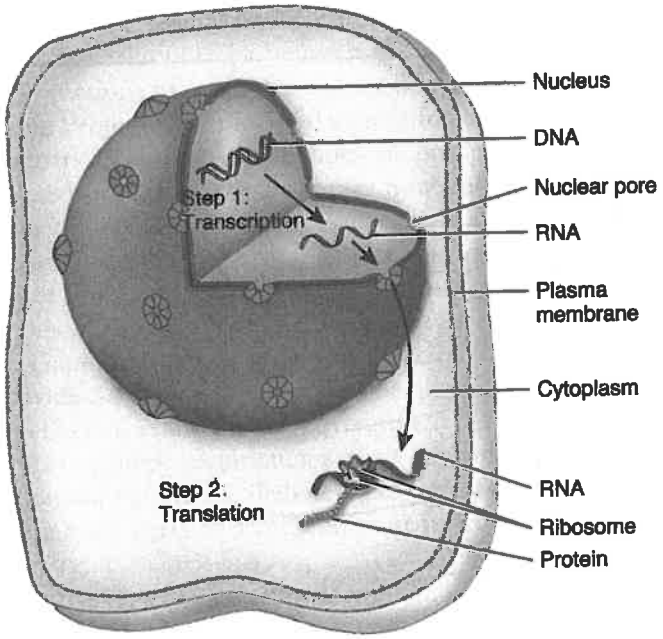
- ***Messenger RNA (mRNA)*** directs synthesis of a protein.
- ***Ribosomal RNA (rRNA)*** joins with ribosomal proteins to make ribosomes.
- ***Transfer RNA (tRNA)*** binds to an amino acid and holds it in place on a ribosome until it is incorporated into a protein during translation. Each of the more than 20 different types of tRNA binds to only one of the 20 different amino acids.

During transcription, nucleotides pair in a complementary manner: The nitrogenous base cytosine (C) in DNA dictates the complementary nitrogenous base guanine (G) in the new RNA strand, a G in DNA dictates a C in RNA, a thymine (T) in DNA dictates an adenine (A) in RNA, and an A in DNA dictates a uracil (U) in RNA. As an example, if a segment of DNA had the base sequence ATGCAT, the newly transcribed RNA strand would have the complementary base sequence UACGUA.

Transcription of DNA ends at another special nucleotide sequence on DNA called a ***terminator***, which specifies the end of the gene (Figure 3.19a). Upon reaching the terminator, RNA polymerase detaches from the transcribed RNA

Figure 3.18 Overview of transcription and translation.

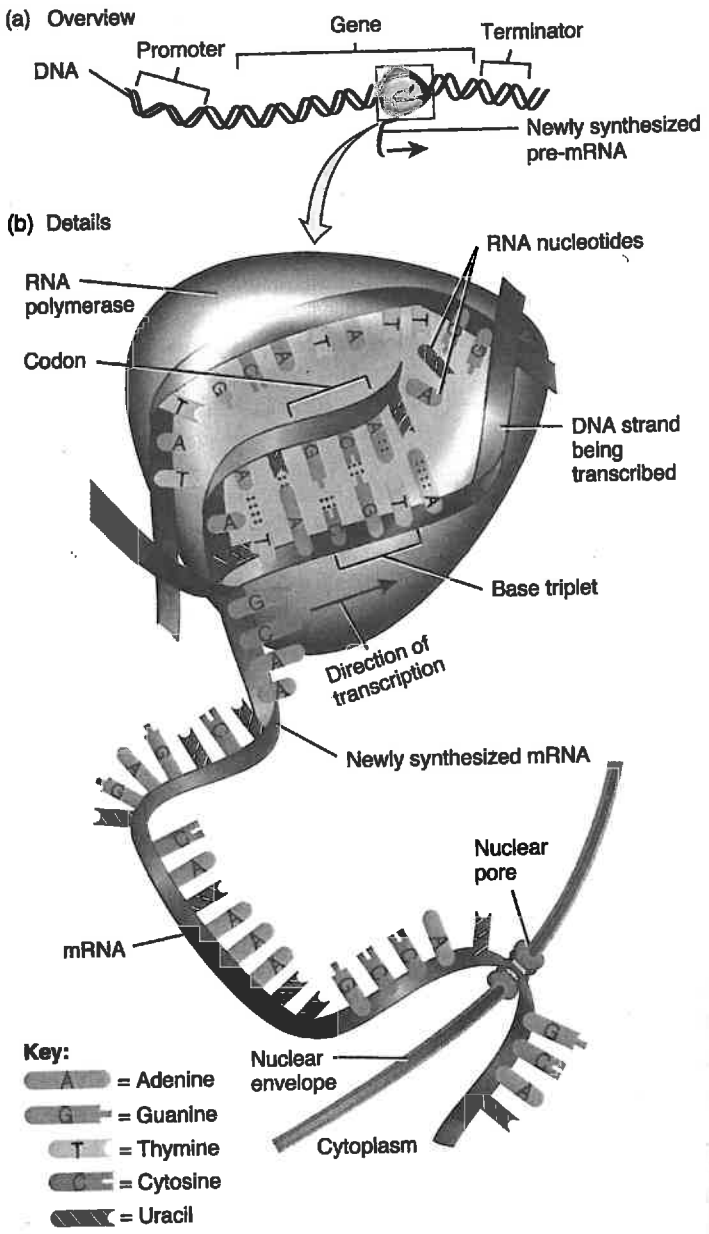
Transcription occurs in the nucleus; translation takes place in the cytoplasm.



Why are proteins important in the life of a cell?

Figure 3.19 Transcription.

During transcription, the genetic information in DNA is copied to RNA.



What enzyme catalyzes transcription of DNA?

