chapter

3 Cells

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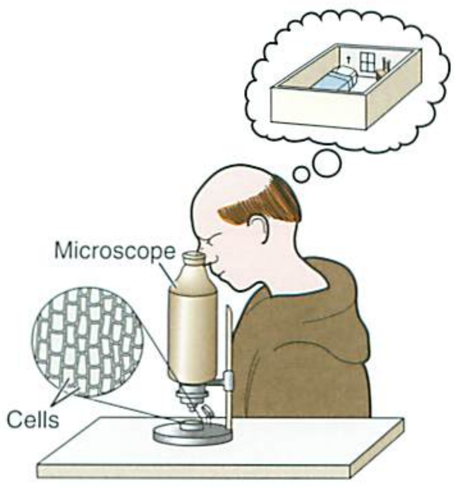
Key Terms

Objectives

1. Label a diagram of the main parts of a typical cell, and do the following:
   - Explain the role of the nucleus.
   - Describe the functions of the main organelles of the cell.
   - Identify the components of the cell membrane.
2. Do the following regarding transport mechanisms:
   - Describe the active and passive movements of substances across a cell membrane.
   - Define tonicity and compare isotonic, hypotonic, and hypertonic solutions.
3. Describe the phases of the cell cycle, including mitosis.
4. Explain what is meant by cell differentiation.
5. Explain the processes and consequences of uncontrolled and disorganized cell growth and apoptosis.

What do this monk and a cell have in common? While looking at a piece of cork under a microscope in the 1600s, Robert Hooke saw cube-like structures that resembled the rooms, or cells, occupied by monks in a monastery. Hooke thus called his structures "cells." The study of cellular structure and function is called *cytology*.



The **cell** is the structural and functional unit of all living matter. Cells vary considerably in size, shape, and function. A red blood cell (RBC), for example, is tiny, whereas a single nerve cell may measure 4 feet in length (Figure 3-1). The shapes and structures of the cells are also very different. The RBC is shaped like a Frisbee and is able to bend. The shape allows it to squeeze through tiny blood vessels and deliver oxygen and other nutrients throughout the body. Some nerve cells are very long, and many resemble bushes or trees. Their shapes enable them to conduct electrical signals quickly over long distances. Cell structure and function are closely related.

TYPICAL CELL

Despite the differences, cells have many similarities. Figure 3-2 is a typical cell with all known cellular components. Each specialized cell, such as a nerve cell, possesses some or all of the properties of the typical cell. Table 3-1 lists and summarizes the functions of the cellular components.

CELL MEMBRANE

The cell is encased by a **cell membrane**, also called the *plasma membrane*. The cell membrane separates intracellular (inside the cell) material from extracellular (outside the cell) material. In addition to physically holding the cell together, the cell membrane performs

4. **According to Figure 2-5**
   a. The covalent bonding of two oxygen atoms yields an oxygen compound.
   b. Two hydrogen atoms bond ionically with one oxygen *atom, yiel*ding water.
   c. Water is formed as two hydrogen atoms share their electrons with one oxygen atom.
   d. A hydrogen atom can react with an oxygen atom but cannot react with another hydrogen atom.

5. **According to Figure 2-6**
   a. As [H^+] decreases, the strip in the diagram becomes a deeper pink.
   b. As pH increases, the strip in the diagram becomes a deeper pink.
   c. The normal blood pH is slightly alkaline.
   d. All of the above are true.

6. **According to Figure 2-7**
   a. ATP means "all the power."
   b. The setting of the mouse trap represents the storage of energy in ATP.
   c. The release of the mouse trap is summarized as ADP + P + energy → ATP.
   d. The lucky mouse represents the source of the stored energy.

other important functions. One of its chief functions is the selection of substances allowed to enter or leave the cell. Because the membrane chooses the substances allowed to cross it, the membrane is said to be selectively permeable, or semipermeable.

What makes up a cell membrane? The cell membrane is composed primarily of phospholipids and protein, as well as a small amount of carbohydrates (Figure 3-3). The phospholipids are arranged in two layers. The protein molecules in the membrane perform several important functions; they provide structural support for the membrane, act as binding sites for hormones, and poke holes, or pores, through the lipid membrane. These pores form channels through which water and dissolved substances flow.

Substances move across the semipermeable membrane in two ways. They can dissolve in the lipid portion of the membrane, as do oxygen and carbon dioxide (lipid-soluble substances). Substances can also cross the membrane by flowing through the pores. Water and electrically charged substances such as sodium and chloride cannot penetrate the lipid membrane and must use the pores. These are called water-soluble substances. The size of the pores also helps select which substances cross the membrane. Substances larger than the pores cannot cross the membrane, whereas smaller substances such as sodium and chloride flow through easily. The solubility characteristics of the membrane also play an important role in pharmacology. Drugs are classified as lipid soluble or water soluble. Drug solubility determines its distribution throughout the body.

? Re-Think

1. What is meant by a semipermeable membrane?
2. How does a fat-soluble substance cross the cell membrane? How does a water-soluble substance cross the cell membrane?

INSIDE THE CELL

The inside of the cell is divided into two compartments: the nucleus and the cytoplasm. The inside of the cell resembles the inside of a raw egg; the "yellow yolk" is the nucleus, and the "white" is the cytoplasm.

NUCLEUS

The **nucleus** is the control center of the cell (see Figure 3-2). In particular, the nucleus contains the genetic information and controls all protein synthesis. Most adult cells have one nucleus; only mature RBCs have no nucleus. Surrounding the nucleus is a double-layered nuclear membrane. The nuclear membrane contains large pores that allow the free movement of certain substances between the nucleus and cytoplasm.

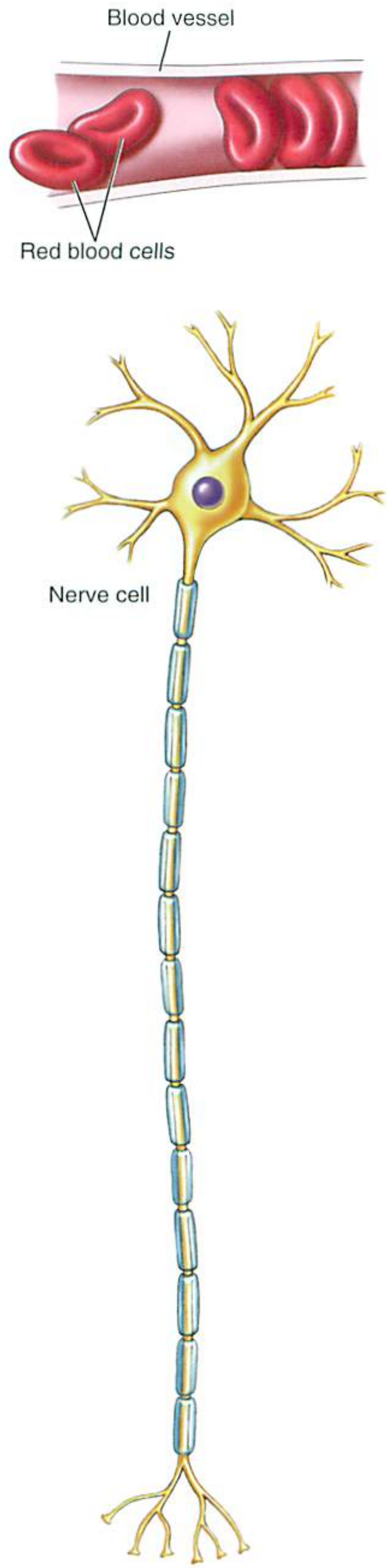


FIGURE 3-1 Cells come in all shapes and sizes.

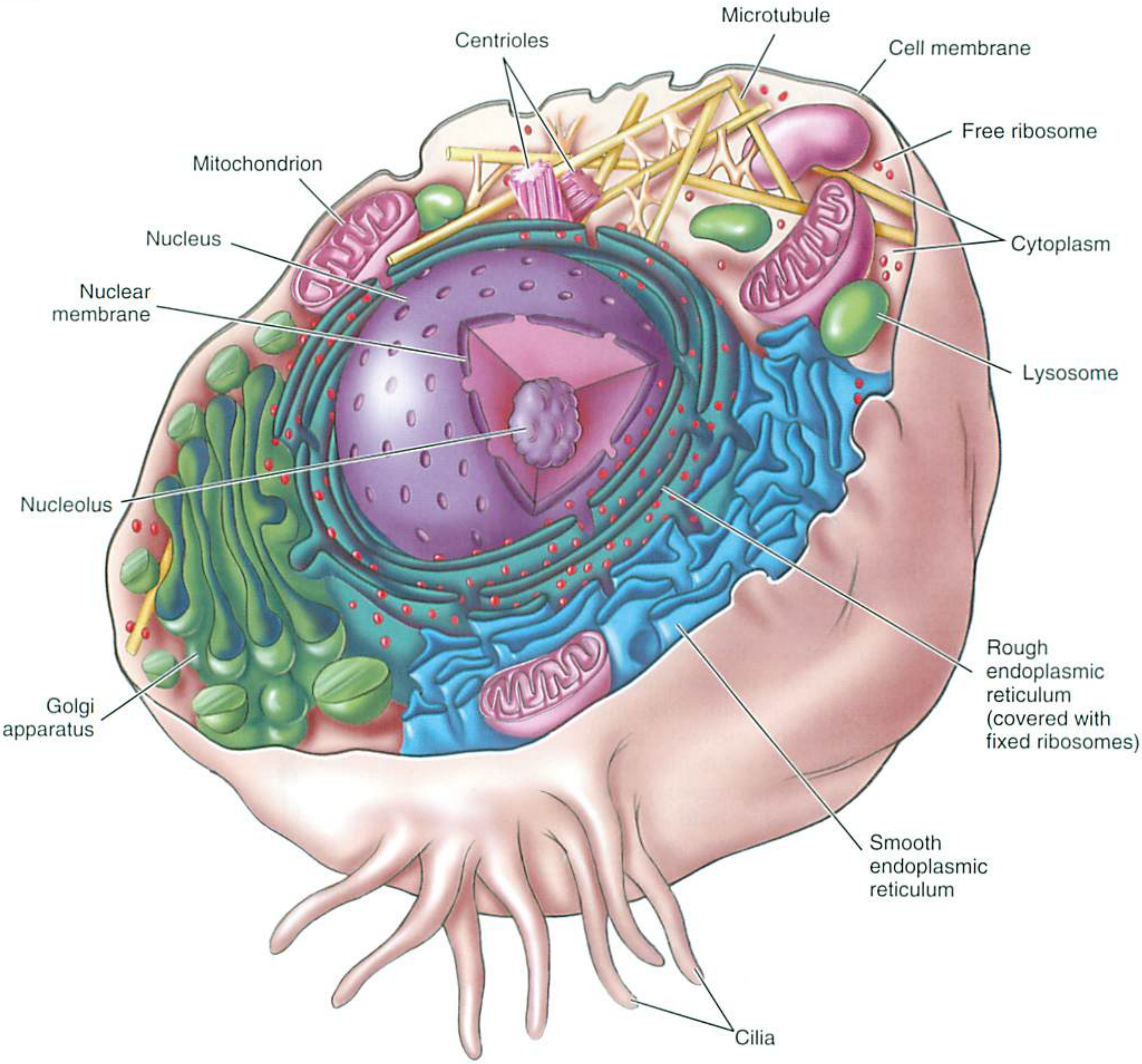


FIGURE 3-2 A typical cell.

