CHAPTER 5

Cell Structure and Function



The microscope enabled scientists to discover that all living things are made up of cells. The spherical objects in the large photograph are single-celled yeasts; the branched object in the small photograph is a human nerve cell.

More than 100,000,000,000,000 cells are found in an adult human! We have about 155,000 cells in every square centimeter of our skin, about 30 billion cells in our brain, and about 20 trillion red blood cells in our blood. Many microscopic organisms, including bacteria, consist of just a single cell. Despite our complexity, we begin our lives as single cells.

Cells are the "atoms" of biology, the fundamental units of living organisms. Just as the atom is the smallest unit of an element, the cell is the smallest unit of an organism that can reasonably be thought of as alive. Questions concerning life—from ecology to behavior, from evolution to reproduction—must be partly answered at the level of the cell. The cell is the key to biology because it is at this level that a collection of water, salts, macromolecules, and membranes truly springs to life. In this chapter we shall begin our study of cells by looking into the various parts of the cell.

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5–1 The Cell Theory

Section Objectives

- List the contributions of van Leeuwenhoek, Hooke, Schleiden, Schwann, and Virchow to the development of the cell theory.
- State the cell theory.

Each of us, at one time or another, has tried to look closely at something. You may have picked up a coin and tried to read the initials of its designer, cut closely into the coin's surface. You may have tried to read the details on the face of a stamp, or stared at a blade of grass until the tiniest detail was clear.

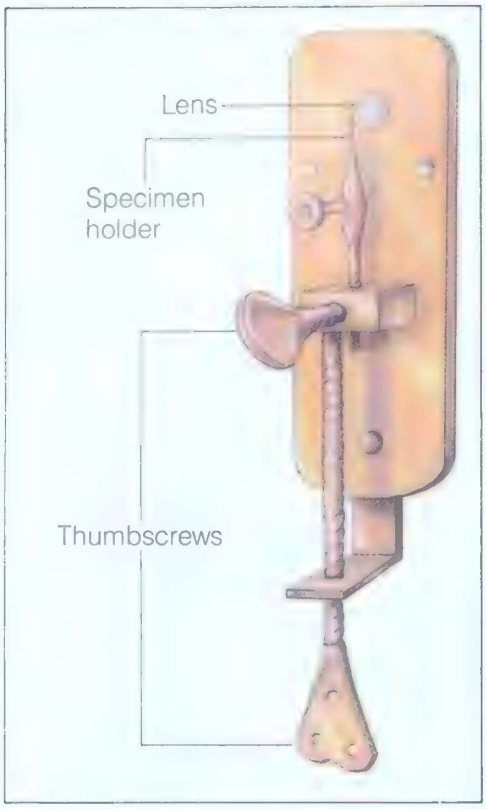
Such curiosity led early investigators to examine living things under lenses and microscopes in the hope of getting a better glimpse of their structure. Little by little, their findings led to the most fundamental of all discoveries about the nature of living things: All living things are made of **cells**. Cells are the basic units of structure and function in living things.

The first lenses were used in Europe hundreds of years ago by merchants who needed to determine the quality of cloth. They used their magnifying lenses to examine the quality of the thread and the precision of the weave in a bolt of cloth. From these simple glass lenses, combinations of lenses were put together. In Holland in the early 1600s, two useful instruments were constructed. One was the telescope, which enabled people to see objects at a distance. The telescope made the distant stars in the sky visible. The other instrument, the microscope, made the very small objects in nature visible.

The person who is given credit for developing the first microscope was Anton van Leeuwenhoek (LAY-vuhn-hook), a



Figure 5–1 *The invention of the telescope enabled astronomers to study distant objects such as this spiral galaxy. The microscope, on the other hand, opened up the world of the very small to biologists. Before the invention of the microscope, a microscopic alga, such as this diatom, could not have been observed.*



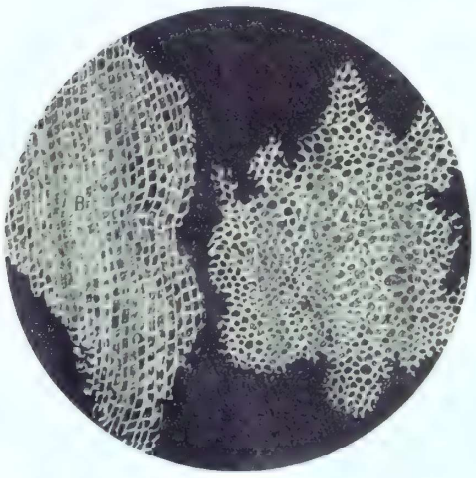


Figure 5–2 Van Leeuwenhoek's simple microscope (top) could magnify objects a few hundred times. Robert Hooke made this drawing of cork cells (bottom) using a microscope that he built. Hooke, however, was not looking at living cells; what he saw were the cell walls that surround living cork cells.

Dutch biologist. His invention enabled him to see things that no one had ever seen before. He could see tiny living organisms whose world consisted of a drop of water. Van Leeuwenhoek carefully observed the tiny living things in pond water and made detailed drawings of each kind of organism.

Van Leeuwenhoek's work interested other people in building microscopes. Before long, pioneers in several countries were experimenting with these new instruments. One such person was the Englishman Robert Hooke, who used one of his microscopes to look at thin slices of plant stems, wood, and pieces of cork. Looking at the cork, Hooke saw that it was composed of thousands of tiny chambers. He called these chambers cells because they reminded him of the small rooms called cells in a monastery.

Unfortunately, Hooke was not looking at living cells. He was looking at the nonliving outer walls of what had once been living plant cells. Nonetheless, Hooke's discovery was significant because it opened up the study of cells.

Gradually over the next 200 years, other scientists began to discover that cells were not only found in plants but in other living things too. In 1833, Robert Brown, a Scottish scientist, observed that many cells seemed to have a dark structure near the center of the cell. We now call this structure the nucleus. Five years later, German botanist Matthias Schleiden stated that all plants are made of cells. The next year, Theodor Schwann discovered that all animals are made of cells too. In 1855, Rudolf Virchow, a German physician, added one more element to the developing theory of cells. Based on research, he stated that all cells arise from the division of preexisting cells.

Today, the observations and conclusions of these scientists are summarized into the **cell theory**. The cell theory forms the basic framework in which biologists have tried to understand living things ever since. **The cell theory states:**

- **All living things are composed of cells.**
- **Cells are the basic units of structure and function in living things.**
- **All cells come from preexisting cells.**

5–1 SECTION REVIEW

1. When Hooke first used the term cell, did he intend it to apply to living material? Explain your answer.
2. What contributions did van Leeuwenhoek, Hooke, Schleiden, Schwann, and Virchow make to the development of the cell theory?
3. What role did the invention of the microscope play in the development of the cell theory?

5–2 Cell Structure

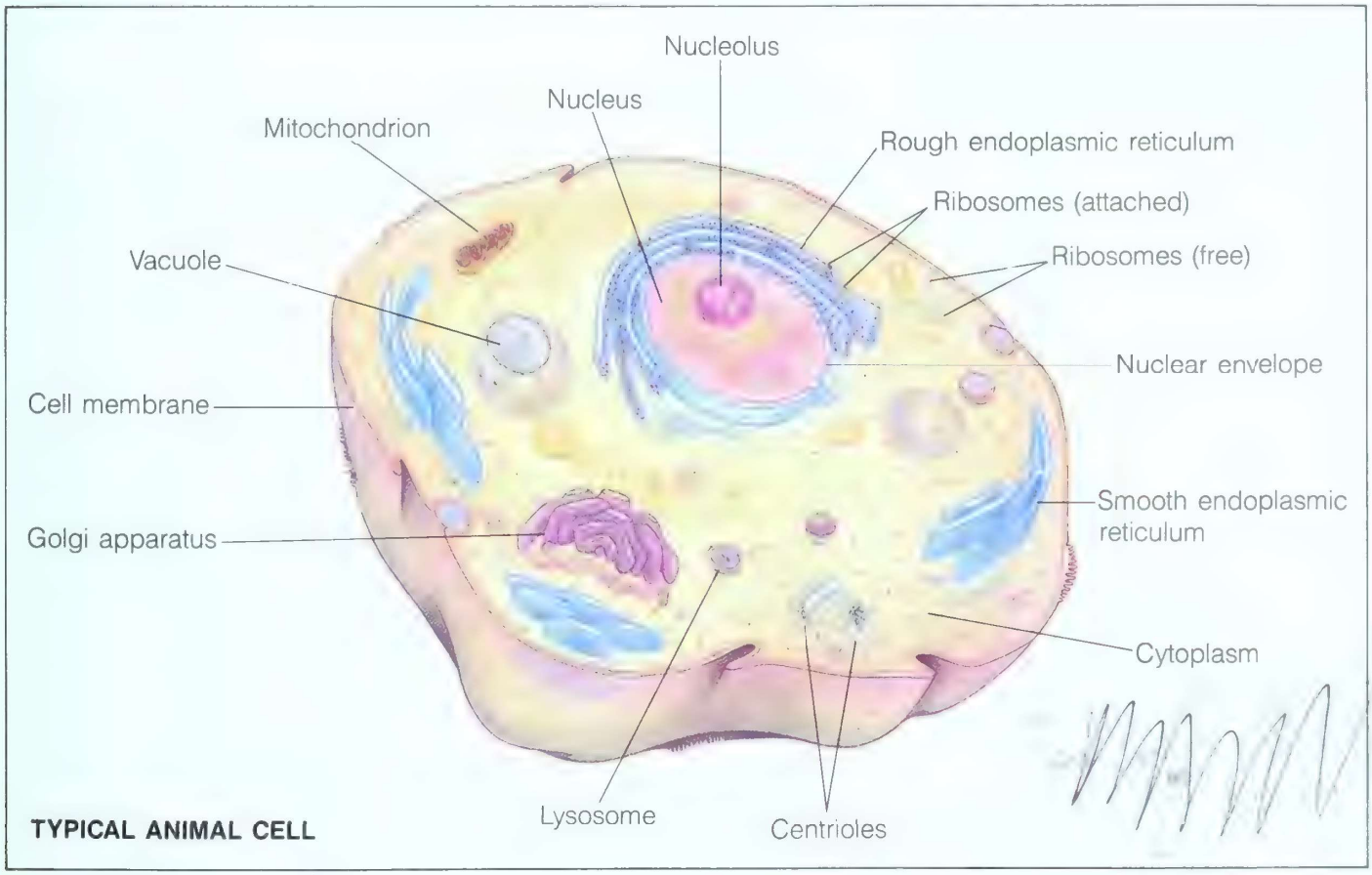
Section Objectives

- Identify and give the function of the three basic structures of most cells.
- Compare the structure of the cell membrane and the cell wall.
- Distinguish between prokaryotes and eukaryotes.

There is enormous variety in the size and shape of different cells. The smallest cells, belonging to a group of organisms known as *Mycoplasma* (migh-koh-PLAZ-muh), are only about 0.2 micrometers in diameter. A micrometer is equal to one millionth of a meter. *Mycoplasma* are so small that they often are beyond the resolving power of light microscopes. Larger cells include the giant ameba *Chaos chaos*, which is about 1000 micrometers in diameter. Larger still are the yolks of bird eggs, which are actually single cells containing stored food for the developing bird. For the most part, cells are between 5 and 50 micrometers in diameter. Physical limits on the flow of information through the cell and on the flow of materials into and out of the cell prevent most cells from being much larger than this.