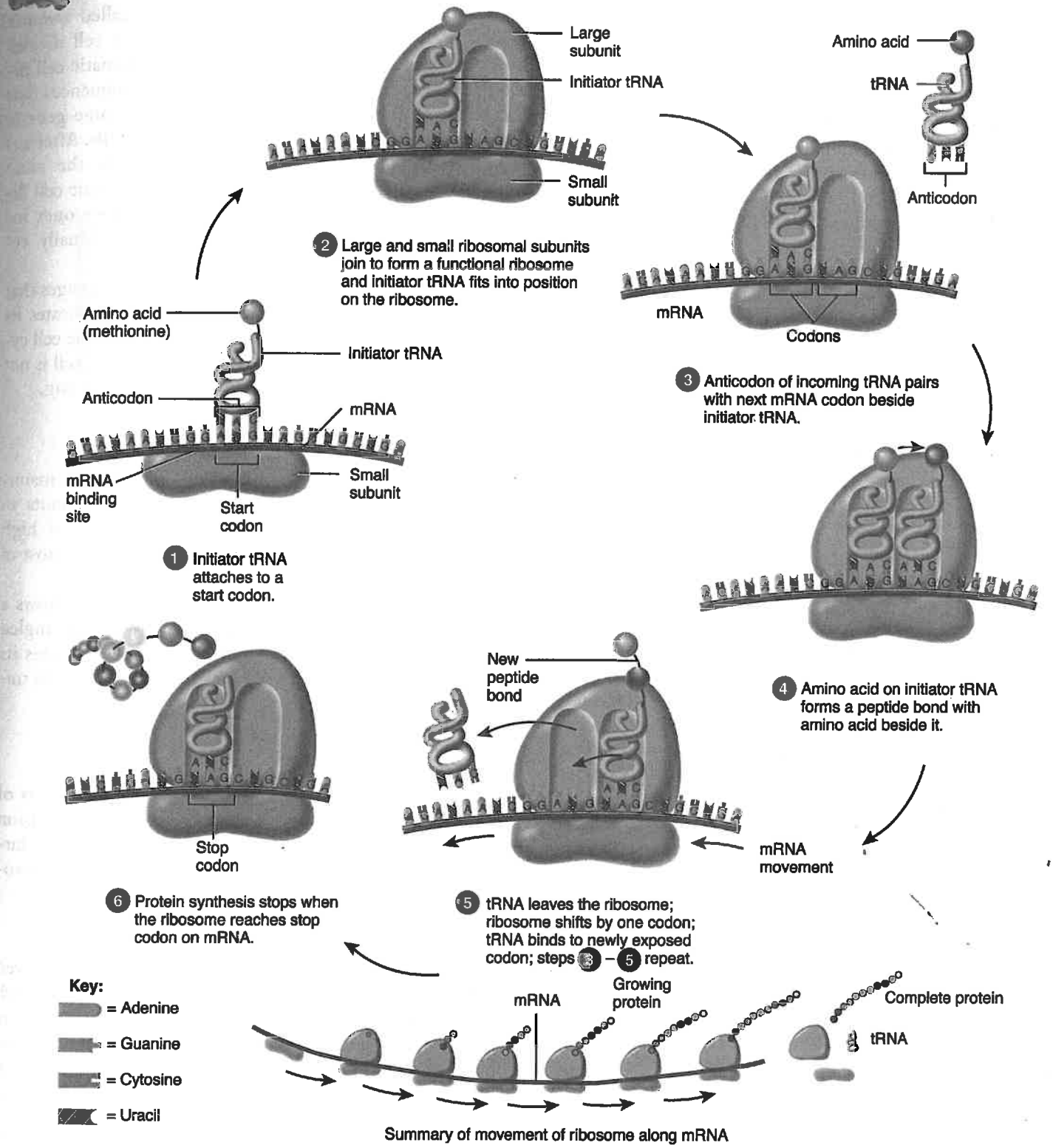
molecule and the DNA strand. Once synthesized, mRNA, rRNA (in ribosomes), and tRNA leave the nucleus of the cell by passing through a nuclear pore. In the cytoplasm, they participate in the next step in protein synthesis, translation.

Translation

Translation is the process in which mRNA associates with ribosomes and directs synthesis of a protein by converting the sequence of nucleotides in mRNA into a specific sequence of amino acids. Translation occurs in the following way (Figure 3.20):

Figure 3.20 Protein elongation and termination of protein synthesis during translation.

During protein synthesis the ribosomal subunits join, but they separate when the process is complete.



What is the function of a stop codon?

1. An mRNA molecule binds to the small ribosomal subunit, and a special tRNA, called *initiator tRNA*, binds to the start codon (AUG) on mRNA, where translation begins.
2. The large ribosomal subunit attaches to the small subunit, creating a functional ribosome. The initiator tRNA fits into position on the ribosome. One end of a tRNA carries a specific amino acid, and the opposite end consists of a triplet of nucleotides called an ***anticodon***. By pairing between complementary nitrogenous bases, the tRNA anticodon attaches to the mRNA codon. For example, if the mRNA codon is AUG, then a tRNA with the anticodon UAC would attach to it.
3. The anticodon of another tRNA with its amino acid attaches to the complementary mRNA codon next to the initiator tRNA.
4. A peptide bond is formed between the amino acids carried by the initiator tRNA and the tRNA next to it.
5. After the peptide bond forms, the tRNA detaches from the ribosome, and the ribosome shifts the mRNA strand by one codon. As the tRNA bearing the newly forming protein shifts, another tRNA with its amino acid binds to a newly exposed codon. Steps 3 through 5 repeat again and again as the protein lengthens.
6. Protein synthesis ends when the ribosome reaches a stop codon, at which time the completed protein detaches from the final tRNA. When the tRNA vacates the ribosome, the ribosome splits into its large and small subunits.

Protein synthesis progresses at a rate of about 15 amino acids per second. As the ribosome moves along the mRNA and before it completes synthesis of the whole protein, another ribosome may attach behind it and begin translation of the same mRNA strand. In this way, several ribosomes may be attached to the same mRNA, an assembly called a ***polyribosome***. The simultaneous movement of several ribosomes along the same mRNA strand permits a large amount of protein to be produced from each mRNA.

■ CHECKPOINT

11. Define protein synthesis.

12. Distinguish between transcription and translation.

SOMATIC CELL DIVISION

OBJECTIVE • Discuss the stages, events, and significance of somatic cell division.

As body cells become damaged, diseased, or worn out, they are replaced by ***cell division***, the process whereby cells reproduce themselves. The two types of cell division are reproductive cell division and somatic cell division. ***Reproductive cell division*** or ***meiosis*** is the process that produces gametes—sperm and oocytes—the cells needed to form the next generation of sexually reproducing organisms. This is described in Chapter 23; here we will focus on somatic cell division.