The nucleus is filled with a fluid substance called *nucleoplasm*. Within the nucleoplasm are two other structures: the nucleolus and chromatin. The nucleolus, or little nucleus, synthesizes ribosomes that move through nuclear pores into the cytoplasm, where they play a role in protein synthesis. The nucleolus also produces a nucleotide necessary for protein synthesis.

Chromatin is composed mainly of strands of DNA (deoxyribonucleic acid), the carriers of the genetic code. In nondividing cells, chromatin appears as a tangled array of fine filaments. In dividing cells, however, chromatin strands coil tightly, forming DNA-containing structures called *chromosomes*. The genetic code and protein synthesis are described more fully in Chapter 4.

? Re-Think

Why is the nucleus called the control center of the cell?

CYTOPLASM

Cytoplasmic Gel

The **cytoplasm**, or the "gel in the cell," is found inside the cell but outside the nucleus (like the white of a raw egg). The cytoplasm contains the cytosol and organelles. The cytosol is the intracellular fluid and is composed primarily of water, electrolytes, proteins, and nutrients. The cytosol also contains inclusion bodies, insoluble materials such as glycogen granules and pigments such as melanin. The **organelles**, or little organs, are dispersed throughout the cytoplasm; each

Table 3-1 Cell Structure and Function

CELL STRUCTURE	DESCRIPTION AND FUNCTION
Cell Membrane	Contains the cellular contents; selects what enters and leaves the cell
Cilia	Hairlike projections that move substances across surface of cell membrane
Flagellum	Single long hair for swimming movement of the sperm
Microvilli	Accordion-like folds in the membrane; increase transport of water and dissolved solute
Nucleus	Control center of the cell; stores genetic information
Chromatin	Threadlike structures in the nondividing cell that contain DNA; chromatin threads form chromosomes in a dividing cell
Nucleolus	Synthesizes RNA and ribosomes
Nucleoplasm	Gel in the nucleus
Nuclear membrane	Separates the nucleoplasm from the cytoplasm
Cytoplasm	Gel located inside the cell but outside the nucleus
Cytosol	Medium composed of water and dissolved solute; organelles suspended in the cytosol
Organelles	Tiny organs suspended in the cytosol
Mitochondria	Site of ATP production; power plants of the cell
Endoplasmic reticulum (ER)	Membranes that form channels for the flow of cellular substances such as proteins
Rough ER	Contains ribosomes where protein is synthesized
Smooth ER	Site of lipid and steroid synthesis; synthesis of glycogen in liver and skeletal muscle
Golgi apparatus	Finishes and packages protein for export
Ribosomes	Site of protein synthesis
Free	Ribosomes that float within the cytosol; make protein used within the cell
Fixed	Ribosomes fixed to the ER, making it appear rough; concerned with the synthesis of protein that is exported
Lysosomes	Intracellular house cleaning, phagocytosis, removal of damaged organelles
Cytoskeleton	Microfilaments and microtubules that provide for intracellular shape, support, and movement
Centrioles	Paired, short, rod-shaped microtubules that form spindles and help separate the chromosomes during mitosis
Inclusion bodies	Temporary insoluble material such as glycogen granules and pigments such as melanin

ATP, Adenosine triphosphate.

organelle has a specific role. Locate the organelles in Figure 3-2 and Table 3-1.

CYTOPLASMIC ORGANELLES

Mitochondria

The **mitochondria** are tiny, slipper-shaped organelles. The number of mitochondria per cell varies, depending on the metabolic activity of the cell (how hard the cell works). The more metabolically active the cell, the greater the number of mitochondria. The liver, for example, is very active and therefore has many mitochondria per cell. Bone cells are less active metabolically and have fewer mitochondria.

The mitochondrial membrane has two layers (Figure 3-4); the outer layer is smooth, whereas the inner layer has many folds, referred to as *cristae*. The enzymes associated with ATP production are located along the cristae. Because the mitochondria produce most of the energy (ATP) in the body, they are referred to as the "power plants" of the cell. (See Chapter 2 for an explanation of ATP and Chapter 4 for a description of ATP production.)

Ribosomes

Ribosomes are cytoplasmic organelles involved with protein synthesis. Some ribosomes are attached to the endoplasmic reticulum and are called *fixed ribosomes*. Fixed ribosomes are largely concerned with the synthesis of exportable protein—that is, protein secreted by the cell for use elsewhere in the body. Other ribosomes, called *free ribosomes*, float freely within the cytoplasm and generally synthesize proteins that are used within the cell.

Endoplasmic Reticulum

The **endoplasmic reticulum (ER)** is a network of membranes within the cytoplasm (see Figure 3-2). These long folded membranes form channels through which substances, especially newly synthesized protein, move. The two types of ER include the type containing

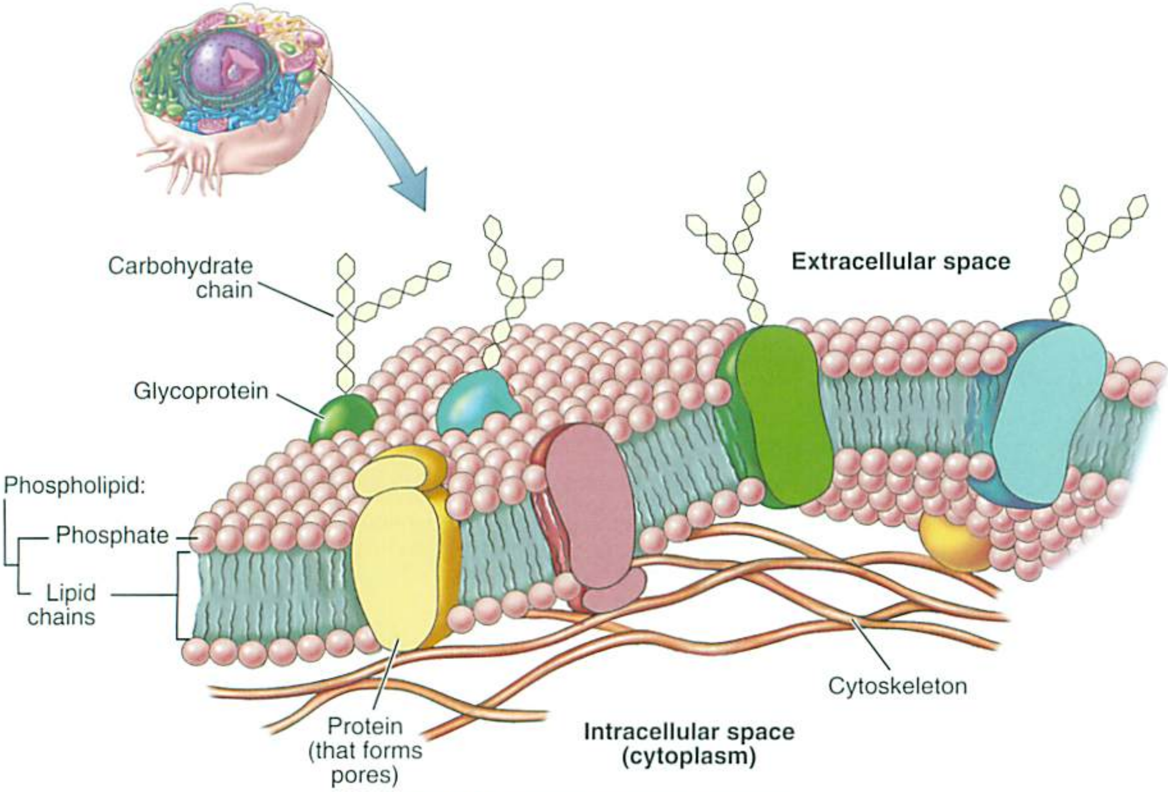


FIGURE 3-3 Structure of the cell membrane.

ribosomes along its surface; it is called *rough endoplasmic reticulum (RER)* because of its rough, sandpaper-like appearance. The RER is primarily concerned with protein synthesis. Protein synthesized along the RER is transported through the channels, and delivered to the Golgi apparatus for further processing. The ER that does not contain ribosomes on its surface appears smooth; it is called *smooth endoplasmic reticulum (SER)*. SER is primarily involved with the synthesis of lipids, steroids, glycerides, and glycogen in skeletal muscle and liver cells.

Golgi Apparatus

The **Golgi apparatus** is a series of flattened membranous sacs (Figure 3-5). Proteins synthesized along the RER are transported to the Golgi apparatus through channels formed by the ER. The Golgi apparatus puts the finishing touches on the protein. For example, a glucose molecule may be attached to a protein within the Golgi apparatus. A segment of the Golgi membrane then wraps itself around the protein and pinches itself off to form a secretory vesicle. In this way, the Golgi apparatus packages the protein. Note that many of the organelles, particularly the ribosomes, ER, and Golgi apparatus, are involved in protein synthesis. (Protein synthesis is described in Chapter 4.)