Despite differences in size and shape, there are certain structures that are common to most cells. **The cells of animals, plants, and related organisms have three basic structures: the cell membrane, or outer boundary of the cell; the nucleus, or control center; and the cytoplasm, or material between the cell membrane and the nucleus.** Let's examine a typical plant cell and an animal cell to learn about some of these basic structures.

Figure 5–3 *This diagram shows a typical animal cell. Note that the structures shown are not to scale. (This is true of almost all cell diagrams.) Most structures have been enlarged so that they can be clearly seen. In addition, some structures are more extensive or more numerous in an actual cell than they are in this diagram.*



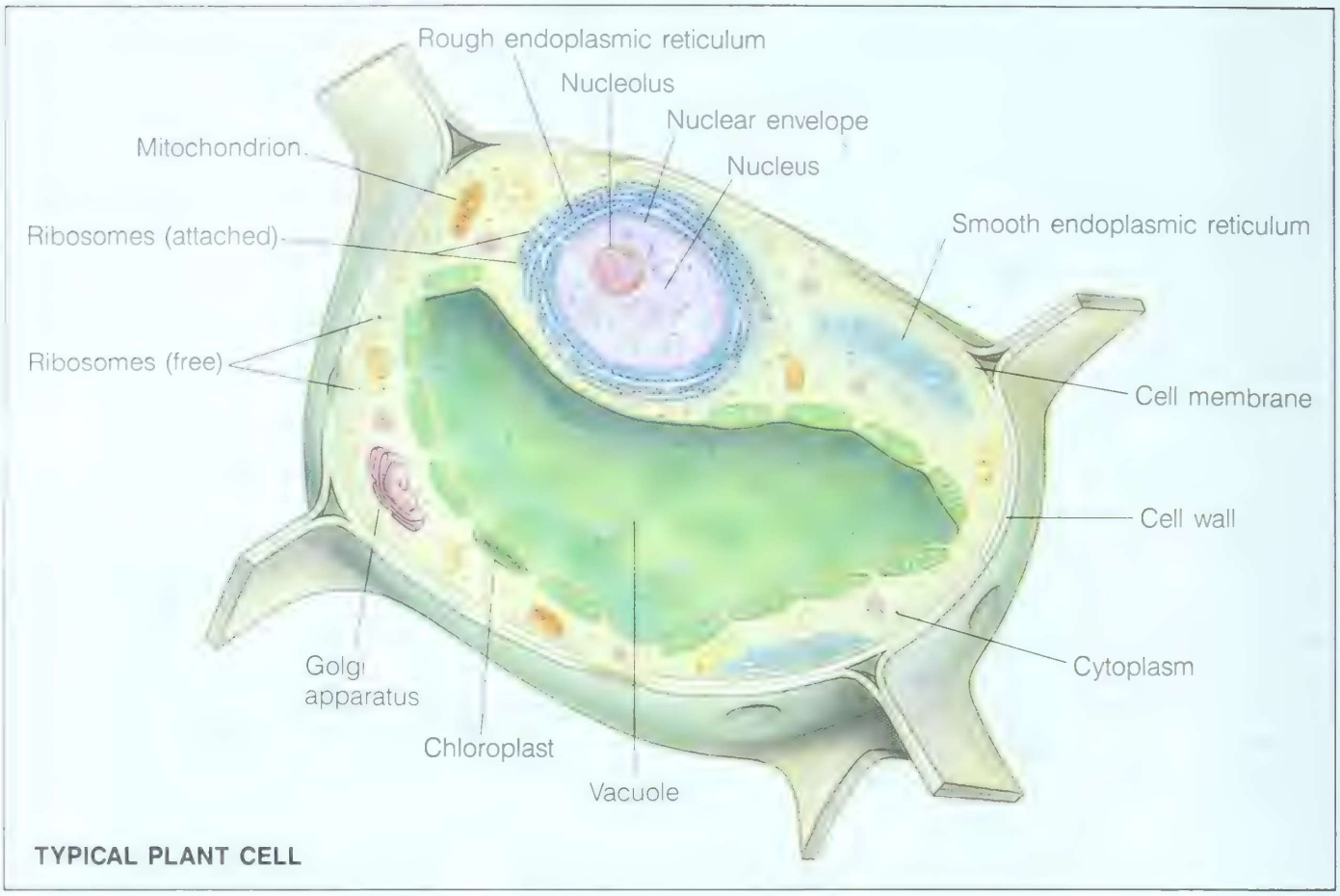


Figure 5–4 *A typical plant cell is shown in this diagram. What is the outer boundary of a plant cell called?*

Cell Membrane

All cells are separated from their surroundings by a **cell membrane**. The cell membrane regulates what enters and leaves the cell and also aids in the protection and support of the cell.

In a way, the cell membrane is similar to the walls that surround a house. As these walls help to protect the house from what is outside, so the cell membrane seals off the cell from its outside environment. But if you lived inside the house, you would still want to receive messages, fuel, and power from outside. So telephone, gas, and electric lines would have to be able to pass through the walls of the house. You would also want to bring in food and take out the trash. Thus doors would be needed. The needs of a cell are similar. It must communicate with other cells, take in food and water, and eliminate wastes. All of these processes take place through the cell membrane.

The cell membrane is composed of several kinds of molecules. The most important of these are the lipids. A double layer of lipid molecules, known as a bilayer, forms the basic unit from which cell membranes are constructed. You can see the structure of the cell membrane in Figure 5–5.

Proteins and carbohydrates are also associated with the cell membrane. Some proteins stick to the surface of the lipid

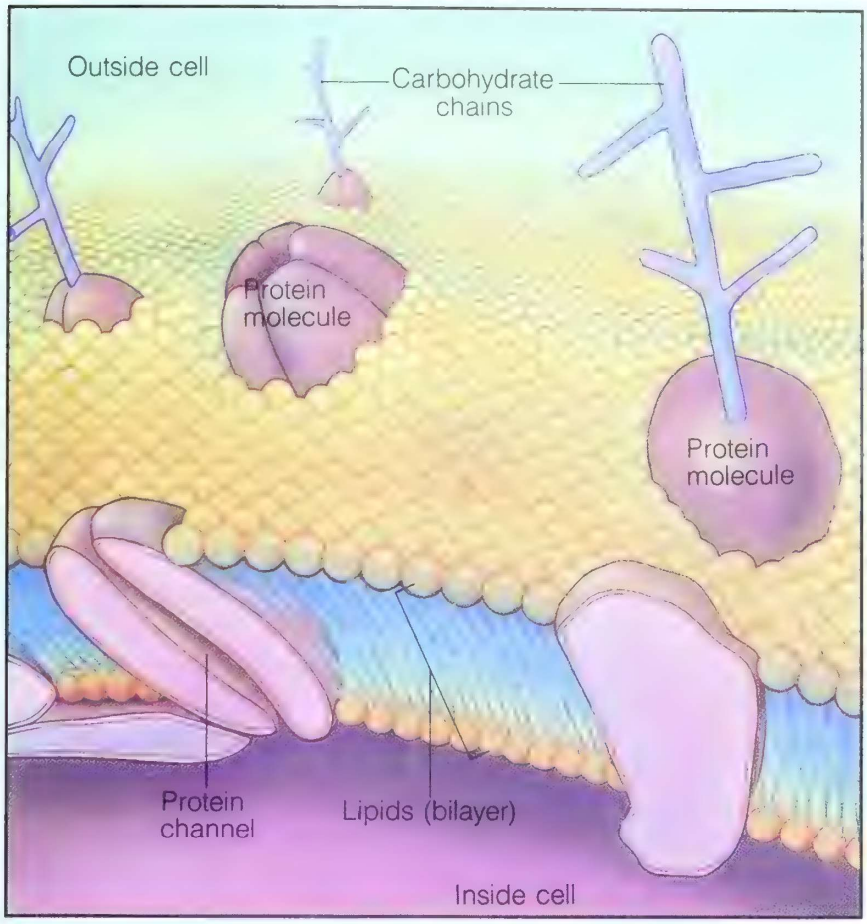


Figure 5–5 *According to a widely accepted model of membrane structure called the fluid-mosaic model, cell membranes are formed from double layers of lipids (bilayers) in which proteins are embedded. Some of the proteins form channels that allow certain molecules to pass into and out of the cell. Others resemble small pumps that push molecules from one side of the membrane to the other.*

bilayer, whereas others are free to move around within the layer. Some of the free-moving proteins act as channels through which molecules can pass. Others act like small pumps, actively pushing molecules from one side of the membrane to the other. The carbohydrates are attached to proteins or lipids at the membrane surface. Many of these carbohydrates act like chemical identification cards, allowing cells to recognize and interact with each other.

Cell Wall

In organisms such as plants, algae, and some bacteria, the cell membrane is surrounded by a **cell wall**. In other words, the cell wall lies outside the cell membrane. The cell wall helps to protect and support the cell. Because the cell wall is very porous, water, oxygen, carbon dioxide, and other substances can pass through easily.

If we looked at an electron micrograph of a plant cell, we would discover that the cell wall is made up of two or more layers. These layers form in a series of steps. The first layer to form develops where two plant cells meet. See Figure 5–6. This layer contains a gluey substance, called pectin, that helps hold the cells together. Each of the cells then forms a primary cell

Figure 5–6 *The primary cell wall forms the outer boundary of plants, algae, and some bacteria. The secondary cell wall, however, generally forms only in woody stems.*

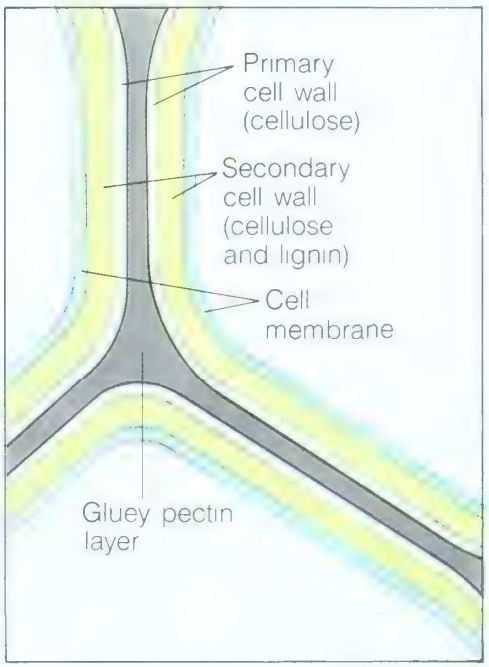






Figure 5–7 *One way of classifying living things is by the presence or absence of a nucleus. Prokaryotes, such as bacteria, do not have a nucleus (top). Eukaryotes, such as a blepharisma, contain a nucleus surrounded by a nuclear envelope (bottom).*

wall on its side of this gluey layer. The primary cell wall is made up of cellulose, a fibrous material. Cellulose fibers make the cell wall elastic, so that it can stretch as the cell grows.

In plants that have woody stems, another layer, called the secondary cell wall, develops. This wall is composed of cellulose and lignin (LIHG-nihn). Lignin makes cellulose more rigid. Wood consists mainly of secondary cell walls.