All body cells, except the gametes, are called ***somatic*** (*soma* = body) ***cells***. In ***somatic cell division***, a cell divides into two identical cells. An important part of somatic cell division is replication (duplication) of the DNA sequences that make up genes and chromosomes so that the same genetic material can be passed on to the newly formed cells. After somatic cell division, each newly formed cell has the same number of chromosomes as the original cell. Somatic cell division replaces dead or injured cells and adds new ones for tissue growth. For example, skin cells are continually replaced by somatic cell divisions.

The ***cell cycle*** is the name for the sequence of changes that a cell undergoes from the time it forms until it duplicates its contents and divides into two cells. In somatic cells, the cell cycle consists of two major periods: interphase, when a cell is not dividing, and the mitotic (M) phase, when a cell is dividing.

Interphase

During ***interphase*** the cell replicates its DNA. It also manufactures additional organelles and cytosolic components in anticipation of cell division. Interphase is a state of high metabolic activity, and during this time the cell does most of its growing.

A microscopic view of a cell during interphase shows a clearly defined nuclear envelope, a nucleolus, and a tangled mass of chromatin (Figure 3.21a). Once a cell completes its replication of DNA and other activities of interphase, the mitotic phase begins.

Mitotic Phase

The ***mitotic phase*** (mī-TOT-ik) of the cell cycle consists of *mitosis*, division of the nucleus, followed by *cytokinesis*, division of the cytoplasm into two cells. The events that take place during mitosis and cytokinesis are plainly visible under a microscope because chromatin condenses into chromosomes.

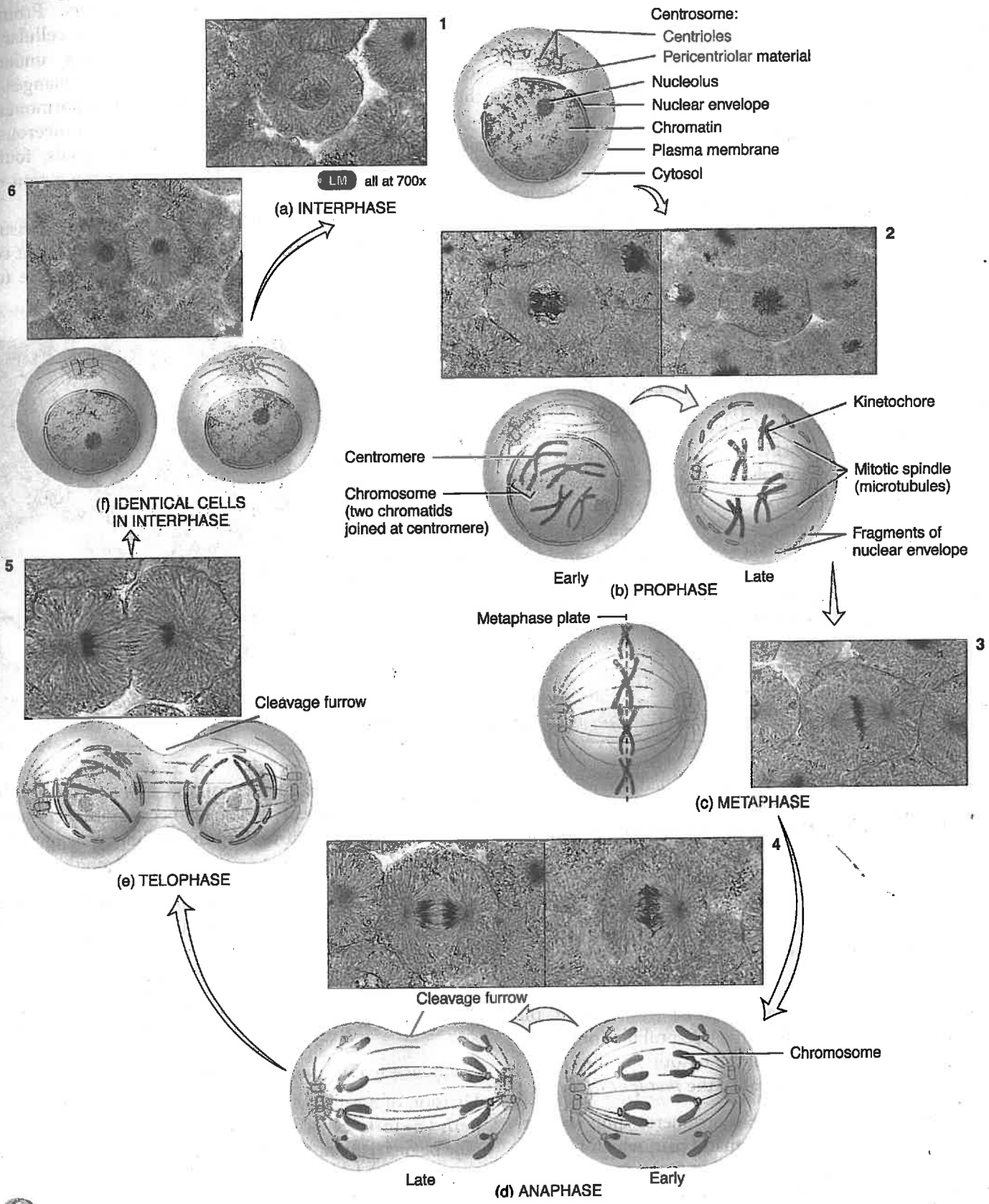
Nuclear Division: Mitosis

During ***mitosis*** (mī-TŌ-sis; *mitos* = thread), the duplicated chromosomes become exactly segregated, one set into each of two separate nuclei. For convenience, biologists divide the process into four stages: prophase, metaphase, anaphase, and telophase. However, mitosis is a continuous process, with one stage merging imperceptibly into the next.

PROPHASE During early prophase, the chromatin fibers condense and shorten into chromosomes that are visible under the light microscope (Figure 3.21b). The condensation process may prevent entangling of the long DNA strands as they move during mitosis. Recall that DNA replication took place during interphase. Thus, each prophase chromosome consists of a pair of identical, double-stranded ***chromatids***. A

Figure 3.21 Cell division: mitosis and cytokinesis. Begin the sequence at (a) at the top of the figure and read clockwise until you complete the process.