Lysosomes

Lysosomes are membranous sacs containing powerful enzymes. Lysosomal enzymes break down intracellular waste and debris, including damaged organelles, and thus help "clean house." Lysosomal enzymes perform several other functions. They participate in the destruction of ingested bacteria, a process called *phagocytosis*. Lysosomes also break down the contractile proteins of inactive muscles. Retired athletes experience a decrease in muscle mass, as do chronically bedridden persons.

Cytoskeleton

The cytoskeleton is composed of threadlike structures called *microfilaments* and *microtubules*. The cytoskeleton helps maintain the shape of the cell and assists the cell in various forms of cellular movement. Cellular movement is particularly evident in muscle cells, which contain large numbers of microfilaments. Microtubules are the primary component of the cytoskeleton. In addition to making the cell strong and rigid, the microtubules anchor the position of the organelles within the cytoplasm. Microtubules also play a key role in cell division; they form the spindle apparatus that helps distribute the chromosomes to opposite ends of the dividing cell. (Cell division is explained in Chapter 4.)

Centrioles

Centrioles are paired, rod-shaped, and short microtubular structures that form the spindle apparatus in a dividing cell. Cells that have no centrioles are incapable of cell division; these include neurons, mature

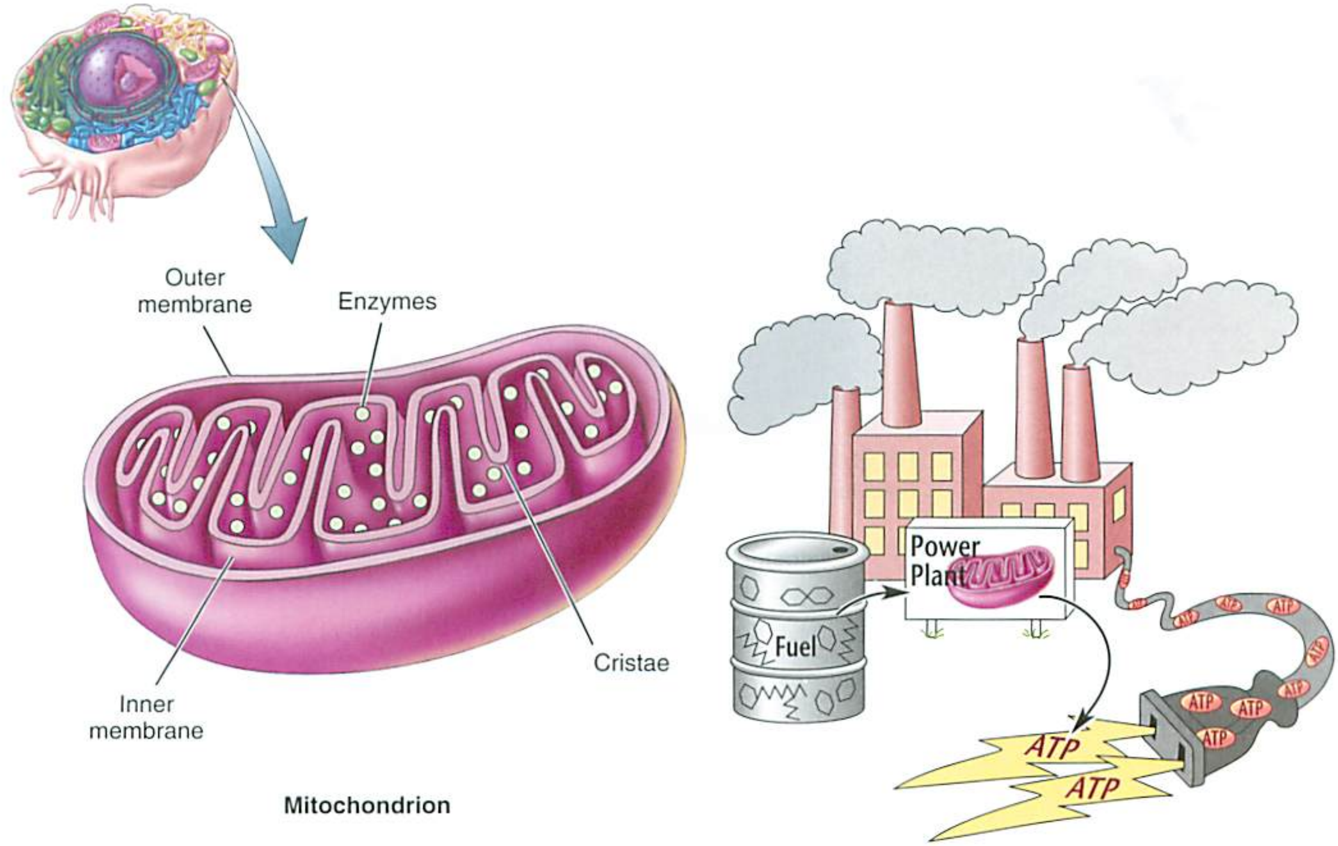


FIGURE 3-4 Mitochondria are the "power plants" of the cells.

RBCs, skeletal muscle cells, and cardiac muscle cells. The cytoplasm surrounding the centrioles is called the *centrosome*. Microtubules of the cytoskeleton begin at the centrosome and spread throughout the cytoplasm.

? Re-Think

1. What is the primary function of the mitochondria?
2. What is the difference between fixed and free ribosomes?
3. What is the difference between the rough and smooth ER?

ON THE CELL MEMBRANE

MICROVILLI

For cells that are particularly involved with the movement of large amounts of water and its dissolved solute, the membrane forms accordion-like folds called *microvilli* (sing., microvillus). The folding of the cell membrane increases surface area, thereby increasing the amount of fluid absorbed. For example, some of the cells in the digestive tract have millions of foldings, called microvilli, to absorb water and the end products of digested food.

CILIA

Cilia are short hairlike projections on the outer surface of the cell membrane. Cilia use wavelike motions to move substances across the surface of the cell. For example, cilia are abundant on the cells that line the respiratory passages. The cilia help move mucus and trapped dust and dirt toward the throat, away from the lungs. Once in the throat, the mucus can be removed by coughing or swallowing. The cilia therefore help clear the respiratory passages. Cigarette smoking damages the cilia and thus deprives the smoker of this benefit.

FLAGELLA

Flagella (meaning whiplike) are similar to cilia in that both are hairlike projections of the cell membrane. Flagella, however, are thicker, longer, and fewer in number; they help move the cell. The tail of the sperm is an example of a flagellum; the tail enables the sperm to swim.

2+2 Sum It Up!

The cell is the structural and functional unit of all living matter. Although cells differ considerably, they also share many similarities. The "typical cell" illustrates these similarities. The cell is surrounded by a cell membrane. The inside of the cell is divided into the nucleus, the control center, and the cytoplasm, which contains the cytosol and many little organs, or organelles, each of which has a special task to perform. Table 3-1 lists the organelles and their functions.

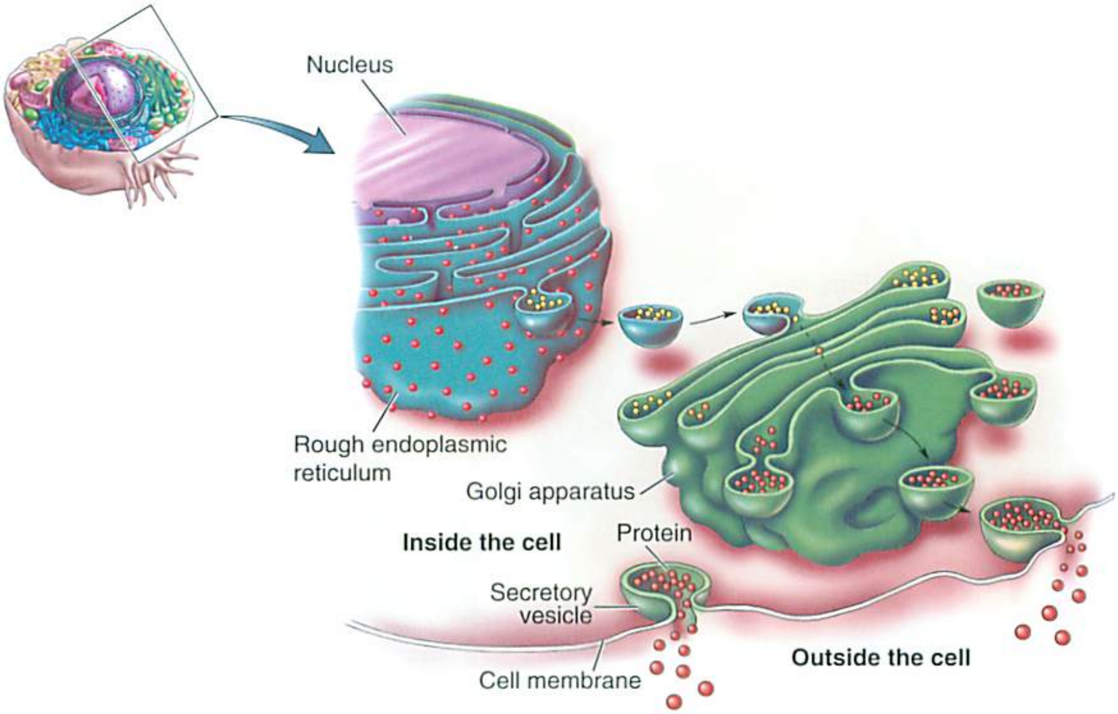


FIGURE 3-5 The Golgi apparatus: packages the protein for export.

MOVEMENT ACROSS THE CELL MEMBRANE

Cells are bathed in an extracellular fluid that is rich in nutrients such as oxygen, glucose, and amino acids. These nutrients are needed in the cell and must therefore be able to cross the cell membrane. The cell's waste, which accumulates within the cell, must also be able to cross the cell membrane. Wastes are eventually eliminated from the body.

A number of mechanisms assist in the movement of water and dissolved substances across the cell membrane. The transport mechanisms can be divided into two groups: **passive transport** and **active transport** mechanisms. Table 3-2 summarizes both types of transport.