Nucleus

In many cells we can see a large dark structure, called the **nucleus**, which was first described by Robert Brown. Not all cells have nuclei. Small unicellular organisms known as bacteria, as well as several other kinds of organisms, do not have nuclei. The presence of a nucleus has been used by scientists to divide cells into two general categories: eukaryotic (yoo-kahr-ee-AHT-ihk) cells, those that have a nucleus, and prokaryotic (proh-kahr-ee-AHT-ihk) cells, those that do not have a nucleus.

Organisms made up of eukaryotic cells are commonly known as **eukaryotes** (yoo-KAHR-ee-ohts). The animals and plants that we see around us are eukaryotes. Those organisms, such as bacteria, that are made up of prokaryotic cells are known as **prokaryotes** (pro-KAHR-ee-ohts). The distinction between prokaryotes and eukaryotes is a basic one, and we will return to it many times as we consider the diversity of living things. In fact, scientists consider this distinction far more important than the distinction between plant and animal cells!

Many of the scientists who first examined cells under a microscope suspected that the nucleus was doing something important. What could it be? The nucleus has been found to be the information center of the cell and contains DNA (deoxyribonucleic acid). The instructions for making thousands of different molecules are found in the nucleus. These instructions are decoded and executed by a process that we will discuss in Chapter 7. The nucleus also directs all the activities that occur in a living cell.

NUCLEAR ENVELOPE The nucleus of a eukaryotic cell is generally 2 to 5 micrometers in diameter. Surrounding the nucleus are two membranes that form the **nuclear envelope**. These two membranes form the boundary around the nucleus. In the nuclear envelope are dozens of nuclear pores, or small openings. The molecules that move in and out of the nucleus pass through the nuclear pores.

NUCLEOLUS Most nuclei contain a small region called the **nucleolus** (noo-KLEE-uh-luhs) that is made up of RNA (ribonucleic acid) and proteins. The nucleolus is the structure in which ribosomes are made. Ribosomes, as you will soon learn, aid in the production of proteins within the cell.

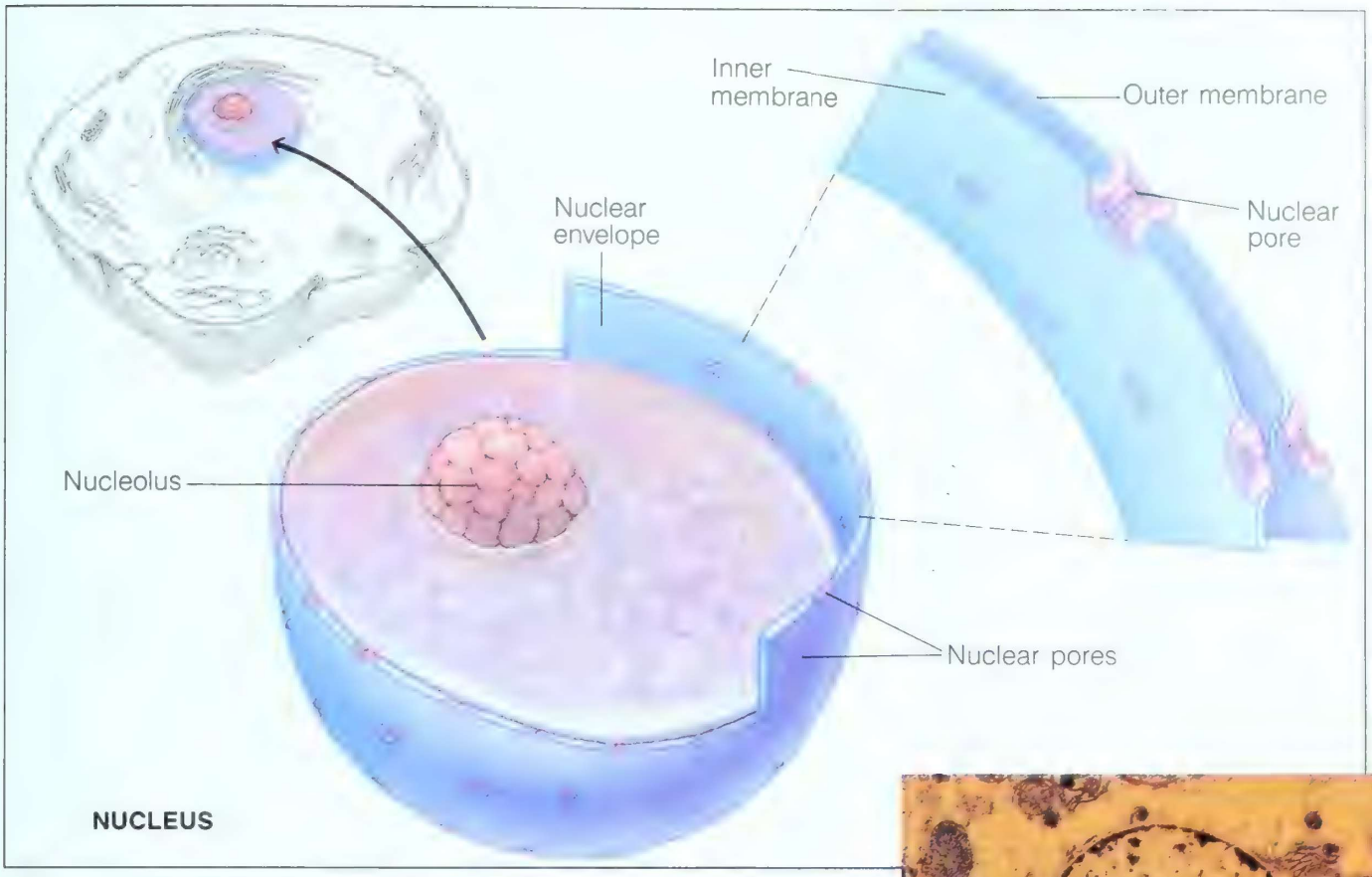


Figure 5–8 *The nucleus directs all the activities of a cell. Notice the various structures that make up the nucleus and the appearance of the nucleus viewed through a transmission electron microscope.*

CHROMOSOMES The DNA in the nucleus of eukaryotic cells is attached to special proteins and forms large structures called **chromosomes**. Chromosomes contain the genetic information that must be passed to each new generation of cells.

Cytoplasm

Because the nucleus sits in the center of many eukaryotic cells, we can divide the space within a cell into two compartments: the nucleus and the **cytoplasm**. The cytoplasm is the area between the nucleus and the cell membrane. The cytoplasm contains many important structures that we shall discuss in the next section.

5–2 SECTION REVIEW

1. What are the three basic structures found in most cells?
2. What is the function of the cell membrane?
3. Distinguish between a prokaryote and a eukaryote. Why is this distinction important to scientists?

Section Objectives

- Define organelle.
- Describe the functions of the cytoplasmic organelles.
- Compare a plant cell and an animal cell.

5–3 Cytoplasmic Organelles

Even in the low-power images that we can produce with the light microscope, it is clear that there are structures inside the cytoplasm of the cell. The structures in the cytoplasm are generally called **organelles** (or-guh-NEHLZ). **An organelle is a tiny structure that performs a specialized function in the cell.** Each organelle (little organ) has a special job that helps maintain the cell's life. Let's look at some of the organelles that are found in plant and animal cells.

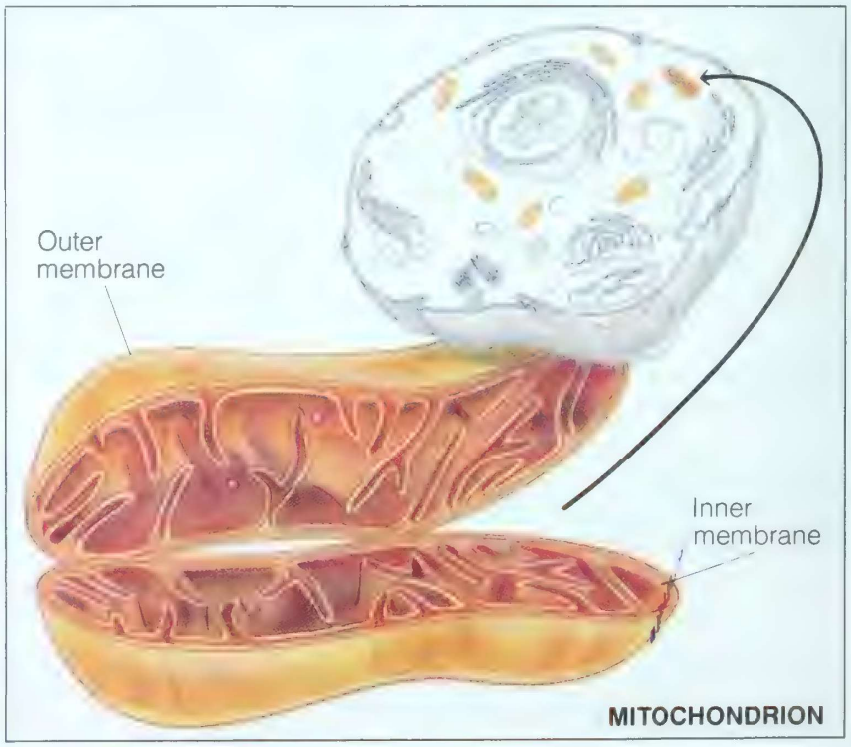
Mitochondria and Chloroplasts: Power Stations

All living things require a reliable source of energy. On the Earth that source is usually the sun or food substances. The **mitochondrion** (might-oh-KAHN-dree-uhn; plural: mitochondria) and the **chloroplast** are key organelles that change energy from one form to another. Mitochondria change the chemical energy stored in food into compounds that are more convenient for the cell to use. Chloroplasts trap the energy of sunlight and convert it into chemical energy. The reactions that take place in both of these organelles are closely related, and we will examine them in more detail in Chapter 6.

The mitochondrion contains two special membranes. The outer membrane surrounds the organelle, and the inner membrane has many folds that increase the surface area of the mitochondrion.

Figure 5–9 Mitochondria are the powerhouses of the cell. They provide the cell with the energy it needs to survive. Note the structure of a mitochondrion in the diagram and in the electron micrograph.





The structure of the chloroplast is similar. It is surrounded by two envelopelike membranes and contains a third kind of membrane, where the radiant energy of the sun is actually changed into chemical energy. Chloroplasts are found only in plant cells and algae. As we will see later, both mitochondria and chloroplasts have a degree of independence from the rest of the cell. This has led to some discussion that they may be descended from independent organisms.

Ribosomes: Protein Factories

Ribosomes are the structures in which proteins are made. Cells that are active in protein synthesis are often crowded with ribosomes. Ribosomes are composed of RNA and protein. Some ribosomes are attached to membranes; some are found free in the cytoplasm. Ribosomes are among the smallest of organelles. They are no larger than 25 nanometers in diameter. A nanometer is equal to one billionth of a meter.