In somatic cell division, a single cell divides to produce two identical cells.



When does cytokinesis begin?

Focus on Wellness

Phytochemicals—Protecting Cellular Function

Many studies over the years have shown that people who consume plenty of plant foods, including vegetables, beans, fruits, and grains, have a lower risk of cancer and heart disease than their meat-and-potato-eating peers. Scientists are just beginning to uncover the biochemical explanations for these associations. Their investigations have led to the discovery of compounds in plants that appear to promote healthy cellular function, and to prevent the types of cellular damage associated with cancer, aging, and heart disease. Collectively, these compounds are called *phytochemicals*, literally "plant chemicals."

A Radical Notion?

Phytochemicals appear to protect cells and interrupt cancerous tumor growth in a number of interesting ways. Some phytochemicals block chemicals that can cause oxidative damage to cells. You will learn about the process of oxidation in Chapter 20 when you read about metabolism. Oxidative damage commonly occurs in cells when byproducts of metabolism, known as oxygen free radicals, "steal" electrons from other molecules. This electron theft causes chain reactions of electron transfers that can damage cell membranes, the membranes of cellular organelles, and even the cells' genetic material.

Some phytochemicals act as antioxidants, donating electrons to free radical molecules, thus protecting cellular structures. Antioxidants include polyphenols, which are found in green tea, and lycopenes, which are found in tomato products.

Disabling the Opponent

Many substances entering the body are potentially carcinogenic, depending upon their interaction with certain enzymes in the liver. Some phytochemicals, such as the allyl sulfides in garlic and onions, enhance the production of enzymes that may render potentially carcinogenic substances harmless. The sulforaphane in broccoli, cauliflower, and other cruciferous vegetables performs a similar function.

Promoting Health

Some phytochemicals protect against cancer by blocking the action of substances called promoters. Promoters encourage the aggressive cellular division of cells that have undergone cancer-causing genetic changes. For example, estrogens are hormones that promote the division of cancerous cells in the breast. Isoflavonoids, found in soy products, weaken the action of estrogens in breast tissue.

Variety is the key to consuming more phytochemicals. Try to eat two to four servings of fruit and three to five servings of vegetables each day.

▶ THINK IT OVER . . .

▶ *What are some dietary changes you could make that would increase your intake of helpful phytochemicals?*

constricted region of the chromosome, called a ***centromere***, holds the chromatid pair together.

Later in prophase, the pericentriolar material of the two centrosomes starts to form the ***mitotic spindle***, a football-shaped assembly of microtubules (Figure 3.21b). Lengthening of the microtubules between centrosomes pushes the centrosomes to opposite poles (ends) of the cell. Finally, the spindle extends from pole to pole. Then the nucleolus and nuclear envelope break down.

METAPHASE During metaphase, the centromeres of the chromatid pairs are aligned along the microtubules of the mitotic spindle at the exact center of the mitotic spindle (Figure 3.21c). This midpoint region is called the ***metaphase plate***.

ANAPHASE During anaphase the centromeres split, separating the two members of each chromatid pair, which move to opposite poles of the cell (Figure 3.21d). Once separated, the chromatids are called chromosomes. As the chromosomes are pulled by the microtubules of the mitotic spindle during anaphase, they appear V-shaped because the centromeres lead the way and seem to drag the trailing arms of the chromosomes toward the pole.

TELOPHASE The final stage of mitosis, telophase, begins after chromosomal movement stops (Figure 3.21e). The identical sets of chromosomes, now at opposite poles of the cell, uncoil and revert to the threadlike chromatin form. A new nuclear envelope forms around each chromatin mass, nucleoli appear, and eventually the mitotic spindle breaks up.

Cytoplasmic Division: Cytokinesis

Division of a cell's cytoplasm and organelles is called ***cytokinesis*** (sī´-tō-ki-NĒ-sis; *-kinesis* = motion). This process usually begins late in anaphase with formation of a ***cleavage furrow***, a slight indentation of the plasma membrane, that extends around the center of the cell (Figure 3.21d,e). Micro-

filaments in the cleavage furrow pull the plasma membrane progressively inward, constricting the center of the cell like a belt around a waist, and ultimately pinching it in two. After cytokinesis there are two new and separate cells, each with equal portions of cytoplasm and organelles and identical sets of chromosomes. When cytokinesis is complete, interphase begins (Figure 3.21f).

One of the distinguishing features of cancer cells is uncontrolled division. The mass of cells resulting from this division is called a neoplasm or tumor. One of the ways to treat cancer is by *chemotherapy*, the use of anticancer drugs. Some of these drugs stop cell division by inhibiting the formation of the mitotic spindle. Unfortunately, these types of anticancer drugs also kill all types of rapidly dividing cells in the body, causing side effects such as nausea, diarrhea, hair loss, fatigue, and decreased resistance to disease.

■ CHECKPOINT

13. Distinguish between somatic and reproductive cell division. Why is each important?
14. What are the major events of each stage of the mitotic phase?

AGING AND CELLS

OBJECTIVE • Describe the cellular changes that occur with aging.

Aging is a normal process accompanied by a progressive alteration of the body's homeostatic adaptive responses. It produces observable changes in structure and function and increases vulnerability to environmental stress and disease. The specialized branch of medicine that deals with the medical problems and care of elderly persons is ***geriatrics*** (jer′-ē-AT-riks; *ger-* = old age; *-iatrics* = medicine). ***Gerontology*** (jer′-on-TOL-ō-jē) is the scientific study of the process and problems associated with aging.

Although many millions of new cells normally are produced each minute, several kinds of cells in the body—skeletal muscle cells and nerve cells—do not divide. Experiments have shown that many other cell types have only a limited capability to divide. Normal cells grown outside the body divide only a certain number of times and then stop. These observations suggest that cessation of mitosis is a normal, genetically programmed event. According to this view, "aging genes" are part of the genetic blueprint at birth. These genes have an important function in normal cells, but their activities slow over time. They bring about aging by slowing down or halting processes vital to life.