The passive transport mechanisms require no additional energy in the form of ATP. Passive transport is something like the downward movement of a ball (Figure 3-6, *A*). The ball is at the top of the hill. Once released, the ball rolls downhill. The ball does not need to be pushed; it moves passively, without any input of energy. Passive transport mechanisms cause water and dissolved substances to move without additional energy, like a ball rolling downhill.

Active transport mechanisms require an input of energy in the form of ATP. Active transport is like the upward movement of a ball (see Figure 3-6, *B*). For the ball to move uphill, it must be pushed, therefore requiring an input of energy.

PASSIVE TRANSPORT MECHANISMS

The passive mechanisms that move substances across the membrane include diffusion, facilitated diffusion, osmosis, and filtration.

DIFFUSION

Diffusion is the most common transport mechanism. Diffusion is the movement of a substance from an area of higher concentration to an area of lower concentration. For example, a tablet of red dye is placed in a glass of water (Figure 3-7, *A*). The tablet dissolves, and the dye moves from an area where it is most concentrated (glass 1) to an area where it is less concentrated (glasses 2 and 3). Diffusion continues until the dye is evenly distributed throughout the glass. The point at which no further net diffusion occurs (glass 3) is called **equilibrium**.

The scent of our pet skunk, Perfume, also illustrates diffusion (see Figure 3-7, *B*). Perfume's scent does not take long to permeate the area! Diffusion is involved in many physiological events. For example, diffusion causes oxygen to move across the membrane of an alveolus of the lung into the blood (see Figure 3-7, *C*). Oxygen diffuses from the alveolus because the concentration of oxygen is higher within the alveolus than within the blood. Conversely, carbon dioxide, a waste product that accumulates within the blood, diffuses in the opposite direction (carbon dioxide moves from

Table 3-2 Transport Mechanisms

MECHANISM	DESCRIPTION AND FUNCTION
Passive	
Diffusion	Movement of a substance from an area of high concentration to an area of low concentration
Facilitated diffusion	Helper molecule within the membrane assists movement of substances from area of high concentration to area of low concentration
Osmosis	Diffusion of water (solvent) from an area with more water to an area with less water. The water compartments are separated by a semipermeable membrane.
Filtration	The pushing of water and dissolved substances from an area of high pressure to an area of low pressure; the water and dissolved substances are pushed
Active	
Active transport pump	Moves a substance uphill (from an area of low concentration to an area of high concentration); requires an input of energy (ATP)
Endocytosis	Taking in or ingestion of substances by the cell membrane
Phagocytosis	Engulfing of solid particles by the cell membrane (cellular eating)
Pinocytosis	Engulfing of liquid droplets (cellular drinking)
Exocytosis	Secretion of cellular products (e.g., protein, debris) out of the cell

ATP, Adenosine triphosphate.

the blood into the alveolus). The lungs then exhale the carbon dioxide, thereby eliminating waste from the body. Thus, the process of diffusion moves oxygen into the blood and carbon dioxide out of the blood.

FACILITATED DIFFUSION

Facilitated diffusion is a form of diffusion that is responsible for the transport of many substances (*facilitate* means "to help"). As in diffusion, substances move from a higher concentration toward a lower concentration (Figure 3-8). In facilitated diffusion, however, the substance is helped across the membrane by a molecule within the membrane. The helper molecule increases the rate of diffusion. The transport of glucose by facilitated diffusion is illustrated in Figure 3-8 by a boy carrying the glucose. Note that he is moving downhill, indicating that facilitated diffusion is a passive transport process.

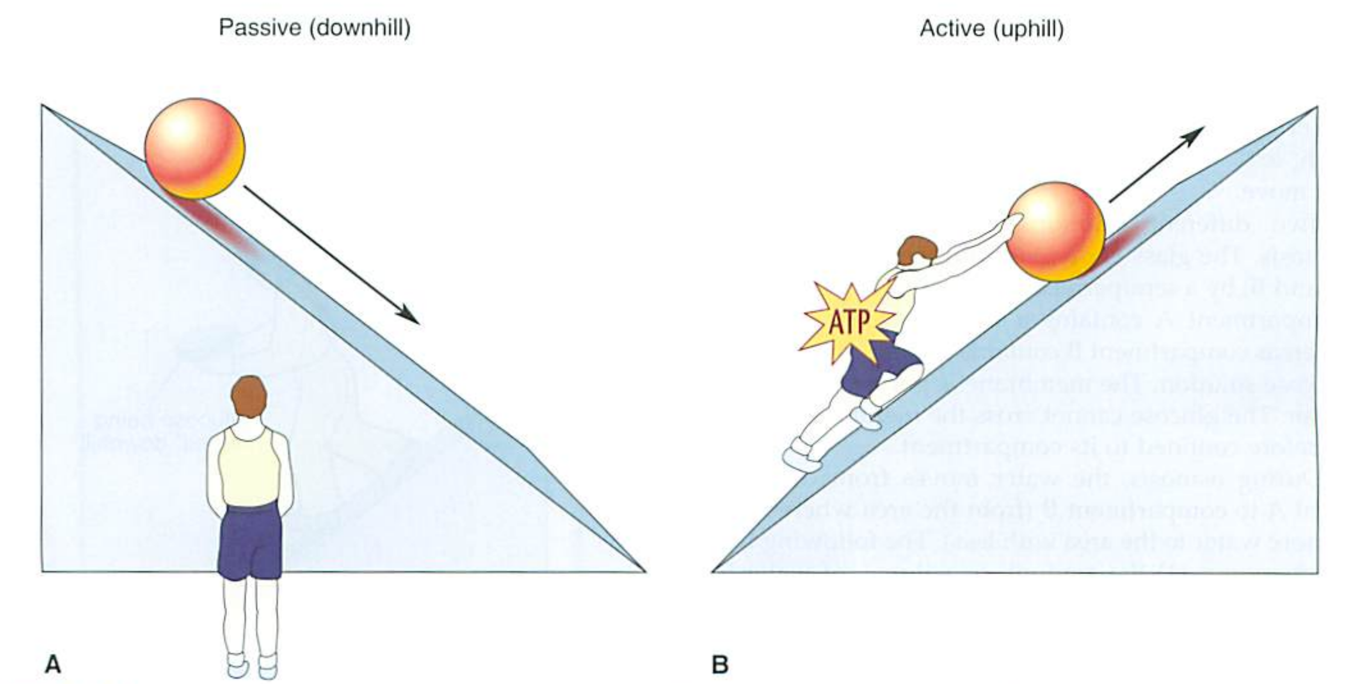


FIGURE 3-6 Transport mechanisms. **A,** Passive transport mechanism. The ball rolls downhill on its own. **B,** Active transport mechanism. The ball must be pushed uphill using adenosine triphosphate (ATP).

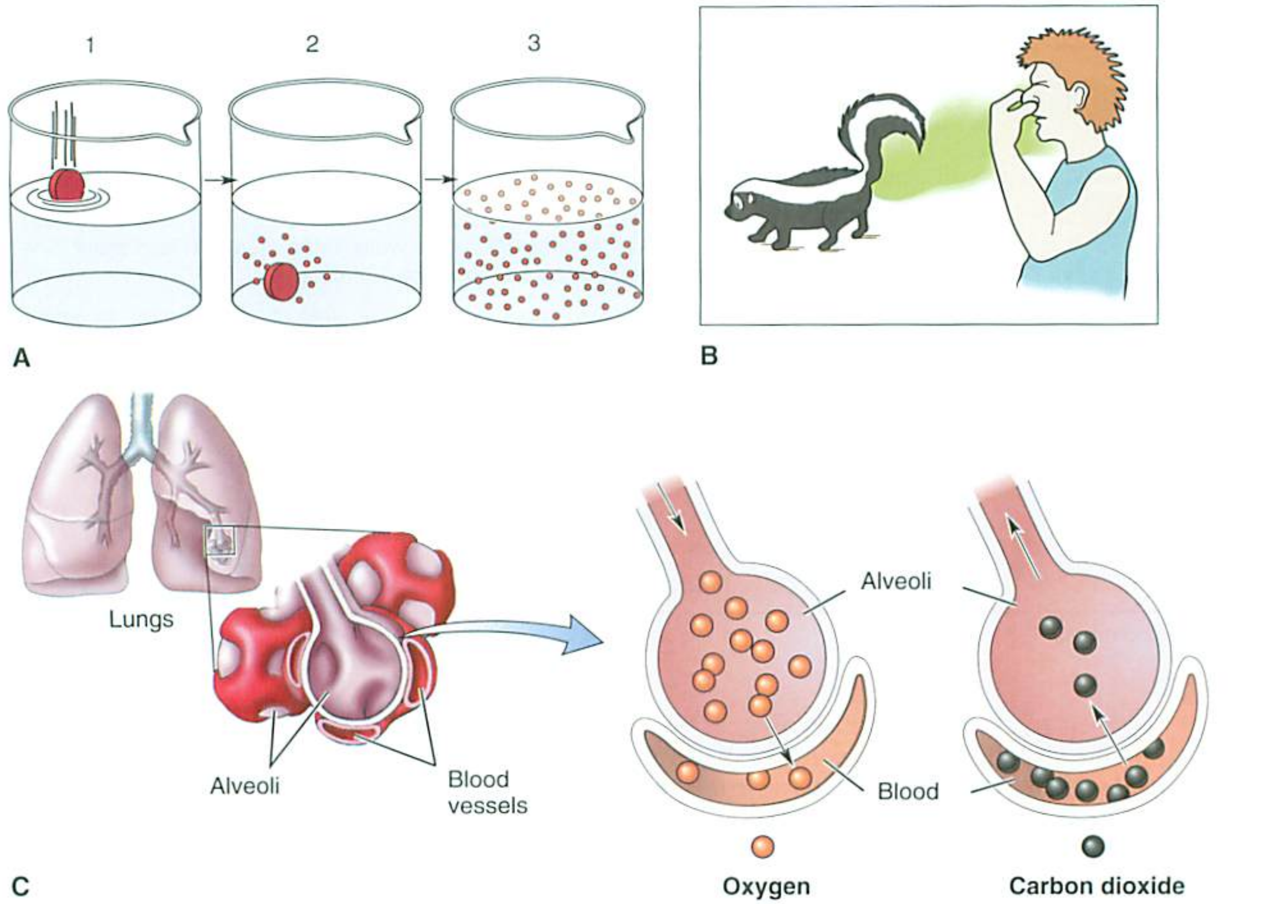


FIGURE 3-7 Diffusion. **A,** Diffusion of a red dye. **B,** Diffusion of Perfume's "perfume." **C,** Diffusion of oxygen and carbon dioxide across the alveolar cell membrane in the lung.