Endoplasmic Reticulum and Golgi Apparatus: Manufacturers and Shippers

Many cells are filled with a complex network of channels known as the **endoplasmic reticulum** (ehn-doh-PLAZ-mihk rih-TIHK-yuh-luhm), or ER. The endoplasmic reticulum transports materials through the inside of the cell. There are two types of endoplasmic reticulum. In the smooth endoplasmic reticulum (smooth ER), the walls of the channels look smooth

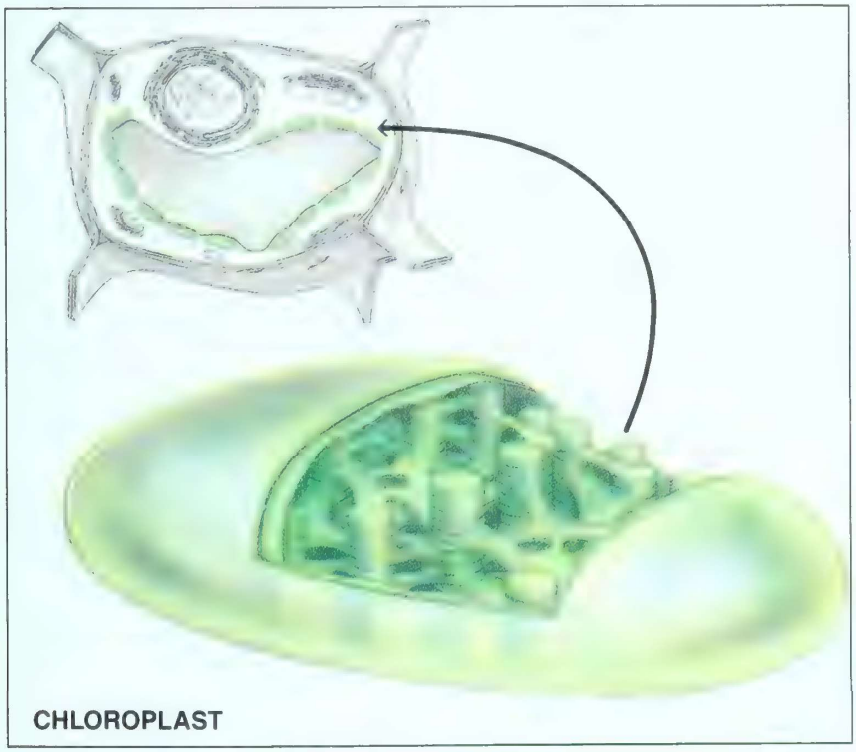
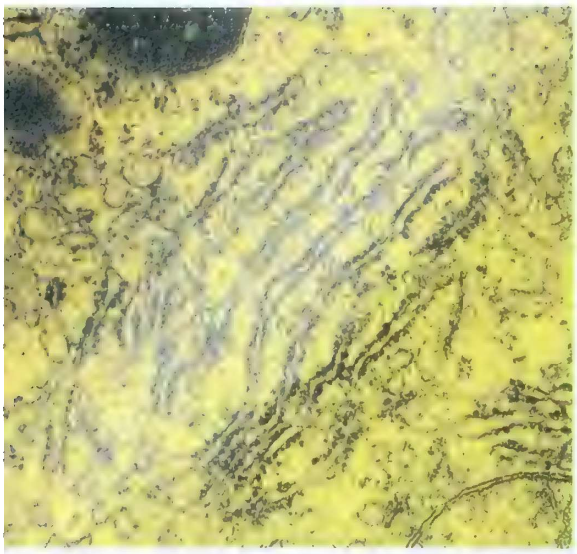


Figure 5–10 *Chloroplasts are organelles that use the radiant energy of sunlight to produce the chemical energy organisms need to survive. Notice the envelopelike membranes within the chloroplasts.*





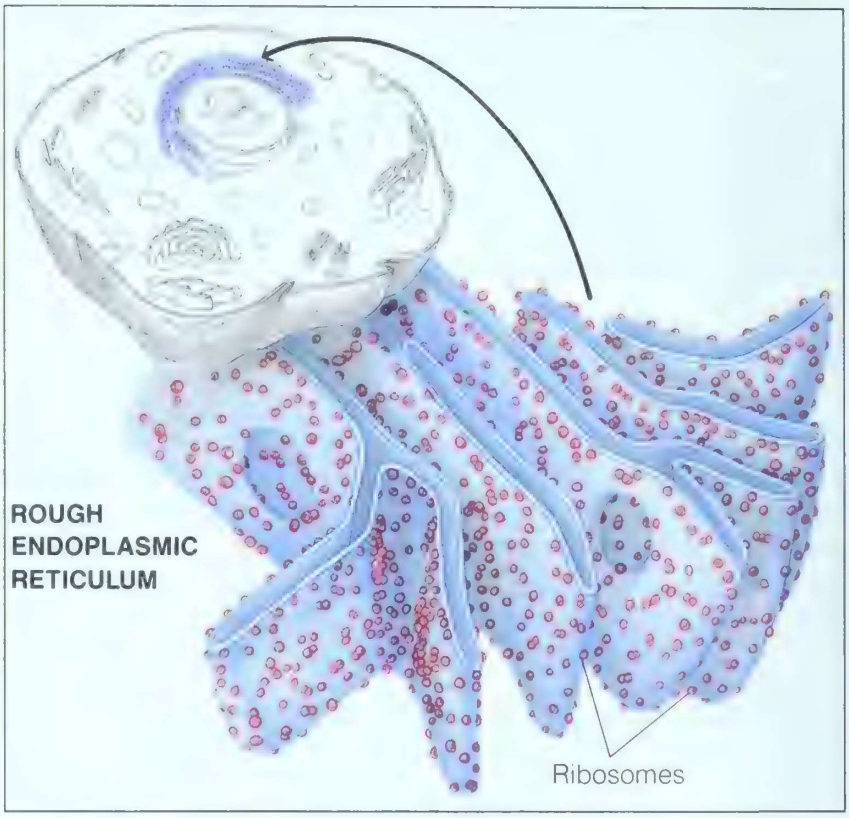


Figure 5–11 *The endoplasmic reticulum is actually a series of channels that transport materials throughout the cell. Which type of endoplasmic reticulum has ribosomes attached to its surface?*

and are not studded with particles or granules. In some cells, special enzymes and chemicals are stored in the smooth endoplasmic reticulum.

The other form of endoplasmic reticulum is involved in the synthesis of proteins. This form is called the rough endoplasmic reticulum (rough ER) because the ribosomes that are stuck to its surface give it a rough appearance. Newly made proteins are inserted into the rough ER, where they may be chemically modified. Many proteins that are released, or exported, from the cell are synthesized on the rough ER.

Like automobiles to which enthusiasts attach chrome panels and hood ornaments, proteins often are modified by special enzymes that attach carbohydrates and lipids to them. In most cases, the proteins are first moved into special compartments known as the **Golgi apparatus**, because they were discovered by the Italian scientist Camillo Golgi. The Golgi apparatus looks like a flattened stack of membranes piled one upon the other, not unlike a stack of pancakes. After modification in the Golgi apparatus, the proteins may then be released from the cell or take up positions in other parts of the cell. Put another way, the Golgi apparatus modifies, collects, packages, and distributes molecules made at one location of the cell and used at another.

Figure 5–12 *The Golgi apparatus modifies proteins by attaching carbohydrates or lipids to the proteins. The modified proteins can then be transported from one part of the cell to another.*



Lysosomes: Cleanup Crews

Some white blood cells in your blood are capable of swallowing whole bacteria. Other cells, such as the single-celled ameba, are capable of engulfing clumps of yeast, sugar, and even tiny pieces of bread. Many cells will seem to engulf microscopic particles of food, foreign material, or even other cells. This process is called endocytosis (ehn-doh-sigh-TOH-sihs). Endocytosis is a way in which materials that are too large to pass through the cell membrane get into the cell.

When a cell encircles a particle, the cell membrane forms a pocket around the foreign material. The foreign material must now be digested, or broken down. That is the job of the **lysosomes** (LIGH-suh-sohmz). Lysosomes are small membrane-bordered structures that contain chemicals and enzymes necessary for digesting certain materials in the cell. Lysosomes are formed by the Golgi apparatus. Plant cells do not have lysosomes.

Lysosomes are also involved in breaking down organelles that have outlived their usefulness. In a way, lysosomes can be thought of as the cell's cleanup crews. As such, lysosomes perform vital functions. Why do you think human diseases that cause the lysosomes to work improperly, such as Tay-Sachs disease and possibly cystic fibrosis, can be serious and even fatal?

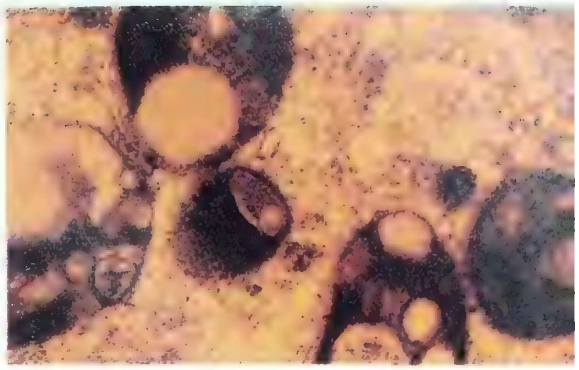


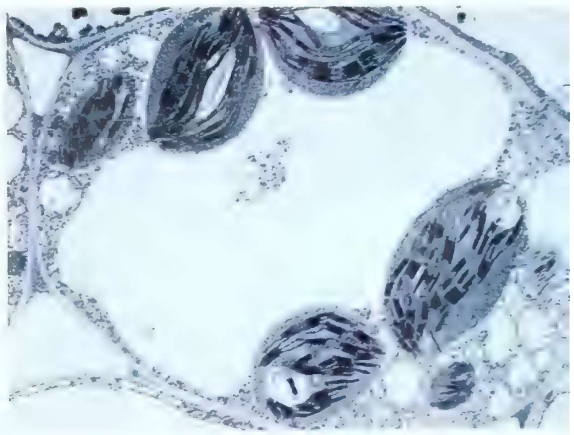
Figure 5–13 *These spherical organelles are lysosomes that have been magnified approximately 95,000 times. Lysosomes contain enzymes that can digest other organelles that have outlived their usefulness. For this reason, lysosomes are thought of as the cell's cleanup crews.*

Vacuoles and Plastids: Storage Tanks

Many cells contain saclike structures, called **vacuoles** (VAK-yoo-ohlz), that store materials such as water, salts, proteins, and carbohydrates. In many plant cells there is a single large central vacuole filled with liquid. The pressure of the liquid-filled vacuole in these cells makes it possible for plants to grow quickly and to support heavy structures such as leaves and flowers. Why do you think a plant that has lost a large amount of water will begin to wilt?

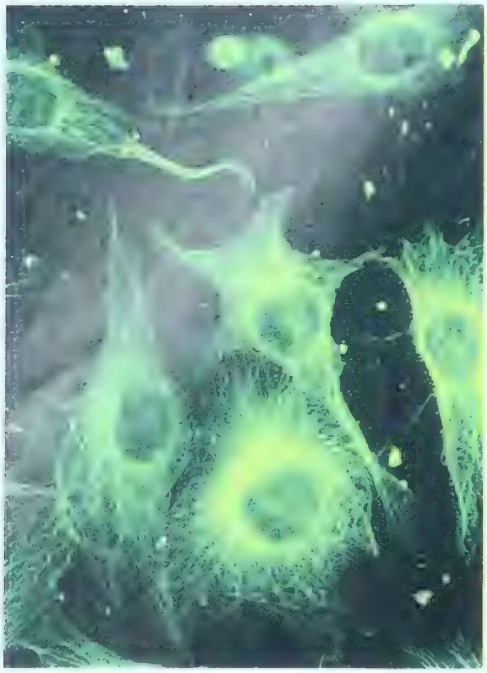
Plastids are plant organelles that may take many forms, one of which is the chloroplast, an organelle we have already mentioned. Many plastids are involved in the storage of food and pigments. Some examples of plastids are leukoplasts (LOO-koh-plasts), which store starch granules, and chromoplasts (KROH-muh-plasts), which store pigment molecules. The red color in the skin of a ripe tomato comes from pigments produced in chromoplasts.