Another aspect of aging involves ***telomeres*** (TĒ-lō-merz), specific DNA sequences found only at the tips of each chromosome. These pieces of DNA protect the tips of chromosomes from erosion and from sticking to one another. However, in most normal body cells each cycle of cell division shortens the telomeres. Eventually, after many cycles of cell division, the telomeres can be completely gone, and even some of the functional chromosomal material may be lost. These observations suggest that erosion of DNA from the tips of our chromosomes contributes greatly to the aging and death of cells.

Glucose, the most abundant sugar in the body, plays a role in the aging process. It is haphazardly added to proteins inside and outside cells, forming irreversible cross-links between adjacent protein molecules. With advancing age, more cross-links form, which contributes to the stiffening and loss of elasticity that occur in aging tissues.

Free radicals produce oxidative damage in lipids, proteins, or nucleic acids. Some effects are wrinkled skin, stiff joints, and hardened arteries. Naturally occurring enzymes in peroxisomes and in the cytosol normally dispose of free radicals. Certain dietary substances, such as vitamin E, vitamin C, beta carotene, and selenium, are antioxidants that inhibit free radical formation.

Some theories of aging explain the process at the cellular level, while others concentrate on regulatory mechanisms operating within the entire organism. For example, the immune system may start to attack the body's own cells. This *autoimmune response* might be caused by changes in certain plasma membrane glycoproteins and glycolipids (cell-identity markers) that cause antibodies to attach to and mark the cell for destruction. As changes in the proteins on the plasma membrane of cells increase, the autoimmune response intensifies, producing the well-known signs of aging.

Progeria (prō-JER-ē-a) is a disease characterized by normal development in the first year of life followed by rapid aging. It is caused by a genetic defect in which telomeres are considerably shorter than normal. Symptoms include dry and wrinkled skin, total baldness, and birdlike facial features. Death usually occurs around age 13.

Werner syndrome is a rare, inherited disease that causes a rapid acceleration of aging, usually while the person is only in his or her twenties. It is characterized by wrinkling of the skin, graying of the hair and baldness, cataracts, muscular atrophy, and a tendency to develop diabetes mellitus, cancer, and cardiovascular disease. Most afflicted individuals die before age 50. Recently, the gene that causes Werner syndrome has been identified. Researchers hope to use the information to gain insight into the mechanisms of aging, as well as to help those suffering from the disorder.

■ CHECKPOINT

15. Briefly outline the cellular changes involved in aging.

• • •

Next, in Chapter 4, we will explore how cells associate to form the tissues and organs that we will discuss later in the text.

COMMON DISORDERS

Cancer

Cancer is a group of diseases characterized by uncontrolled or abnormal cell proliferation. When cells in a part of the body divide without control, the excess tissue that develops is called a ***tumor*** or ***neoplasm*** (NĒ-ō-plazm; *neo-* = new). The study of tumors is called ***oncology*** (on-KOL-ō-jē; *onco-* = swelling or mass). Tumors may be cancerous and often fatal, or they may be harmless. A cancerous neoplasm is called a ***malignant tumor*** or ***malignancy***. One property of most malignant tumors is their ability to undergo ***metastasis*** (me-TAS-ta-sis), the spread of cancerous cells to other parts of the body. A ***benign tumor*** is a neoplasm that does not metastasize. An example is a wart. Most benign tumors may be surgically removed if this interferes with normal body function or they become disfiguring. Some can be inoperable and perhaps fatal.

Growth and Spread of Cancer

Cells of malignant tumors duplicate rapidly and continuously. As malignant cells invade surrounding tissues, they often trigger ***angiogenesis***, the growth of new networks of blood vessels. As the cancer grows, it begins to compete with normal tissues for space and nutrients. Eventually, the normal tissue decreases in size and dies. Some malignant cells may detach from the initial (primary) tumor and invade a body cavity or enter the blood or lymph, then circulate to and invade other body tissues, establishing secondary tumors. The pain associated with cancer develops when the tumor presses on nerves or blocks a passageway in an organ so that secretions build up pressure.

Causes of Cancer

Several factors may trigger a normal cell to lose control and become cancerous. One cause is environmental agents: substances in the air we breathe, the water we drink, and the food we eat. A chemical agent or radiation that produces cancer is called a ***carcinogen*** (car-SIN-ō-jen). Carcinogens induce ***mutations***, permanent changes in the DNA base sequence of a gene. The World Health Organization estimates that carcinogens are associated with 60–90% of all human cancers. Examples of carcinogens are hydrocarbons found in cigarette tar, radon gas from the earth, and ultraviolet (UV) radiation in sunlight.

Intensive research efforts are now directed toward studying cancer-causing genes, or ***oncogenes*** (ON-kō-jēnz). When inappropriately activated, these genes have the ability to transform a normal cell into a cancerous cell. Most oncogenes derive from normal genes called ***proto-oncogenes*** that regulate growth and development. The proto-oncogene undergoes some change that either causes it to be expressed inappropriately or make its products in excessive amounts or at the wrong time. Some oncogenes cause excessive production of growth factors, chemicals that stimulate cell growth. Others may trigger changes in a cell-surface receptor, causing it to send signals as though it were being activated by a growth factor. As a result, the growth pattern of the cell becomes abnormal.

Some cancers have a viral origin. Viruses are tiny packages of nucleic acids, either RNA or DNA, that can reproduce only while inside the cells they infect. Some viruses, termed ***oncogenic viruses***, cause cancer by stimulating abnormal proliferation of cells. For instance, the *human papillomavirus (HPV)* causes virtually all cervical cancers in women.

Recent studies suggest that certain cancers may be linked to a cell having abnormal numbers of chromosomes. As a result, the cell could potentially have extra copies of oncogenes or too few copies of tumor-suppressor genes, which in either case could lead to uncontrolled cell proliferation. There is also some evidence suggesting that cancer may be caused by normal stem cells that develop into cancerous stem cells capable of forming malignant tumors.

Carcinogenesis: A Multistep Process

Carcinogenesis (kar'-si-nō-JEN-e-sis), the process by which cancer develops, is a multistep process in which as many as 10 distinct mutations may have to accumulate in a cell before it becomes cancerous. In colon cancer, the tumor begins as an area of increased cell proliferation that results from one mutation. This growth then progresses to abnormal, but noncancerous, growths called adenomas. After several more mutations, a carcinoma develops. The fact that so many mutations are needed for a cancer to develop indicates that cell growth is normally controlled with many sets of checks and balances.