OSMOSIS

Osmosis is a special case of diffusion. Osmosis is the diffusion of water through a selectively permeable membrane. A selectively permeable—or semipermeable—membrane allows the passage of some substances while restricting the passage of others. During osmosis, the water diffuses from an area with more water to one with less. The dissolved substances, however, do not move.

Two different solutions in the glass illustrate osmosis. The glass is divided into two compartments (A and B) by a semipermeable membrane (Figure 3-9). Compartment A contains a dilute glucose solution, whereas compartment B contains a more concentrated glucose solution. The membrane is permeable only to water. The glucose cannot cross the membrane and is therefore confined to its compartment.

During osmosis, the water moves from compartment A to compartment B (from the area where there is more water to the area with less). The following two effects occur: (1) the amount, or volume, of water in compartment B becomes greater than the volume in compartment A; and (2) the concentrations of the solutions in both compartments change. The solution in compartment A becomes more concentrated, whereas the solution in compartment B becomes more dilute.

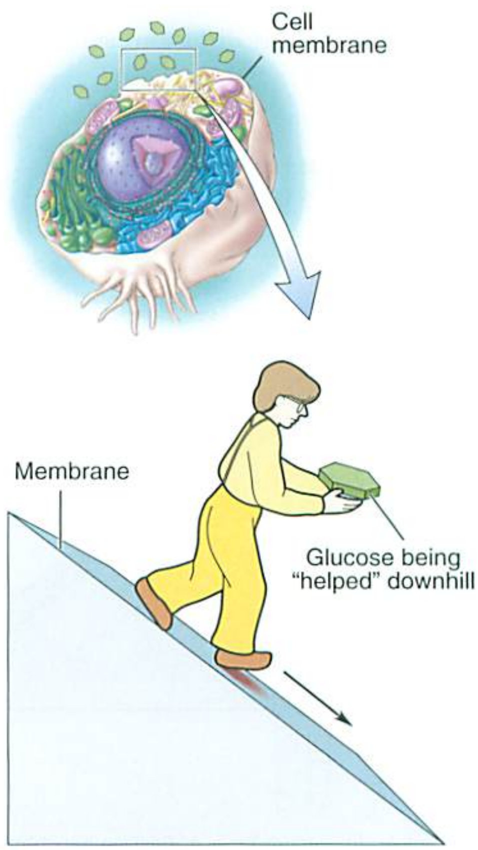


FIGURE 3-8 Facilitated diffusion.

Because water moves toward the more concentrated solution, it appears to be "pulled" in that direction. Sometimes osmosis is described as a "pulling" pressure. For example, Na^+ is said to pull or hold water. More correctly stated, water diffuses into the more concentrated saline solution.

Because osmosis causes water to move into a compartment, it can cause swelling. For example, tissue injury causes leakage and accumulation of proteins within the tissue space. The confined proteins act osmotically. Water diffuses toward the protein, causing the tissues to swell, a condition called *edema*.

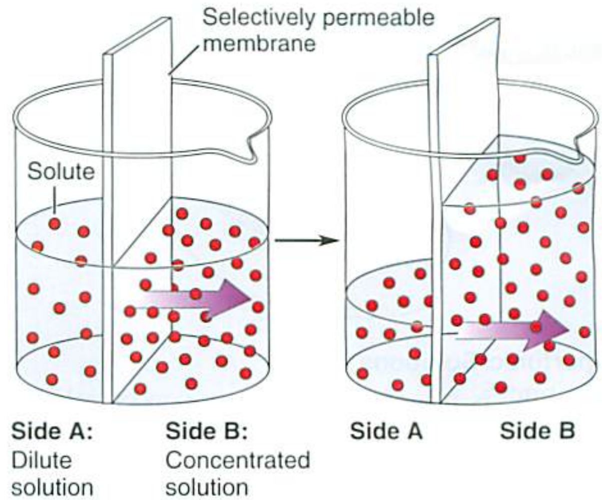


FIGURE 3-9 Osmosis. The effect of osmotically active particles on the movement of water.

Re-Think

What are the driving forces for diffusion, facilitated diffusion, and osmosis?

TONICITY

Tonicity is the ability of a solution to affect the volume and pressure within a cell. Note what happens when a cell is placed in solutions of different concentrations (Figure 3-10). The following three terms are used to illustrate tonicity: *isotonic, hypotonic,* and *hypertonic.*

Isotonic Solution

An isotonic solution has the same concentration as intracellular fluid (*iso* means "same"). Consider an RBC placed in an isotonic solution. Because the solution is isotonic, no net movement of water occurs; the cell neither gains nor loses water.

Hypotonic Solution

If an RBC is placed in pure water (a solution containing no solute), then water moves into the cell by osmosis (from where there is more water to where there is less water). The pure water, being more dilute than the inside of the cell, is said to be hypotonic. Hypotonic solutions cause RBCs to burst, or lyse, in a process referred to as *hemolysis*. Because of hemolysis, pure water is not administered intravenously.

Do You Know...

Why a Blood Clot May Continue to "Grow," Even When the Bleeding Stops?

The components of the blood clot are osmotically active particles. Water therefore diffuses into the blood clot, causing it to enlarge. If the expanding blood clot is located within the brain, it presses on the brain tissue, causing a variety of life-threatening neurological deficits.

A boiled hot dog may also illustrate this bursting effect. The hot dog, which contains a lot of salt, is

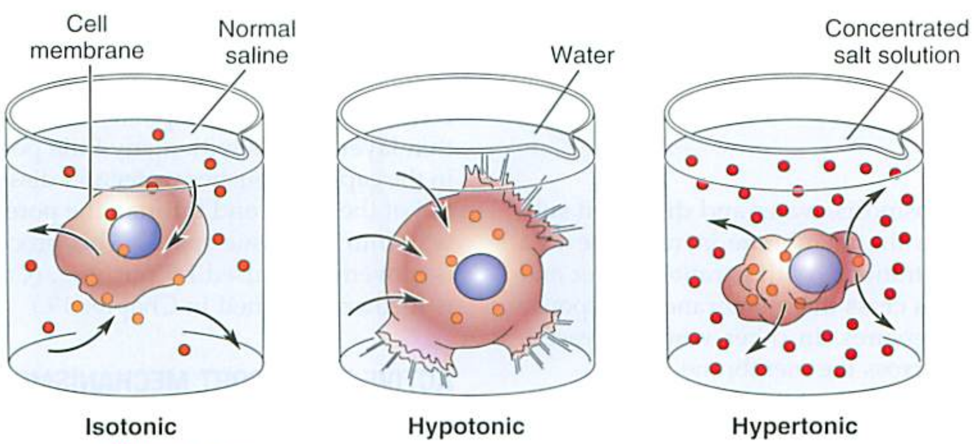
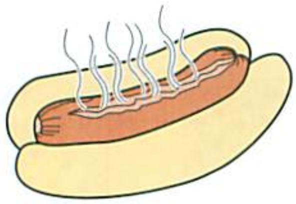


FIGURE 3-10 Effects of osmosis: isotonic, hypotonic, and hypertonic solutions.

boiled in plain water. Because the plain water is hypotonic relative to the hot dog, water diffuses into the hot dog, and it bursts.



Hypertonic Solutions

If an RBC is placed within a very concentrated salt solution, water diffuses out of the RBC into the bathing solution, causing the RBC to shrink, or crenate. The salt solution is referred to as a *hypertonic solution.*

Why is the tonicity of a solution important? If the cell gains water, the RBC membrane bursts. If the RBC loses water, the cell shrinks. In both cases, RBC function is impaired. Isotonic solutions do not cause cells to swell or shrink. While the RBC was used to explain tonicity, other cells respond in the same way. Clinically, isotonic solutions are frequently administered intravenously. Commonly used isotonic solutions include normal saline (0.9% NaCl), 5% D/W (5% dextrose or glucose in water, or D_5W), and Ringer's solution. Under special conditions, hypotonic or hypertonic solutions may be administered intravenously.

? Re-Think

1. Why does the exposure of an RBC to a hypotonic environment cause hemolysis?
2. What is the advantage of administering an isotonic IV solution?

Do You Know...

How to Shrink a Swollen Brain?

This can be done by administering a hypertonic solution (e.g., mannitol) intravenously. Because a hypertonic solution contains more solute than what is present in the interstitial or tissue fluid of the brain, water leaves the brain tissue in response to osmosis and moves into the blood. As the blood is carried away from the brain, brain swelling (cerebral edema) decreases.

FILTRATION

With diffusion and osmosis, water and dissolved substances move across the membrane in response to a difference in concentrations. With **filtration**, water and dissolved substances cross the membrane in response to differences in pressures. In other words, pressure pushes substances across the membrane.