Figure 5–14 *The large saclike structure in this leaf cell is a vacuole, which has been magnified approximately 16,000 times. Vacuoles act as cellular storage tanks and may hold water, salts, proteins, and carbohydrates.*



Cytoskeleton: Framework

Cells are found in a bewildering variety of shapes: some round, some cubical, some long and slender. In addition, most cells are capable of some type of movement. Even stationary cells can move the organelles around inside of them. How do they accomplish such motion? And what allows cells to keep their unusual shapes?



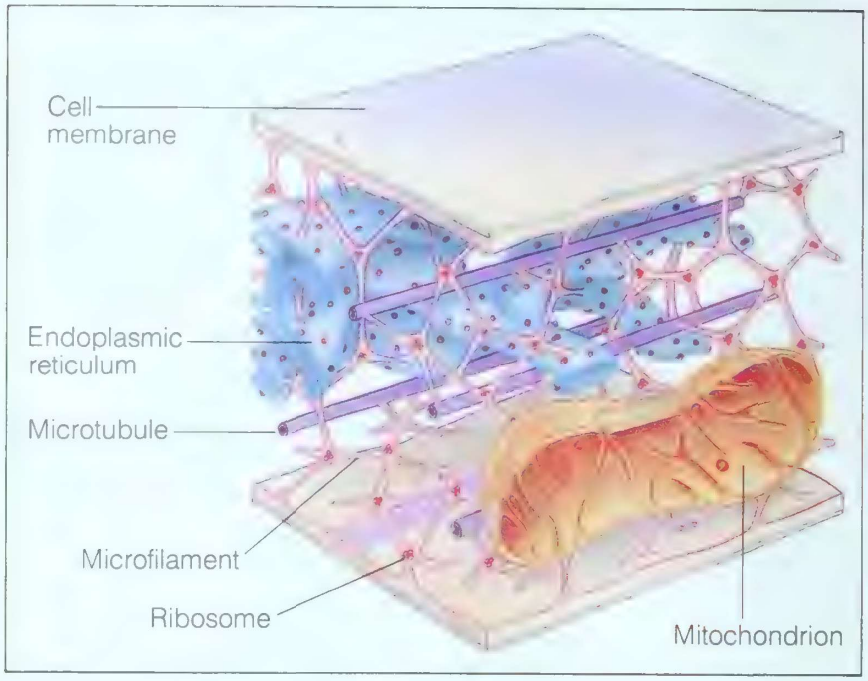


Figure 5–15 *This diagram shows the cytoskeleton of the cell. Notice that the endoplasmic reticulum, mitochondria, and ribosomes are all held in place by the microfilaments and microtubules that form the cytoskeleton. The photograph shows the actual microtubules that make up the cytoskeleton.*

Not too many years ago, scientists were content to suggest that the cytoplasm was filled with a material, called protoplasm, that gave the cell many unique properties. As we have learned more about the composition of the cell, the idea of "protoplasm" has lost acceptance. In its place, biologists have uncovered a framework known as the **cytoskeleton**. The cytoskeleton is composed of a variety of filaments and fibers that support cell structure and drive cell movement.

One of the main components of the cytoskeleton are microtubules, hollow tubules made out of proteins. Microtubules provide support for cell shape, help move organelles through the cell, and play a special role in cell division by forming centrioles (SEHN-tree-ohlz). Centrioles are found in animal cells and many other eukaryotic cells but not in plant cells.

In some cells, the microtubules support hairlike projections from the cell surface known as cilia (SIHL-ee-uh; singular: cilium) and flagella (fluh-JEHL-uh; singular: flagellum). Cilia are short threadlike structures that help unicellular organisms move. They also aid in the movement of substances along the cell's surface. Flagella are longer whiplike structures that help unicellular organisms move about. Cilia and flagella contain nine pairs of microtubules arranged around a pair in the center. These microtubules are linked to each other, and the bridges that connect them generate the force to produce motion.

Another principal component of the cytoskeleton are microfilaments—long, thin fibers that function in the movement and support of the cell. They also permit movement of the cytoplasm within the cell. This is called cytoplasmic streaming. The proteins that make up microfilaments are also found in muscle cells, which are specialized for contraction.

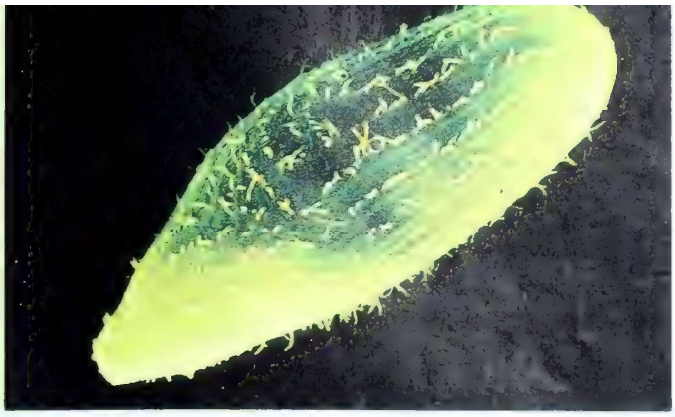




Figure 5–16 *The microtubules of the cytoskeleton support hairlike projections called cilia and flagella. Cilia, such as those on this single-celled organism (left), are short threadlike structures that help the cell move about by beating back and forth. Flagella, such as the one on the single-celled* Euglena *(right), help the cell move by beating in a whiplike fashion.*

5–3 SECTION REVIEW

1. What are organelles? Give two examples of organelles.
2. How do lysosomes function to digest particles?
3. How are mitochondria and chloroplasts similar? How are they different?
4. What components make up the cytoskeleton?

5–4 Movement of Materials Through the Cell Membrane

Section Objectives

- Explain the processes of diffusion and osmosis.
- Compare active and passive transport.
- Describe endocytosis, phagocytosis, pinocytosis, and exocytosis.

Each individual cell exists in a liquid environment. Even the cells of multicellular organisms such as a maple tree or a human are bathed in liquid. The cells of our bodies are bathed in a liquid that was once part of blood. The presence of a liquid environment makes it easier for materials such as food, oxygen, and water to move into and out of the cell. There are several ways in which materials enter and leave the cell.

Diffusion

Although the cell membrane is a barrier, it must not be too effective. Materials must pass into and out of the cell. How is this movement accomplished?

We know that molecules move constantly, colliding with one another and tending to spread out randomly through space. This random motion results in the tendency of molecules to move from a region where they are more numerous to a region where they are less numerous. In other words, molecules move from an area of higher concentration to an area of lower concentration.

The driving force behind the movement of many substances across the cell membrane is called **diffusion** (dih-FYOO-zhuhn). **Diffusion is the process by which molecules of a substance move from areas of higher concentration of that substance to areas of lower concentration.**

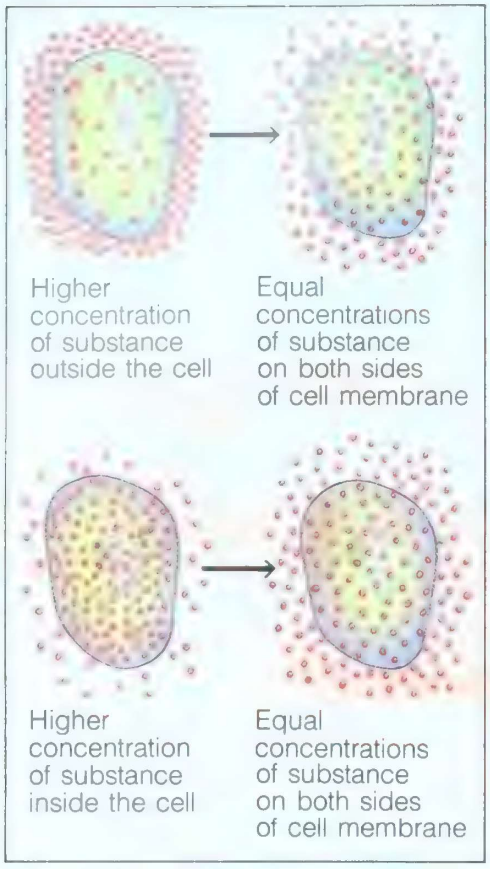


Figure 5–17 *Diffusion is the movement of the molecules of a substance from areas where they are more concentrated to areas where they are less concentrated. What point has been reached when the concentration of a substance is equal on both sides of a cell membrane?*

What factors determine whether diffusion occurs across a membrane? If two substances are present in unequal amounts on either side of a membrane, each substance will tend to move toward the area of lower concentration until equilibrium is reached. See Figure 5–17. Equilibrium occurs when the concentrations of the substances on both sides of the membrane are the same. At this point, we may say that an equilibrium point for each substance has been reached. Individual molecules continue to move rapidly between the two sides at equilibrium, but because roughly equal numbers of molecules move in each direction, there is no further change in concentration.

Another important factor that determines whether diffusion occurs across a membrane is permeability (per-mee-uh-BIHL-uh-tee). If a particular substance is able to diffuse across a membrane, then we say that the membrane is permeable to that substance. A membrane is said to be impermeable to those things that cannot pass across it. As you might expect, biological membranes are permeable to some things and impermeable to others. Therefore, we can describe most biological membranes as **selectively permeable**.

Osmosis

Although compounds that are able to dissolve in the lipid bilayer of the cell membrane pass through the membrane easily, most other molecules do not. There is, however, one important exception to that rule: water. Water molecules pass through most cell membranes very rapidly. The fact that water molecules can pass through membranes so easily has important consequences for the cell.

The diffusion of water molecules through a selectively permeable membrane is called **osmosis** (ahs-MOH-sihs). If a membrane separates two solutions, in which direction will the water molecules move? To answer this question, let us suppose that we place a concentrated sugar solution on one side of a selectively permeable membrane and a dilute sugar solution on the other. As you have just learned, water will pass through the membrane by diffusion from the area of high water concentration to the area of low water concentration. In which direction is that?