Treatment of Cancer

Many cancers are removed surgically. However, when cancer is widely distributed throughout the body or exists in organs such as the brain whose functioning would be greatly harmed by surgery, chemotherapy and radiation therapy may be used instead. Sometimes surgery, chemotherapy, and radiation therapy are used in combination. Chemotherapy involves administering drugs that cause the death of cancerous cells. Radiation therapy breaks chromosomes, thus blocking cell division. Because cancerous cells divide rapidly, they are more vulnerable to the destructive effects of chemotherapy and radiation therapy than are normal cells. Unfortunately for the patients, hair follicle cells, red bone marrow cells, and cells lining the gastrointestinal tract also are rapidly dividing. Hence, the side effects of chemotherapy and radiation therapy include hair loss due to death of hair follicle cells, vomiting and nausea due to death of cells lining the stomach and intestines, and susceptibility to infection due to slowed production of white blood cells in red bone marrow.

MEDICAL TERMINOLOGY AND CONDITIONS

Anaplasia (an′-a-PLĀ-zē-a; *an-* = not; *-plasia* = to shape) The loss of tissue differentiation and function that is characteristic of most malignancies.

Apoptosis (ap′-op-TŌ-sis; a falling off, like dead leaves from a tree) An orderly, genetically programmed cell death in which "cell-suicide" genes become activated. Enzymes produced by these genes disrupt the cytoskeleton and nucleus; the cell shrinks and pulls away from neighboring cells; the DNA within the nucleus fragments; and the cytoplasm shrinks, although the plasma membrane remains intact. Phagocytes in the vicinity then ingest the dying cell. Apoptosis removes unneeded cells during development before birth and continues after birth both to regulate the number of cells in a tissue and to eliminate potentially dangerous cells such as cancer cells.

Atrophy (AT-rō-fē; *a-* = without; *-trophy* = nourishment) A decrease in the size of cells with subsequent decrease in the size of the affected tissue or organ; wasting away.

Biopsy (BĪ-op-sē; *bio-* = life; *-opsy* = viewing) The removal and microscopic examination of tissue from the living body for diagnosis.

Dysplasia (dis-PLĀ-zē-a; *dys-* = abnormal) Alteration in the size, shape, and organization of cells due to chronic irritation or inflammation; may progress to a neoplasm (tumor formation, usually malignant) or revert to normal if the irritation is removed.

Hyperplasia (hī′-per-PLĀ-zē-a; *hyper-* = over) Increase in the number of cells of a tissue due to an increase in the frequency of cell division.

Hypertrophy (hī-PER-trō-fē) Increase in the size of cells in a tissue without cell division.

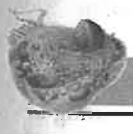
Metaplasia (met′-a-PLĀ-zē-a; *meta-* = change) The transformation of one type of cell into another.

Necrosis (ne-KRŌ-sis = death) A pathological type of cell death, resulting from tissue injury, in which many adjacent cells swell, burst, and spill their cytoplasm into the interstitial fluid; the cellular debris usually stimulates an inflammatory response, which does not occur in apoptosis.

Progeny (PROJ-e-nē; *pro-* = forward; *-geny* = production) Offspring or descendants.

Proteomics (prō′-tē-Ō-miks; *proteo-* = protein) The study of the proteome (all of an organism's proteins) in order to identify all the proteins produced; it involves determining how the proteins interact and ascertaining the three-dimensional structure of proteins so that drugs can be designed to alter protein activity to help in the treatment and diagnosis of disease.

Tumor marker A substance introduced into circulation by tumor cells that indicates the presence of a tumor, as well as the specific type. Tumor markers may be used to screen, diagnose, make a prognosis, evaluate a response to treatment, and monitor for recurrence of cancer.



STUDY OUTLINE

Introduction (p. 44)

1. A cell is the basic, living, structural and functional unit of the body.
2. Cell biology is the study of cell structure and function.

A Generalized View of the Cell (p. 45)

1. Figure 3.1 on page 45 shows a generalized view of a cell that is a composite of many different cells in the body.
2. The principal parts of a cell are the plasma membrane; the cytoplasm, which consists of cytosol and organelles; and the nucleus.

The Plasma Membrane (p. 46)

1. The plasma membrane surrounds and contains the cytoplasm of a cell; it is composed of proteins and lipids.
2. The lipid bilayer consists of two back-to-back layers of phospholipids, cholesterol, and glycolipids.
3. Integral proteins extend into or through the lipid bilayer; peripheral proteins associate with the inner or outer surface of the membrane.
4. The membrane's selective permeability permits some substances to pass across it more easily than others. The lipid bilayer is permeable to water and to most lipid-soluble molecules. Small- and medium-sized water-soluble materials may cross the membrane with the assistance of integral proteins.
5. Membrane proteins have several functions. Channels and transporters are integral proteins that help specific solutes across the membrane; receptors serve as cellular recognition sites; some membrane proteins are enzymes; and others are cell identity markers.

Transport Across the Plasma Membrane (p. 47)

1. Fluid inside body cells is called intracellular fluid (ICF); fluid outside body cells is extracellular fluid (ECF). The ECF in the microscopic spaces between the cells of tissues is interstitial

fluid. The ECF in blood vessels is plasma, and that in lymphatic vessels is lymph.