A syringe can illustrate filtration (Figure 3-11). Syringe 1 is filled with water. If a force is applied to the plunger, the water is pushed out through the

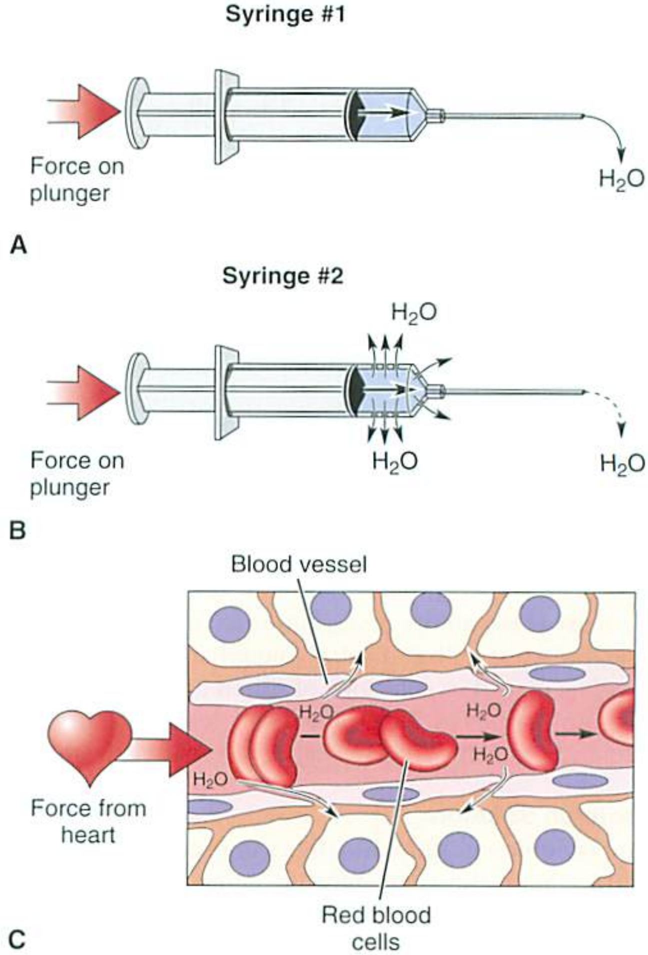


FIGURE 3-11 Filtration. **A,** Water is forced through the needle. **B,** Water (H_2O) is forced through the holes in the barrel of the syringe. **C,** Water is forced out of the capillary through holes, or pores.

needle. The water moves in response to a pressure difference, with greater pressure at the plunger than at the tip of the needle. In the second syringe, tiny holes are made in the sides of the barrel. When force is applied to the plunger, water squirts out the sides of the syringe and out the tip of the needle.

Where does filtration occur in the body? The movement of fluid across the capillary wall can be compared with the movement of water in the syringe with holes in its side (syringe 2). A capillary is a tiny vessel that contains blood. The capillary wall is composed of a thin layer of cells with many little pores. The pressure in the capillary pushes water and dissolved substances out of the blood and through the pores in the capillary wall into the tissue spaces. This process is *filtration;* it is movement caused by pushing. (Capillary filtration is further explained in Chapter 19.)

ACTIVE TRANSPORT MECHANISMS

The active transport mechanisms include active transport pumps, endocytosis, and exocytosis.

ACTIVE TRANSPORT PUMPS

Active transport refers to a transport mechanism that requires an input of energy (ATP) to achieve its goal. It is necessary to pump certain substances because the amount of some substances in the cell is already so great that the only way to move additional substances into the cell is to pump them in. For example, the cell normally contains a large amount of potassium ions (K^+). The only way to move additional K^+ into the cell is to pump it in. To move the K^+ from an area of low concentration to an area of high concentration (uphill), energy is invested (Figure 3-12, *A*).

ENDOCYTOSIS

Endocytosis is a transport mechanism that involves the intake of food or liquid by the cell membrane (see Figure 3-12, *B*). In endocytosis, the particle is too large to move across the membrane by diffusion. Instead, the particle is surrounded by the cell membrane, which engulfs it and takes it into the cell. There are two forms of endocytosis. If the endocytosis involves a solid particle, it is called *phagocytosis* (fag-oh-sye-TOH-sis) (*phago-* means "eating"). For example, white blood cells eat, or phagocytose, bacteria, thereby helping the body defend itself against infection. If the cell ingests a water droplet, the endocytosis is called *pinocytosis* (pin-oh-sye-TOH-sis), or "cellular drinking."

EXOCYTOSIS

Whereas endocytosis brings substances into the cells, **exocytosis** moves substances out of the cells (see Figure 3-12, *C*). For example, the cells of the pancreas make proteins for use outside the pancreas. The pancreatic cells synthesize the protein and wrap it in a membrane. This membrane-bound vesicle moves toward and fuses with the cell membrane. The protein is then expelled from the vesicle into the surrounding space.

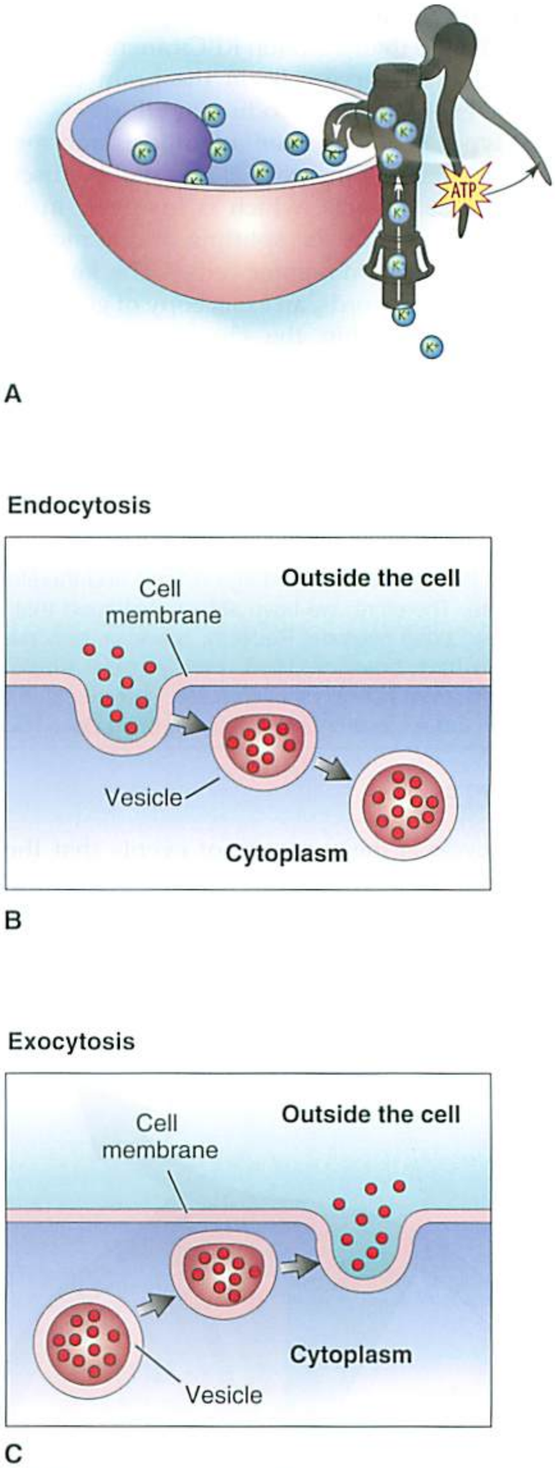


FIGURE 3-12 Active transport. **A,** The active pumping of potassium ions (K^+) into the cell. **B,** Endocytosis. **C,** Exocytosis.

2+2 Sum It Up!

Water and dissolved substances must be able to move across cell membranes. This is achieved through passive and active transport mechanisms. Passive transport mechanisms require no investment of energy (ATP) and include diffusion, facilitated diffusion, osmosis, and filtration. Concentrations of solutions are expressed as tonicity: isotonic, hypotonic, and hypertonic. The active transport mechanisms require an input of ATP and include the active transport pumps, endocytosis (phagocytosis and pinocytosis), and exocytosis.

? Re-Think

Why does an active transport pump require an input of energy?

CELL DIVISION

Cell division is necessary for the body's growth, repair, and reproduction. The frequency of cell division varies considerably from one tissue to the next. Some cells reproduce very frequently, whereas other cells reproduce very slowly or not at all. For example, the cells that line the digestive tract are replaced every few days, and more than 2 million RBCs are replaced every second. Certain nerve cells in the brain and spinal cord, however, do not reproduce at all.

Two types of cell division are mitosis and meiosis. Meiosis occurs only in sex cells and will be discussed in Chapter 26. **Mitosis**, which is involved in bodily growth and repair, is the splitting of one mother cell into two identical "daughter cells." The key word is *identical*. In other words, an exact copy of genetic information, stored within the chromosomes, must be passed from the mother cell to the two daughter cells. Mitosis is described in more detail in the next section ("Cell Cycle").

Do You Know...

Some Good News About the Aging Older Brain?

Neurons in the brain do not undergo mitosis and therefore do not replicate. Therefore, we have always assumed that there are no "new" brain neurons. Recently, however, new neurons in the brain have been identified, even in older brains. The neurons arise from newly discovered stem cells located in the brain. Brain cell replacement in the aging brain does happen!

CELL CYCLE

The **cell cycle** is the sequence of events that the cell goes through from one mitotic division to the next. The cell cycle is divided into two major phases: interphase and mitosis (Figure 3-13).

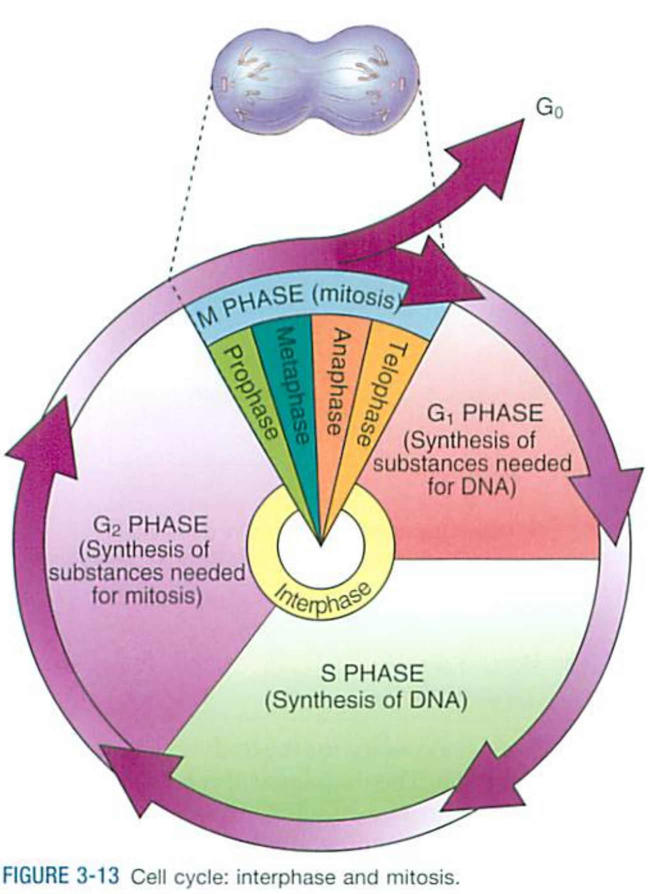


FIGURE 3-13 Cell cycle: interphase and mitosis.