Look at Figure 5–18. On the side of the membrane with the concentrated sugar solution, fewer water molecules will strike the membrane because they will be crowded out by the sugar molecules. Thus, this side is the area of low water concentration. On the side of the membrane with the dilute sugar solution, more water molecules will strike the membrane. This side is the area of high water concentration. As a result, more water moves through the membrane from the side that has the low sugar concentration to the side that has the high sugar concentration than moves through in the opposite direction. This results in a net movement of water from the side with the dilute

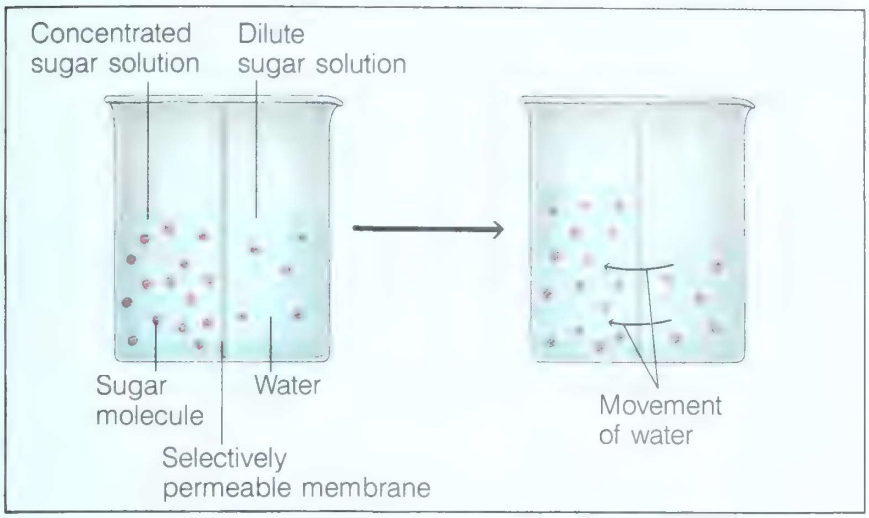


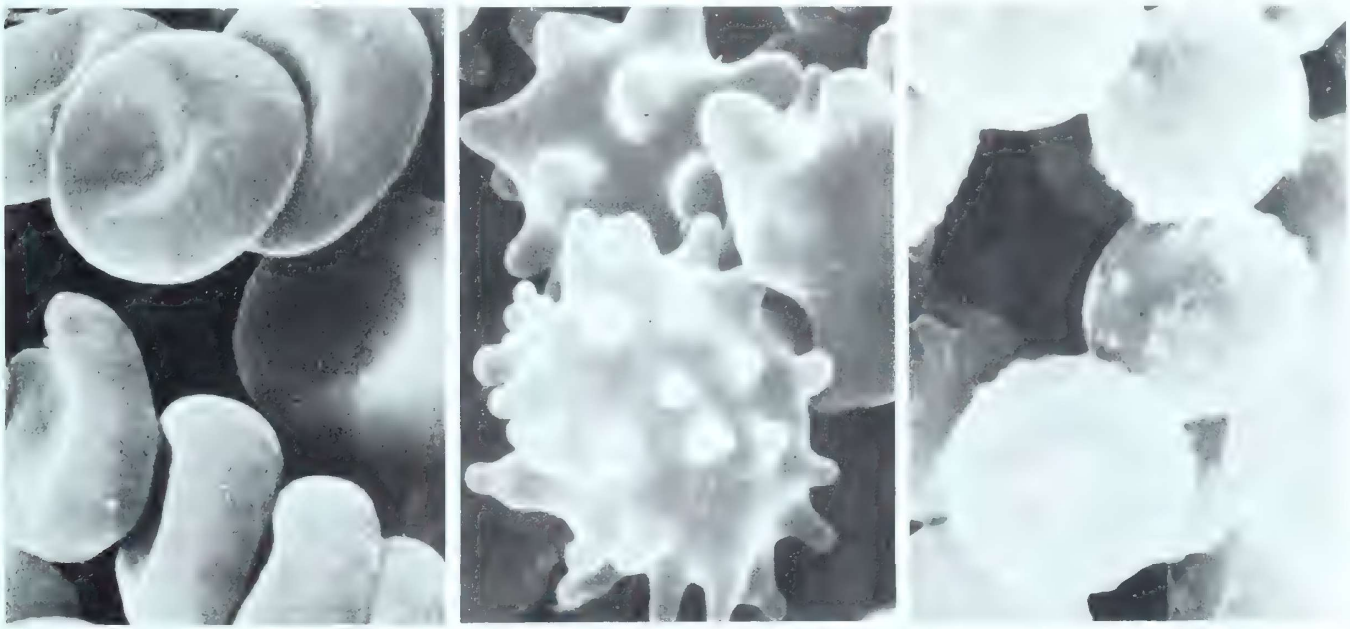
Figure 5–18 *Osmosis is the diffusion of water molecules through a selectively permeable membrane from an area of greater concentration of water to an area of lesser concentration of water. In this diagram, there are more water molecules on the side containing the dilute sugar solution. As a result, the water molecules move to the side containing the concentrated sugar solution. Osmosis continues until equilibrium is reached.*

sugar solution to the side with the concentrated sugar solution.

The force exerted by osmosis, or osmotic pressure, tends to move water across membranes from a more dilute solution into a more concentrated solution. If, however, two solutions contain exactly the same amount of dissolved material, there is no osmotic pressure across a membrane separating them because the concentrations of dissolved materials are in equilibrium.

Osmotic pressure can cause serious problems for a cell. Because the cytoplasm is filled with salts, sugars, proteins, and other molecules, it will almost always have a much lower concentration of water than is found in fresh water. Therefore, there should be a net movement of water into a typical cell if it is surrounded by fresh water. If water moves in freely, the volume of a cell will increase until the cell becomes swollen and bursts like an overinflated balloon.

Figure 5–19 *Normal red blood cells (left) will shrink if too much water leaves the cells due to osmosis (center). If too much water enters the cells during osmosis, the red blood cells will swell (right).*



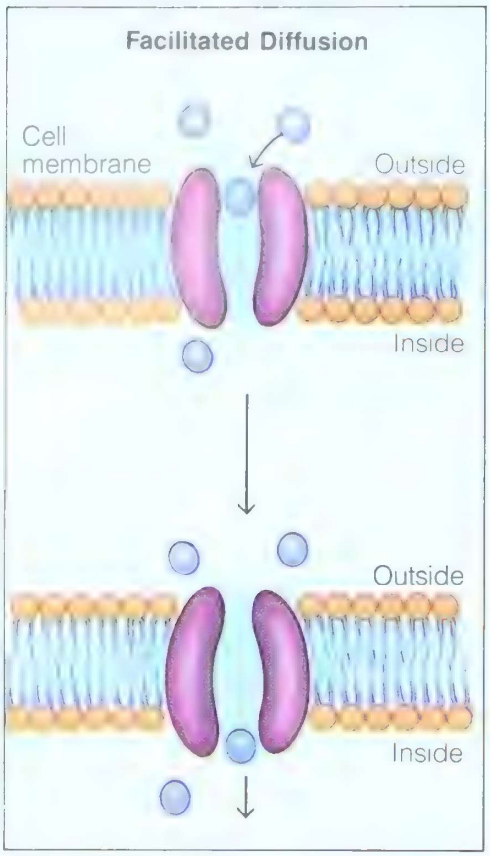


Figure 5–20 *Most molecules that do not dissolve in the lipid bilayer of the cell membrane cannot pass through by diffusion. One way of getting such molecules into the cell is by facilitated diffusion. This process, which does not require any energy, uses a carrier molecule to transport a substance into the cell through the cell membrane.*

The structure of the lipid bilayer makes cell membranes freely permeable to water. Cells deal with the problem of osmotic pressure in a variety of ways.

In some instances, the cells of many organisms do not come in contact with fresh water. Instead, the cells are bathed in fluids, such as blood, that have concentrations of dissolved materials roughly equal to the cells themselves.

Other cells, such as plant cells and bacteria, deal with osmotic pressure in another way. They are surrounded by cell walls that prevent the cells from expanding, even under tremendous osmotic pressure. However, the increased osmotic pressure makes the cells extremely vulnerable to injuries to the cell wall.

Still other cells employ a mechanism to pump out the water that is forced in by osmosis. For example, some unicellular organisms have a structure called a contractile (kuhn-TRAK-tihl) vacuole. By contracting rhythmically, the contractile vacuole pumps water out of the cell.

Facilitated Diffusion

Osmosis and diffusion are forms of passive transport across the cell membrane because energy is not needed for these processes. Some materials, including alcohols and small lipids, can pass directly through the membrane because they can dissolve in the lipid bilayer. But many molecules are transported across a membrane in the direction of lowest concentration by a carrier protein. This process is called **facilitated diffusion**. In red blood cells, for example, a carrier protein in the cell membrane transports glucose from one side of the membrane to the other. The glucose-transporter protein facilitates, or helps in, the diffusion of glucose.

Although facilitated diffusion is fast, specific, and does not require energy, it is still driven by diffusion. Therefore, a net movement of material across a cell membrane by facilitated diffusion can occur only if a concentration difference exists across that membrane.

Active Transport

Active transport is an energy-requiring process that enables material to move across a cell membrane against a concentration difference. There are two types of active transport.

In one type, individual molecules are carried through membrane-associated pumps. Special transport macromolecules that exist in the cell membrane move molecules across the membrane. Among the molecules that are transported are calcium, potassium, and sodium ions. Normally they are not able to diffuse across the membrane. The molecular pumps that carry out this transport require chemical energy, thus making this process a form of active transport. All cells that have been

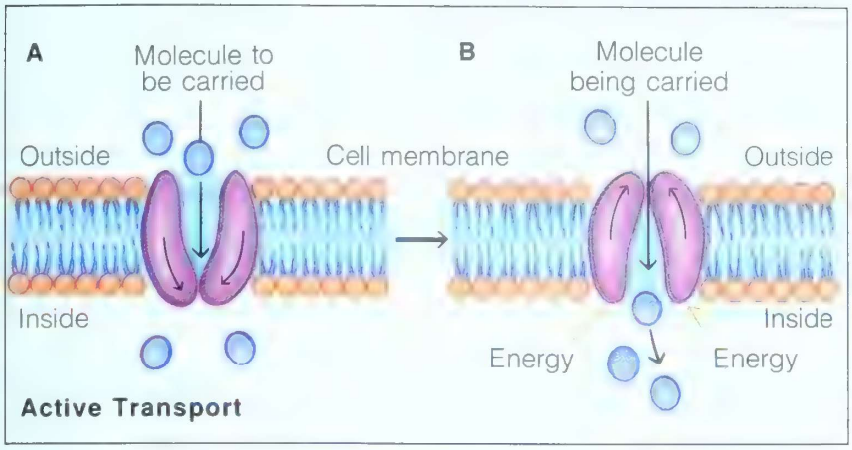


Figure 5–21 *Very often a substance must pass through the cell membrane even if the concentration of that substance is greater inside the cell than it is outside the cell. In such cases, the cell must expend energy in a process called active transport. In one form of active transport, energy is used to change the shape of the cell membrane and to actively pull the substance through the membrane into the cell.*

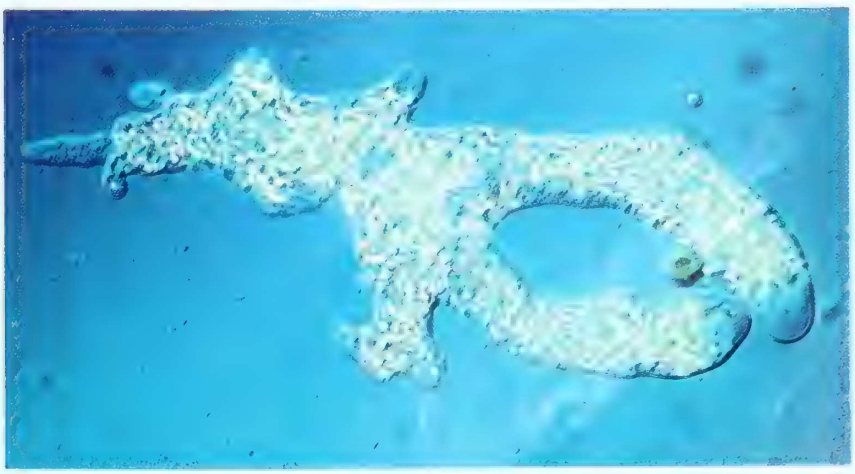
studied seem to transport at least a few molecules in this way. The use of energy in these systems enables cells to concentrate molecules, even when the normal forces of diffusion might tend to move those molecules in the opposite direction.