2. Any material dissolved in a fluid is called a solute, and the fluid that dissolves materials is the solvent. Body fluids are dilute solutions in which a variety of solutes are dissolved in the solvent water.
3. The selective permeability of the plasma membrane supports the existence of concentration gradients, differences in the concentration of chemicals between one side of the membrane and the other.
4. Materials move through cell membranes by passive processes or by active processes. In passive processes, a substance moves down its concentration gradient across the membrane. In active transport, cellular energy is used to drive the substance "uphill" against its concentration gradient.
5. In transport in vesicles, tiny vesicles either detach from the plasma membrane while bringing materials into the cell or merge with the plasma membrane to release materials from the cell.
6. Diffusion is the movement of substances due to their kinetic energy. In net diffusion, substances move from an area of higher concentration to an area of lower concentration until equilibrium is reached. At equilibrium the concentration is the same throughout the solution.
7. In simple diffusion, substances move through the lipid bilayer or through channels in integral proteins. Ion channels selective for K^+, Cl^-, Na^+, and Ca^{2+} allow these ions to diffuse across the plasma membrane by simple diffusion. In facilitated diffusion, substances cross the membrane with the assistance of transporters, which bind to a specific substance on one side of the membrane and release it on the other side after the transporter undergoes a change in shape.
8. Osmosis is the movement of water molecules through a selectively permeable membrane from an area of higher to an area of lower water concentration.
9. In an isotonic solution, red blood cells maintain their normal shape; in a hypotonic solution, they gain water and undergo hemolysis; in a hypertonic solution, they lose water and undergo crenation.
10. With the expenditure of cellular energy, usually in the form of ATP, solutes can cross the membrane against their concentration gradient by means of active transport. Actively transported solutes include several ions such as Na^+, K^+, H^+, Ca^{2+}, I^-, and Cl^-; amino acids; and monosaccharides.
11. The most important active transport pump is the sodium-potassium pump, which expels Na^+ from cells and brings K^+ in.
12. Transport in vesicles includes both endocytosis (phagocytosis and bulk-phase endocytosis) and exocytosis.
13. Phagocytosis is the ingestion of solid particles. It is an important process used by some white blood cells to destroy bacteria that enter the body. Bulk-phase endocytosis is the ingestion of extracellular fluid.
14. Exocytosis involves movement of secretory or waste products out of a cell by fusion of vesicles with the plasma membrane.

Cytoplasm (p. 52)

1. Cytoplasm includes all the cellular contents between the plasma membrane and nucleus; it consists of cytosol and organelles.
2. The fluid portion of cytoplasm is cytosol, composed mostly of water, plus ions, glucose, amino acids, fatty acids, proteins, lipids, ATP, and waste products; the cytosol is the site of many chemical reactions required for a cell's existence.
3. Organelles are specialized cellular structures with characteristic shapes and specific functions.
4. The cytoskeleton is a network of several kinds of protein filaments that extend throughout the cytoplasm; they provide a structural framework for the cell and generate movements. Components of the cytoskeleton include microfilaments, intermediate filaments, and microtubules.
5. The centrosome consists of two centrioles and pericentriolar material. The centrosome serves as a center for organizing microtubules in interphase cells and the mitotic spindle during cell division.
6. Cilia and flagella are motile projections of the cell surface. Cilia move fluid along the cell surface; a flagellum moves an entire cell.
7. Ribosomes, composed of ribosomal RNA and ribosomal proteins, consist of two subunits and are the sites of protein synthesis.
8. Endoplasmic reticulum (ER) is a network of membranes that extends from the nuclear envelope throughout the cytoplasm.
9. Rough ER is studded with ribosomes. Proteins synthesized on the ribosomes enter the ER for processing and sorting. The ER is also where glycoproteins and phospholipids form.
10. Smooth ER lacks ribosomes. It is the site where fatty acids and steroids are synthesized. Smooth ER also participates in releasing glucose from the liver into the bloodstream, inactivating or detoxifying drugs and other potentially harmful substances, and releasing calcium ions that trigger contraction in muscle cells.
11. The Golgi complex consists of flattened sacs called cisterns that receive proteins synthesized in the rough ER. Within the Golgi cisterns the proteins are modified, sorted, and packaged into vesicles for transport to different destinations. Some processed proteins leave the cell in secretory vesicles, some are incorporated into the plasma membrane, and some enter lysosomes.
12. Lysosomes are membrane-enclosed vesicles that contain digestive enzymes. They function in digestion of worn-out organelles (autophagy) and even in digestion of their own cell (autolysis).
13. Peroxisomes are similar to lysosomes but smaller. They oxidize various organic substances such as amino acids, fatty acids, and toxic substances and, in the process, produce hydrogen peroxide. The hydrogen peroxide is degraded by an enzyme in peroxisomes called catalase.
14. Proteasomes contain proteases that continually degrade unneeded, damaged, or faulty proteins.

15. Mitochondria consist of a smooth outer membrane, an inner membrane containing cristae, and a fluid-filled cavity called the matrix. They are called "powerhouses" of the cell because they produce most of a cell's ATP.

Nucleus (p. 57)

1. The nucleus consists of a double nuclear envelope; nuclear pores, which control the movement of substances between the nucleus and cytoplasm; nucleoli, which produce ribosomes; and genes arranged on chromosomes.
2. Most body cells have a single nucleus; some (red blood cells) have none, and others (skeletal muscle cells) have several.
3. Genes control cellular structure and most cellular functions.

Gene Action: Protein Synthesis (p. 58)

1. Most of the cellular machinery is devoted to protein synthesis.
2. Cells make proteins by transcribing and translating the genetic information encoded in the sequence of four types of nitrogenous bases in DNA.
3. In transcription, genetic information encoded in the DNA base sequence is copied into a complementary sequence of bases in a strand of messenger RNA (mRNA). Transcription begins on DNA in a region called a promoter.
4. Translation is the process in which mRNA associates with ribosomes and directs synthesis of a protein, converting the nucleotide sequence in mRNA into a specific sequence of amino acids.
5. In translation, mRNA binds to a ribosome, specific amino acids attach to tRNA, and anticodons of tRNA bind to codons of mRNA, bringing specific amino acids into position on a growing protein.
6. Translation begins at the start codon and terminates at the stop codon.

Somatic Cell Division (p. 62)

1. Cell division is the process by which cells reproduce themselves.
2. Cell division that results in an increase in the number of body cells is called somatic cell division; it involves a nuclear division called mitosis plus division of cytoplasm, called cytokinesis.
3. Cell division that results in the production of sperm and oocytes is called reproductive cell division.
4. The cell cycle is an orderly sequence of events in which a cell duplicates its contents and divides in two. It consists of interphase and a mitotic phase.
5. Before the mitotic phase, the DNA molecules, or chromosomes, replicate themselves so that identical chromosomes can be passed on to the next generation of cells.
6. A cell that is between divisions and is carrying on every life process except division is said to be in interphase.
7. Mitosis is the replication and distribution of two sets of chromosomes into separate and equal nuclei; it consists of prophase, metaphase, anaphase, and telophase.
8. Cytokinesis usually begins late in anaphase and ends in telophase.
9. A cleavage furrow forms and progresses inward, cutting through the cell to form two separate identical cells, each with equal portions of cytoplasm, organelles, and chromosomes.