INTERPHASE

During interphase, the cell carries on with its normal functions and gets ready for mitosis through growth and DNA replication. Interphase is divided into three phases: first gap phase (G_1), phase (S), and second gap phase (G_2).

- First gap phase (G_1)—During this phase, the cell carries on its normal activities and begins to make the DNA and other substances necessary for cell division.
- Phase S—During the S phase, the cell duplicates its chromosomes, thereby making enough DNA for two identical cells.
- Second gap phase (G_2)—This phase is the final preparatory phase for cell division (mitosis); it includes the synthesis of enzymes and other proteins needed for mitosis. At the end of G_2, the cell enters the mitotic (M) phase.

MITOSIS

During the mitotic (M) phase, the cell divides into two cells in such a way that the nuclei of both cells contain identical genetic information. Mitosis consists of four phases: prophase, metaphase, anaphase, and telophase (Figure 3-14). During prophase, the chromosomes coil so tightly that they become visible under a light microscope. Each chromosome pair is composed of two identical strands of DNA called *chromatids;* each chromatid is attached at a point called the *centromere*. At the same time, two pairs of centrioles move to opposite poles of the nucleus. Late in prophase, the nuclear membrane disappears. During metaphase, the chromatids are aligned in a narrow central zone; spindle fibers connect the chromatids and centrioles. Anaphase begins when the centromere splits and the chromatids are pulled to opposite poles (end of anaphase). During telophase, each new cell reverts to the interphase state; the nuclear membrane reforms, the chromosomes uncoil, and the chromatin strands reappear. Telophase and cytokinesis mark the end of mitosis. Cytokinesis (sye-toh-kin-EE-sis), which begins in late anaphase, is the pinching of the cell membrane to split the cytoplasm into two distinct cells.

Repeat! Mitosis is a type of cell division that produces two genetically identical daughter cells. How can you remember the stages of mitosis? Think of "Play Me A Tune": *p*rophase, *m*etaphase, *a*naphase, *t*elophase.

At the end of mitosis, the daughter cells have two choices. They can enter G_1 and repeat the cycle (and divide again) or they can enter another phase, called *G zero* (G_0) (see Figure 3-13). Cells in G_0 "drop out" of the cell cycle and rest; they do not undergo mitosis. Cells may re-enter the cell cycle after days, weeks, or years. The inability to stop cycling and enter G_0 is

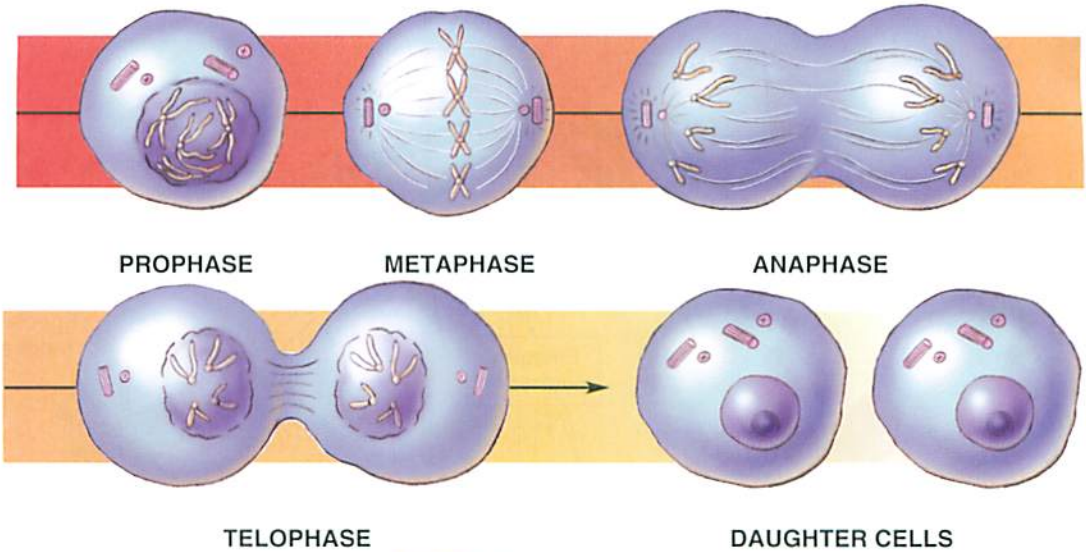


FIGURE 3-14 Stages of mitosis.

characteristic of cancer cells. Cancer cells constantly divide and proliferate. Anticancer drugs are more active against cells that are cycling than against cells resting in G_0. Thus, tumors that contain many cycling cells respond best to chemotherapy.

Anticancer drugs are classified according to the cell cycle phases that they affect. Some anticancer drugs are called *cell cycle phase–specific*. These drugs affect the cell when it is in a particular phase. With the use of this terminology, the anticancer drug methotrexate is considered cell cycle S phase–specific. Other drugs are cell cycle M phase–specific and cell cycle G_2 phase–specific. Some anticancer drugs can act at any phase of the cell cycle and are called *cell cycle phase–nonspecific*. By knowing the cell cycle terminology, you can understand anticancer drugs better.

? Re-Think

1. Explain how interphase prepares the cell for mitosis.
2. What happens during mitosis?

CELL DIFFERENTIATION

Mitosis assures us that the division of one cell produces two identical cells. How do we account for the differences in cells such as muscle cells, RBCs, and bone cells? In other words, how do cells differentiate or develop different characteristics?

An embryo begins life as a single cell, the fertilized ovum. Through mitosis, the single cell divides many times into identical cells. Then, at some time during their development, the cells start to specialize, or **differentiate** (Figure 3-15). One cell, for example, may switch on enzymes that produce RBCs. Other enzymes are switched on and produce bone cells. Regardless of the mechanism, you started life as a single adorable cell and ended up as billions of specialized cells!

What does it mean when a tissue biopsy (surgical removal of tissue for examination) shows many poorly differentiated cells? It means that the tissue cells have failed to differentiate or specialize. In other words, the poorly differentiated cells of a liver tumor do not resemble normal liver cells. Failure to differentiate is characteristic of cancer cells.

STEM CELLS

Stem cells are relatively undifferentiated or unspecialized cells whose only function is the production of additional unspecialized cells. Each time a stem cell divides, one of its daughter cells differentiates while the other daughter cell prepares for further stem cell division. The rate of stem cell division varies with the tissue type; the stem cells within the bone marrow and skin are capable of dividing more than once a day, whereas the stem cells in adult cartilage may remain inactive for years. Stem cell research is of particular interest because of the possibility of replacing damaged tissue and growing new organs. How amazing it would be if newly discovered stem cells could be used to repair a damaged spinal cord or restore the dopamine-secreting cells in the brains of persons with Parkinson's disease. Several years ago, an individual who was paralyzed after a spinal cord injury donated her own stem cells taken from deep within her nose. The stem cells were surgically placed within her spinal cord. The stem cells then differentiated into nerve cells. Although it is too early to claim success, some return of spinal cord function has been reported. Another advance in stem cell research is the development of a new technique that coaxes adult cells to regress to an embryonic state. These undifferentiated cells are called *induced pluripotent stem cells* (iPS cells). The iPS cells can then be induced to specialize into the desired cell type, such as bone, muscle, or blood cells. A major hurdle in

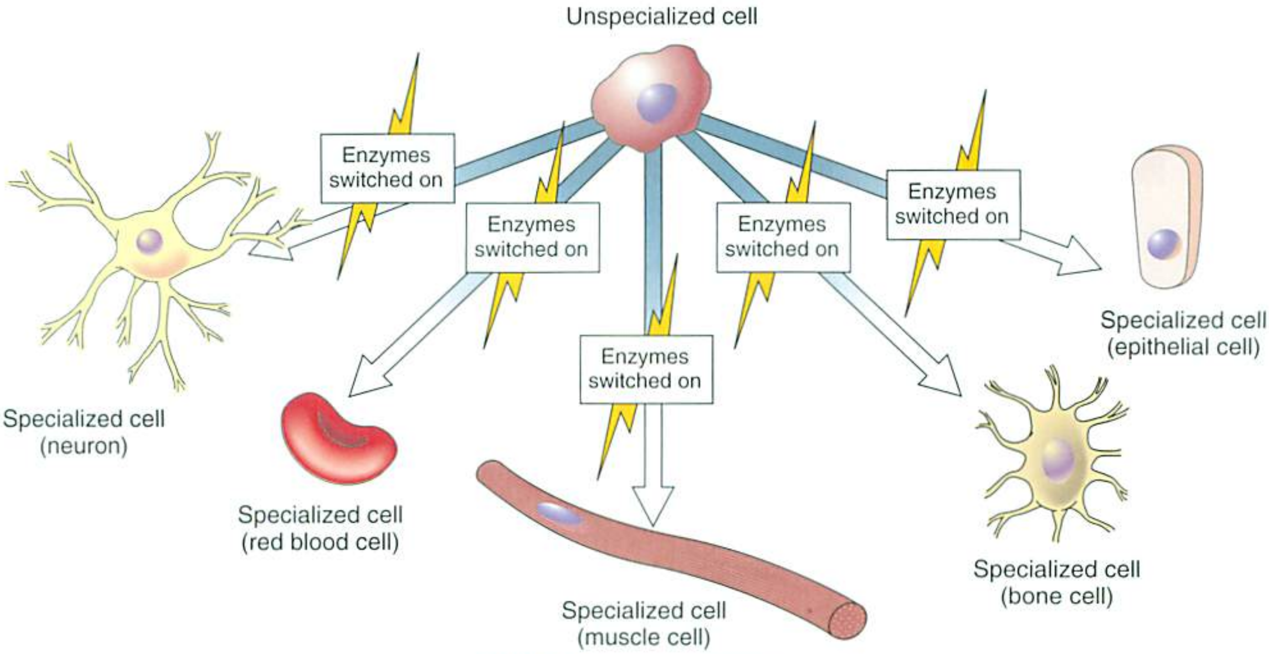


FIGURE 3-15 Cell differentiation.

stem cell research has been the use of embryos as stem cell donors. This technique required the destruction of the embryo, thereby creating an ethical dilemma for many. The development of iPS cells eliminates this issue and hopefully will hasten stem cell research.