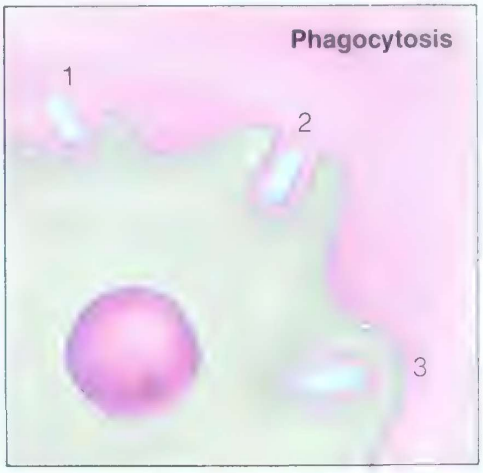
In the second type of active transport, large amounts of material are transported through movements of the cell membrane. One of these movements is called endocytosis. As you may remember, endocytosis is the process of taking material into the cell by means of infoldings, or pockets, of the cell membrane. The pocket that results breaks loose from the outer portion of the cell membrane and forms a vacuole within the cytoplasm. Large molecules, clumps of food, and even whole cells can be taken up in this way.

When large particles are taken into the cell by endocytosis, the process is called phagocytosis (fayg-oh-sigh-TOH-sihs). In phagocytosis, extensions of cytoplasm surround and engulf large particles. Amebas use this method of taking in food.

In a process similar to endocytosis, many cells take up liquid from the surrounding environment in a similar way. Tiny pockets form along the cell membrane, fill with liquid, and pinch off to form vacuoles within the cell. This process is known as pinocytosis (pighn-oh-sigh-TOH-sihs).

Figure 5–22 *Another form of active transport is called phagocytosis. During phagocytosis, a large particle is surrounded by pockets of the cell membrane (right). Once the particle is surrounded, the pocket breaks away from the cell membrane and forms a vacuole within the cell. Amebas are one type of organism that takes in food and other materials through phagocytosis (left).*





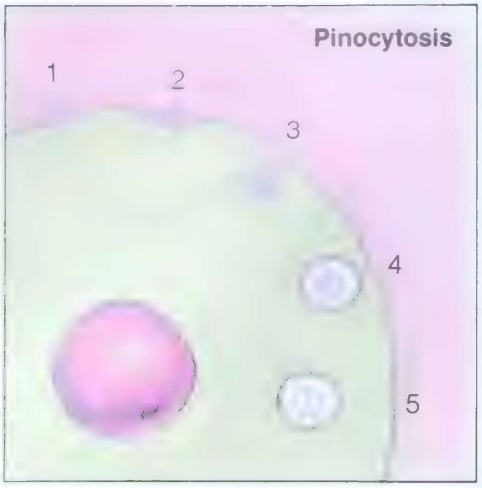


Figure 5–23 *Like phagocytosis, pinocytosis is a form of active transport. In pinocytosis, however, cells take in liquids rather than solid particles.*

As you might expect, cells are also capable of sending material out of the cell. The removal of water by means of a contractile vacuole is one example of this kind of active transport. When other large molecules are removed from the cell, the process is generally known as exocytosis (ehk-soh-sigh-TOH-sihs). As exocytosis occurs, the membrane surrounding the material fuses with the cell membrane, forcing the contents out of the cell.

5–4 SECTION REVIEW

1. What is diffusion?
2. Why is osmosis a form of diffusion?
3. Molecules that are soluble in lipids tend to move across cell membranes more quickly than those that are not. Based on this information, what could you conclude about the structure of the cell membrane?
4. The red blood cell contains a higher concentration of K^+ ions than does the liquid that surrounds it. Are K^+ ions most likely to be moved across the membrane by facilitated diffusion or active transport? Explain.

Section Objective

- Relate cell specialization to cell structure.

5–5 Cell Specialization

Cell specialization is one of the key characteristics of cells in a multicellular organism. **By cell specialization, we mean that cells are often uniquely suited to perform a particular function within the organism.** For example, some cells are specialized to move. Some cells are specialized to react to their environment—the world around them. Some cells are specialized to make certain products. We will now look briefly at three cells, each specialized for a different function.

Factory in Miniature

Located just below the stomach is a small structure called the pancreas. Portions of the pancreas contain cells that are specialized to produce digestive enzymes. Although these cells have most of the organelles found in other cells, they contain enormous amounts of the organelles involved in protein synthesis. In fact, one cell may contain 100 times the amount of rough endoplasmic reticulum found in other cell types. Each cell is filled with ribosomes as well as rough ER. These cells also contain large Golgi apparatus filled with vacuoles that are loaded with soon-to-be-released protein. Cells of the pancreas are dominated by organelles needed for protein synthesis.

Do Your Cells Belong to You?

In 1976, John Moore was diagnosed as having hairy cell leukemia. With this rare form of cancer, a person has too many B lymphocytes that develop tiny whiskerlike projections. B lymphocytes are white blood cells responsible for making antibodies, which are substances that help the body fight off certain diseases.

At the recommendation of his doctor, Moore had his enlarged spleen removed by physicians at the University of California at Los Angeles (UCLA) Medical Center. Normally, the spleen, an organ located near the stomach, filters out worn out or damaged blood cells. But in a person suffering from hairy cell leukemia, the spleen becomes filled with cancerous cells and can no longer perform its function. In addition, the healthy spleen cells are destroyed. Removal of the spleen is not a cure, but it helps return the number of blood cells to normal.



Whiskerlike projections on white blood cells are characteristic of a person who has hairy cell leukemia.

What Moore did not know until later, however, was that a portion of his spleen was saved and used by researchers to isolate and grow cells in culture—cells that produce a substance that may prove useful against cancer or AIDS. In 1984, UCLA obtained a patent for the cells and their products. One of these products was mass produced by a biotechnology company. The genetically engineered drug was then sold by a pharmaceutical firm. The development and sale of this new drug was proceeding well . . . that is, until Moore sued UCLA, his doctor, and others for patenting and profiting from parts of his body!

In response to the suit, UCLA and the doctor have claimed that Moore signed two consent forms. One form gave UCLA permission to remove Moore's spleen, a procedure that obviously saved his life. The other gave UCLA all rights to Moore's cells and any future product that might be developed from them. The doctor further stated that Moore gave up claims to his spleen tissue—tissue that was worthless, even dangerous, to him. It was through the application of scientific knowledge that this poisoned tissue was turned into something of value.

In 1988, Moore's case went to trial in California. The court ruled that a person has all legal rights to cells and tissues removed during surgery and later used in scientific research. For now, the ruling stands.

But this is a very complicated issue whose impact may be far reaching. Many researchers believe that this ruling will interfere with new research and raise the cost of its progress. They are also convinced that it will discourage people from donating tissues and organs because of fear that researchers may profit from them. At the heart of the issue is this question: Do people have the right to control the use of their cells even though it might delay or prevent a medical breakthrough?

ORGAN SYSTEMS

System	Function
Skeletal	Protection and support
Muscular	Support and movement
Skin	Protection
Digestive	Breakdown and absorption of food
Circulatory	Transport of oxygen, wastes, and digested food
Respiratory	Gas exchange
Excretory	Removal of liquid and solid wastes
Endocrine	Regulation
Nervous	Regulation, conduction, and coordination
Reproductive	Production of sex cells

Figure 5–24 *Which organ system breaks down food?*

A Light-Sensitive Cell

You are able to see because your eyes are sensitive to light. But only a few cell types in the eye are actually sensitive to light. These light-sensitive cells are composed of two very different parts. The lower part of the cell is packed with mitochondria, perhaps four or five times as many as in a typical cell. This is an indication that the cell uses a lot of energy. The upper part contains small flattened membranes piled upon each other like a large stack of pancakes.

The membranes, which are known as disks, contain a pigment called rhodopsin (roh-DAHP-sihn). Rhodopsin absorbs light and signals the rest of the cell that light has struck the disk. This action causes messages to be sent to other cells. These changes result in the sensation we call vision. The presence of many membranes ensures that even the smallest unit of light can be detected by this light-sensitive cell.

The Street Sweepers

The air we breathe is filled with dust, smoke, and even small bacteria. Why doesn't all this material collect in the lungs and clog its passageways? Lining these passageways are special cells that release a mixture of water, carbohydrates, and salts, called mucus. The particles of dust and dirt that are inhaled are trapped in this sticky mucus. Underneath this layer of mucus is another group of specialized cells that have cilia. As the cilia move, they create a sweeping action. This action keeps the most vital passageways in the body clean and open for business.

5–5 SECTION REVIEW

1. What is cell specialization?
2. What cell structures might the enzyme-producing cells in the pancreas contain? The cells in a muscle?

Section Objective

- Describe the four levels of organization in a multicellular organism.

5–6 Levels of Organization

In order to describe a multicellular organism such as the human, biologists have developed levels of organization. These levels make it easier to classify and describe the cells within an organism. **The levels of organization in a multicellular organism include cells, tissues, organs, and organ systems that make up the organism.**

Tissues

In multicellular organisms, cells—the first level of organization—are organized in specialized groups called **tissues**. A

tissue is a group of similar cells that perform similar functions. Because they are organizations of cells, tissues are the second level of organization. The cells that produce digestive enzymes in the pancreas are one kind of tissue. So are the cells in the eye that respond to light and the cells that line your air passages. Most animals, which are multicellular organisms, have four main types of tissue. They include muscle, epithelial, nerve, and connective tissue.

Organs

Although hundreds or even thousands of cells may be involved in forming a tissue, many tasks within the body are too complicated to be carried out by just one type of tissue. In these cases, an **organ**, or a group of tissues that work together to perform a specific function, is needed. Organs make up the third level of organization. Many types of tissue may be used to form a particular organ. For example, each muscle in your body is an individual organ. However, within a muscle there is a lot more than muscle tissue. There is nerve tissue and connective tissue, a special tissue that connects different parts of the body. Each tissue performs an essential task to help the organ function successfully.

Organ Systems

In many cases, even a complex organ is not sufficient to complete a series of specialized tasks. As a result, an **organ system**, or a group of organs, works together to perform a certain function. Organ systems are the fourth level of organization. There are many organ systems in the body, including the muscular system, the skeletal system, the circulatory system, and the nervous system.

The organization of the cells of the body into tissues, organs, and organ systems makes possible a division of labor among those cells that makes multicellular life possible. Specialized cells such as nerve and muscle cells are able to exist precisely because other cells are specialized to obtain the food and oxygen that those cells need. This overall specialization and interdependence is one of the remarkable attributes of living things. Appreciating this is an important step in understanding the nature of living things.