Aging and Cells (p. 65)

1. Aging is a normal process accompanied by progressive alteration of the body's homeostatic adaptive responses.
2. Many theories of aging have been proposed, including genetically programmed cessation of cell division, shortening of telomeres, addition of glucose to proteins, buildup of free radicals, and an intensified autoimmune response.

SELF-QUIZ

1. If the extracellular fluid contains a greater concentration of solutes than the cytosol of the cell, the extracellular fluid is said to be
   a. isotonic b. hypertonic c. hypotonic
   d. cytotonic e. epitonic

2. The proteins found in the plasma membrane
   a. are primarily glycoproteins
   b. allow the passage of many substances into the cell
   c. allow cells to recognize other cells
   d. help anchor cells to each other
   e. have all of the above functions

3. To enter many body cells, glucose must bind to a specific membrane transport protein, which assists glucose to cross the membrane without using ATP. This type of movement is known as
   a. facilitated diffusion b. simple diffusion
   c. vesicular transport d. osmosis e. active transport

4. A red blood cell placed in a hypotonic solution undergoes
   a. hemolysis b. crenation c. equilibrium
   d. a decrease in osmotic pressure e. shrinkage

5. Which of the following normally pass through the plasma membrane only by transport in vesicles?
   a. water molecules b. sodium ions c. proteins
   d. oxygen molecules e. hydrogen ions

6. Which of the following statements concerning diffusion is NOT true?
   a. Diffusion speeds up as body temperature rises.
   b. A small surface area slows down the rate of diffusion.
   c. A low-weight particle diffuses faster than a high-weight particle.
   d. It moves materials from an area of low concentration to an area of high concentration by kinetic energy.
   e. Diffusion over a greater distance takes longer than diffusion over a short distance.

7. Which of the following processes requires ATP?
   a. diffusion b. active transport c. osmosis
   d. facilitated diffusion e. net diffusion

8. Nicotine in cigarette smoke interferes with the ability of cells to rid the breathing passageways of debris. Which organelles are "paralyzed" by nicotine?
   a. flagella b. ribosomes c. microfilaments
   d. cilia e. lysosomes

9. Many proteins found in the plasma membrane are formed by the _____ and packaged by the _____.
   a. ribosomes, Golgi complex
   b. smooth endoplasmic reticulum, Golgi complex
   c. Golgi complex, lysosomes
   d. mitochondria, Golgi complex
   e. nucleus, smooth endoplasmic reticulum

10. Match the following:

____ a. cellular movement	A. centrosome
____ b. selective permeability	B. cytoskeleton
____ c. protein synthesis	C. Golgi complex
____ d. lipid synthesis, detoxification	D. lysosomes
____ e. packages proteins and lipids	E. mitochondria
____ f. ATP production	F. plasma membrane
____ g. digest bacteria and worn-out organelles	G. ribosomes
____ h. forms mitotic spindle	H. smooth ER

11. If the smooth endoplasmic reticulum were destroyed, a cell would not be able to
   a. form lysosomes b. synthesize certain proteins
   c. generate energy d. phagocytize bacteria
   e. synthesize fatty acids and steroids

12. Water moves into and out of red blood cells through the process of
   a. endocytosis b. phagocytosis c. osmosis
   d. active transport e. facilitated diffusion

13. A cell undergoing mitosis goes through the following stages in which sequence?
   a. interphase, metaphase, prophase, cytokinesis
   b. interphase, prophase, cytokinesis, telophase
   c. anaphase, metaphase, prophase, telophase
   d. anaphase, metaphase, prophase, cytokinesis
   e. prophase, metaphase, anaphase, telophase

14. Transcription involves
   a. transferring information from the mRNA to tRNA
   b. codon binding with anticodons c. joining amino acids by peptide bonds d. copying information contained in the DNA to mRNA e. synthesizing the protein on the ribosome

15. If a DNA strand has a nitrogenous base sequence TACGA, then the sequence of bases on the corresponding mRNA would be
   a. ATGCT b. AUGCU c. GUACU d. CTGAT
   e. AUCUG

16. Place the following events of protein synthesis in the proper order.
   1. DNA uncoils and mRNA is transcribed. 2. tRNA with an attached amino acid pairs with mRNA. 3. mRNA passes from the nucleus into the cytoplasm and attaches to a ribosome. 4. Protein is formed. 5. Two amino acids are linked by a peptide bond.
   a. 1, 2, 3, 4, 5 b. 1, 3, 2, 5, 4 c. 1, 2, 3, 5, 4
   d. 1, 5, 3, 2, 4 e. 2, 1, 3, 4, 5

17. Match the following descriptions with the phases shown.
   ____ a. nuclear envelope (membrane) and nucleoli reappear
   ____ b. centromeres of the chromatid pairs line up in the center of the mitotic spindle
   ____ c. DNA duplicates
   ____ d. cleavage furrow splits cell into two identical cells
   ____ e. chromosomes move toward opposite poles of cell
   ____ f. chromatids are attached at centromeres; mitotic spindle forms
   A. prophase
   B. cytokinesis
   C. telophase
   D. anaphase
   E. metaphase
   F. interphase

18. In which phase is a cell highly active and growing?
   a. anaphase b. prophase c. metaphase
   d. telophase e. interphase

19. If a virus were to enter a cell and destroy its ribosomes, how would the cell be affected?
   a. It would be unable to undergo mitosis.
   b. It could no longer produce ATP.
   c. Movement of the cell would cease.
   d. It would undergo autophagy.
   e. It would be unable to synthesize proteins.

20. Which of the following statements concerning cancer is NOT true?
   a. A benign tumor is noncancerous.
   b. When a cancerous growth presses on nerves, it can cause pain.
   c. Angiogenesis is the spread of cancerous cells to other parts of the body.
   d. Ultraviolet radiation and radon gas are carcinogens.
   e. Cancer is uncontrolled mitosis in abnormal cells.