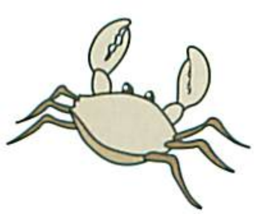
? Re-Think

What is the relationship between stem cells and cellular differentiation?

ORDER, DISORDER, AND DEATH

Most cell growth is orderly. Cells normally reproduce at the proper rate and align themselves in the correct positions. At times, however, cell growth becomes uncontrolled and disorganized. Too many cells are produced. This process is experienced by the patient as a lump or tumor (tumor means swelling).

Tumors may be classified as benign (noncancerous) or malignant (cancerous). Cancer cells are appropriately named. *Cancer* means "crab"; cancer cells, like a crab, send out clawlike extensions that invade surrounding tissue. Cancer cells also detach from the original tumor (primary site) and spread throughout the body (secondary sites). Widespread invasion of the body by cancer cells often causes death. The spreading of cancer cells is referred to as *metastasis.*



There is also a programmed sequence of events that leads to cell death called *apoptosis,* or cell suicide. Apoptosis helps rid the body of old, unnecessary, and unhealthy cells. Because the body replaces a million cells per second, the elimination of some cells by apoptosis is necessary. Apoptosis, however, can go into overdrive, causing excessive cellular death and disease.

A Pap smear is a diagnostic procedure used to detect cancer. A sample of cells (a smear) is obtained, usually from around the cervix. The smear is then examined under a microscope for changes that could indicate cancer. A positive Pap smear can indicate cancer in its early stages. Early detection is associated with a very high cure rate.

Sometimes cells are injured so severely that they die, or necrose (from the Greek word *necros,* meaning "death"). For example, the cells may be deprived of oxygen for too long a period, be poisoned, be damaged by bacterial toxins, or suffer the damaging effects of radiation.

2+2 Sum It Up!

The union of the sperm and egg forms a single cell that divides by mitosis into billions of identical cells. The cell cycle is the sequence of events that the cell goes through from one mitotic division to the next. The cell cycle is divided into two phases: the interphase and the mitotic phase. Mitosis splits a cell into two genetically identical cells. There are four stages of mitosis: prophase, metaphase, anaphase, and telophase. The cells then specialize, or differentiate, into many different types of cells, all of which are needed to perform a wide variety of functions. Most cells grow in an orderly way. Cells can, however, grow abnormally. The result is sometimes a tumor, which may be benign or malignant (cancerous).

As You Age

1. All cells show changes as they age. The cells become larger, and their capacity to divide and reproduce tends to decrease.
2. Normal cells have built-in mechanisms to repair minor damage; this ability to carry out repair declines in aging cells.
3. When DNA is damaged, changes in membranes and enzymes occur in the cell. Changes in the transport of ions and nutrients occur at the cell membrane. The chromosomes in the nucleus undergo such changes as clumping, shrinkage, and fragmentation.
4. Certain genetic disorders such as Down syndrome are more common in children born to older women.
5. Organelles such as mitochondria and lysosomes are present in reduced numbers as a person ages. In addition, cells function less efficiently.

Note: The Medical Terminology and Disorders table appears in Chapter 4.

Get Ready for Exams!

Summary Outline

The cell is the structural and functional unit of all living matter.

I. A Typical Cell
- A. Cell membrane (plasma membrane)
  1. Composition: phospholipid bilayer and protein
  2. Semipermeable: selection of nutrients and waste that cross the membrane
  3. Structures on cell membrane: cilia, flagella, microvilli
- B. Structures inside the cell
  1. Nucleus: control center of the cell; stores genetic information and contains chromatin and the nucleolus
  2. Cytoplasm: gel-like substance inside the cell membrane but outside the nucleus; cytosol and organelles
  3. Organelles: in the cytoplasm
  4. Mitochondria: "power plants" of the cell
  5. Ribosomes (free and fixed): concerned with protein synthesis
  6. Endoplasmic reticulum (two types): rough endoplasmic reticulum (RER) and smooth endoplasmic reticulum (SER)
  7. Golgi apparatus: packages and puts the finishing touches on newly synthesized protein
  8. Lysosomes: intracellular "housekeepers"
  9. Cytoskeleton: (microfilaments and microtubules) provides shape and support to the cell
  10. Centrioles: play a role in cell reproduction

II. Movement Across the Cell Membrane: Passive and Active Mechanisms
- A. Passive transport mechanisms
  1. Passive transport mechanisms: require no input of energy (ATP)
  2. Diffusion: causes a substance to move from an area of greater concentration to an area of lesser concentration
  3. Facilitated diffusion: same as diffusion but uses a helper molecule to increase the rate of diffusion
  4. Osmosis: a special case of diffusion using a semipermeable membrane; involves diffusion of water from an area with more water to an area of less water
  5. Concentrations of a solution expressed as tonicity; solutions are isotonic, hypotonic, or hypertonic
  6. Filtration: movement of water and dissolved substances from an area of high pressure to an area of low pressure
- B. Active transport mechanisms
  1. Active transport: requires an input of energy (ATP)
  2. Active transport pumps: move substances from an area of low concentration to an area of high concentration
  3. Endocytosis: moves substances into a cell; pinocytosis: cellular "drinking"; phagocytosis: cellular "eating"
  4. Exocytosis: moves substances out of a cell

III. Cell Division
- A. Mitosis: produces two identical cells
- B. Meiosis: occurs only in sex cells

IV. Cell Cycle
- A. Interphase (G_1, S, and G_2 phases)
- B. Mitosis (M phase)
  1. The splitting of one mother cell into two identical daughter cells
  2. Four phases of mitosis: prophase, metaphase, anaphase, and telophase
  3. A cell can exit from the cell cycle and enter G_0 (resting).
- C. Cell cycle phase–specific and phase-nonspecific drugs
  1. Some drugs aim at specific phase of cell cycle.
  2. Some drugs are cell cycle phase–nonspecific.

V. Cell Differentiation: From Stem Cells to Specialized Cells

VI. Order, Disorder, and Death

Review Your Knowledge

Matching: *Cell* Structure

Directions: Match the following words with their descriptions below.

a. mitochondria
b. endoplasmic reticulum
c. ribosomes
d. cilia
e. lysosomes
f. nucleus
g. cytoplasm

1. ___ Control center of the cell; contains the DNA
2. ___ Short hairlike projections on the outer surface of the cell
3. ___ Power plants of the cell; most ATP made here
4. ___ Classified as rough and smooth
5. ___ These organelles are attached to the endoplasmic reticulum; involves protein synthesis
6. ___ Digestive organelles that engage in phagocytosis; intracellular "house cleaning"
7. ___ Gel in the cell (outside the nucleus)

Matching: Transport and Tonicity

Directions: Match the following words with their descriptions below. Some words may be used more than once.

a. hypotonic
b. diffusion
c. pinocytosis
d. isotonic
e. hypertonic
f. osmosis
g. filtration
h. facilitated diffusion
i. exocytosis

1. ___ Pressure gradient is the driving force for this type of passive transport.
2. ___ Passive transport mechanism whereby glucose is "helped" across the membrane by a helper molecule within the membrane
3. ___ Protein-containing vesicle within a cell fuses with the cell membrane and ejects the protein
4. ___ Called "cellular drinking"
5. ___ An example of this transport mechanism is the swelling of a blood clot as water is pulled into the clot.
6. ___ Describes a solution that is more concentrated than the inside of a cell
7. ___ Solution that causes a red blood cell to swell with water and burst
8. ___ Solution that has the same concentration as the inside of a red blood cell
9. ___ Drop of red dye is added to beaker of water; in 2 hours, the beaker of water is uniformly colored red.
10. ___ Because of its salt concentration, normal saline is considered this.

Multiple Choice

1. The selectively permeable membrane
   a. permits filtration but not diffusion or osmosis.
   b. determines which substances enter and leave the cell.
   c. allows for the unrestricted movement of water and electrolytes across the cell membrane.
   d. permits diffusion but not osmosis.
2. Which of the following is not true of the mitochondria?
   a. Numbers of mitochondria reflect the metabolic activity of the cell.
   b. Mitochondria are the organelles that make most of the body's ATP.
   c. Mitochondria are located in the cytoplasm.
   d. Mitochondria are the sites of protein synthesis.
3. Which of the following is an incorrect statement regarding the cellular organelles?
   a. Most ATP is produced in the mitochondria.
   b. Lysosomes contain potent enzymes that digest cellular waste and debris.
   c. Most DNA is located within the Golgi apparatus.
   d. The RER is concerned with protein synthesis.
4. A beaker contains two compartments. Compartment A contains a 20% glucose solution and compartment B contains a 5% glucose solution. The membrane is permeable to water, but impermeable to glucose. Which statement is true at equilibrium?
   a. The volume in A is greater than the volume in B.
   b. The volume in A is less than the volume in B.
   c. The volume remains the same in both compartments.
   d. Glucose diffuses from A to B.
5. With regard to the cell cycle,
   a. the M phase is the same as interphase.
   b. cells cannot enter phase G_0 when they complete the cycle.
   c. cell division occurs during the M phase.
   d. prophase, metaphase, anaphase, and telophase occur during phase G_1.
6. The blood pressure forces water and dissolved solute out of the capillaries into the tissue space. This process is called
   a. osmosis.
   b. active transport.
   c. pinocytosis.
   d. filtration.
7. What might happen if pure water were administered intravenously (directly into the blood via the veins)?
   a. The patient becomes dehydrated.
   b. The red blood cells undergo hemolysis.
   c. The red blood cells lose volume and shrink.
   d. The water dilutes the blood; water is "pulled" into the capillaries from the tissue spaces.