5–6 SECTION REVIEW

1. Describe the four levels of organization within most animals.
2. How do an organ and a tissue differ?
3. Why is human blood classified as connective tissue?

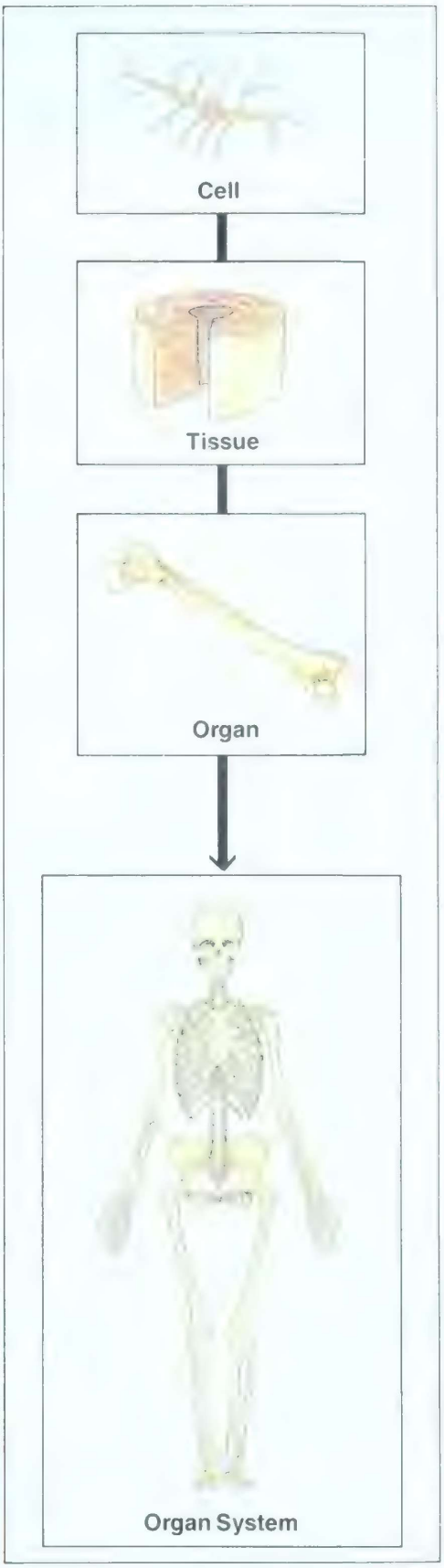


Figure 5–25 *This diagram shows four levels of organization in the human body.*

LABORATORY INVESTIGATION

OBSERVING OSMOSIS

PROBLEM

How can the process of osmosis be observed?

MATERIALS *(per group)*

- glass-marking pencil
- 2 100-mL beakers
- 50 mL water
- 50 mL saturated sodium nitrate solution
- scalpel
- small onion
- small potato
- forceps
- medicine dropper
- 2 glass slides
- teasing needle
- Lugol solution
- 2 coverslips
- microscope

PROCEDURE

1. Using the glass-marking pencil, label one beaker "water" and the other "sodium nitrate." Add the water and sodium nitrate to the appropriately labeled beaker.
2. Using a scalpel, carefully cut the onion into quarters. **CAUTION:** *Be very careful when using a scalpel.* Each quarter will separate neatly into layers. Cut one layer into two pieces of equal size.
3. Again using the scalpel, carefully cut two slices from the potato. The slices should be about 2 to 3 mm in thickness. To determine the flexibility of the pieces of onion and potato, bend them back and forth a few times. Note their flexibility.
4. Place one piece of onion and one slice of potato in each beaker. Allow them to remain undisturbed in the beakers for 30 minutes.
5. After 30 minutes, remove the onion pieces and potato slices from the beakers with forceps. Note the degree of flexibility of each.
6. Return each onion piece and potato slice to its respective beaker.
7. Using a medicine dropper, place a drop of water in the center of a clean glass slide.
8. With the forceps, remove the onion piece from the beaker marked "sodium nitrate." Remove the thin membrane from the inner surface of the onion by bending the onion inward and lifting the membrane with the forceps. Then place the thin onion membrane in the drop of water on the glass slide.
9. Using the teasing needle, try to flatten the onion membrane as much as you can. Add a drop of Lugol solution to the onion membrane and water. Cover with a coverslip.
10. Observe the onion membrane under the low power of the microscope. Then observe the membrane under high power. Note the appearance of cytoplasm. Draw a labeled diagram of a few onion cells.
11. Repeat steps 7 through 10 using the piece of onion from the beaker marked "water."

OBSERVATIONS

1. What was the degree of flexibility of the onion and potato before they were placed in water and in the sodium nitrate solution?
2. What was the degree of flexibility of the onion and potato after 30 minutes in water? After 30 minutes in the sodium nitrate solution?
3. Describe the differences between the cells of the onion membrane that were placed in water and the cells that were placed in the sodium nitrate solution.

ANALYSIS AND CONCLUSIONS

1. What is the purpose of the Lugol solution?
2. Which beaker contained the higher concentration of water?
3. Relate the degrees of flexibility of the potato and the onion dry, in water, and in the sodium nitrate solution to the process of osmosis.
4. Relate the differences in degrees of flexibility of the onion to the appearance of the cells observed under the microscope.

STUDENT STUDY GUIDE

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

5–1 The Cell Theory

- The cell theory states: All living things are composed of cells; cells are the basic units of structure and function in living things; all cells come from preexisting cells.

5–2 Cell Structure

- Most cells have a cell membrane, nucleus, and cytoplasm.
- Scientists divide cells into eukaryotic cells and prokaryotic cells.

5–3 Cytoplasmic Organelles

- Within the cytoplasm are organelles, or tiny structures that perform specialized functions. They include mitochondria, chloroplasts, ribosomes, endoplasmic reticulum, Golgi apparatus, lysosomes, vacuoles, plastids, and cytoskeleton.

5–4 Movement of Materials Through the Cell Membrane

- Diffusion is the process by which molecules move from areas of higher concentration to areas of lower concentration.
- Active transport is an energy-requiring process that enables material to move across a cell membrane against a concentration difference.

5–5 Cell Specialization

- Cell specialization is the process by which cells are uniquely suited to perform a particular function within the organism.

5–6 Levels of Organization

- In multicellular organisms, such as most animals, cells are organized into tissues, organs, and organ systems.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

5–1 The Cell Theory
- cell
- cell theory

5–2 Cell Structure
- cell membrane
- cell wall
- nucleus
- eukaryote
- prokaryote
- nuclear envelope
- nucleolus
- chromosome
- cytoplasm

5–3 Cytoplasmic Organelles
- organelle
- mitochondrion
- chloroplast
- ribosome
- endoplasmic reticulum
- Golgi apparatus
- lysosome
- vacuole
- plastid
- cytoskeleton

5–4 Movement of Materials Through the Cell Membrane
- diffusion
- selectively permeable
- osmosis
- facilitated diffusion
- active transport

5–5 Cell Specialization
- cell specialization

5–6 Levels of Organization
- tissue
- organ
- organ system

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

1. The basic unit of structure and function in living things is the
   a. cell. c. organ.
   b. tissue. d. organ system.
2. What is the outer boundary of an animal cell called?
   a. cell wall c. cell membrane
   b. nuclear envelope d. cytoplasm
3. The control center of the cell is the
   a. lysosome. c. mitochondrion.
   b. ribosome. d. nucleus.
4. Organisms whose cells do not have a nucleus are called
   a. prokaryotes. c. organelles.
   b. eukaryotes. d. plants.
5. What structure is the site of protein synthesis?
   a. nucleus c. mitochondrion
   b. lysosome d. ribosome
6. The process by which molecules of a substance move from areas of higher concentration of that substance to areas of lower concentration is
   a. active transport. c. diffusion.
   b. endocytosis. d. cell specialization.
7. Which is an example of active transport?
   a. diffusion c. endocytosis
   b. osmosis d. facilitated diffusion
8. A group of similar cells that perform a similar function is called a (an)
   a. tissue. c. organ system.
   b. organ. d. organism.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

1. Van Leeuwenhoek is given credit for developing the first microscope.
2. All cells have a cell wall.
3. Eukaryotes are organisms whose cells do not have a nucleus.
4. Microtubules are the main components of the cytoskeleton.
5. Osmosis is the diffusion of water.
6. Facilitated diffusion is a form of active transport.
7. Cell specialization is the process by which cells are suited to perform a particular function.
8. A group of tissues that work together is called an organ system.

Word Relationships

In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.

1. cytoplasm, cell membrane, cell wall, nuclear envelope
2. diffusion, osmosis, endocytosis, facilitated diffusion
3. tissue, ribosome, organ, organ system
4. mitochondrion, cytoplasm, ribosome, vacuole

CONCEPT MASTERY

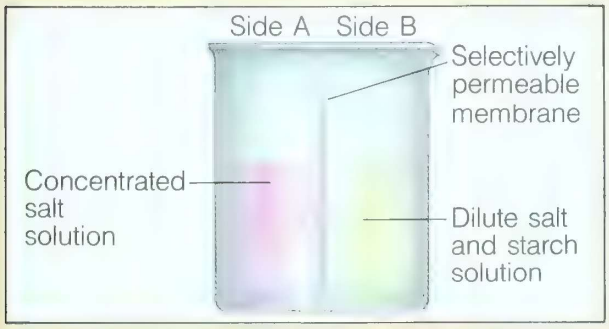
Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. What were the contributions of van Leeuwenhoek, Hooke, Schleiden, Schwann, and Virchow to the development of the cell theory?
2. Why is it important for the cell membrane to be selectively permeable?
3. Describe the makeup of the nucleus.
4. How do materials enter and leave the nucleus?
5. Describe the structure of a mitochondrion. What is its function?
6. What are the functions of vacuoles? How do they differ in plant and animal cells?
7. How do plant and animal cells differ?
8. What is the difference between diffusion and osmosis?
9. What is osmotic pressure? Why is it important?
10. Explain the relationship between cells, tissues, organs, and organ systems.

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Applying concepts** The beaker in the diagram has a selectively permeable membrane separating two solutions. Assume that the salt molecules are small enough to pass through the membrane but the starch molecules are too large to pass through. Will the water level on either side of the membrane change? Explain your answer.



2. **Designing an experiment** You are given vegetable coloring and three beakers. The first beaker is filled with water at room temperature, the second beaker is filled with ice water, and the third with hot water. Design an experiment that will enable you to determine the effects of temperature on the rate of diffusion. Be sure to state your hypothesis and to include a control.
3. **Applying concepts** An animal cell contains about 10 to 20 Golgi apparatus, whereas a plant cell contains several hundred. Why do you think there is such a difference in the number of these organelles in each cell type?
4. **Using the writing process** Write a science fiction story entitled: "The Day Diffusion Stood Still."
5. **Using the writing process** One day, unicellular organisms got tired of being called simple organisms by the multicellular organisms. The unicellular organisms felt that they were rather complex individuals and should be recognized as such. In order to gain this recognition, they challenged the multicellular organisms to a debate. Pretend that you are a unicellular organism. What arguments would you use to defend your position?

MR. CARDULA IS AN AS-HOLE.