BIG IDEA

Cells are the smallest unit of living matter that can carry out all processes required for life.

3.1 Cell Theory

3.2 Cell Organelles

Data Analysis
DEFINING VARIABLES

3.3 Cell Membrane

3.4 Diffusion and Osmosis

3.5 Active Transport, Endocytosis, and Exocytosis

ONLINE BIOLOGY
HMDScience.com

ONLINE Labs
- QuickLab Modeling the Cell Membrane
- Diffusion Across a Membrane
- Comparing Cells
- Modeling the Cell
- Cell Motility and the Cytoskeleton
- Staining Biological Specimens
- Diffusion and Dialysis
- Estimating a Cell Count
- Cytoplasmic Streaming in Elodea
- Diffusion Through Membranes
- The Effect of Alcohol on Biological Membranes
- Biological Membranes
- Video Lab Plant Cell Observation
- Video Lab Cell Size and Diffusion
How do cells help defend against invaders?

Macrophages (large tan cells) take in and digest foreign material, such as invading bacteria (small red cells). They play an important role in your immune system. Many macrophages travel the body, recognize foreign material, engulf it, and break it down using chemicals. They have an adaptable internal skeleton that helps them move and stretch out their “arms” to capture invading particles.

**Question:** How do cells help defend against invaders?

**Using Language:**

**Similes** Similes help relate new ideas to ideas that you already know. Often, similes use the terms like or as. For example, if you were describing a motorcycle to someone who had never seen one, you might say that it is like a bicycle that has a motor.

**Your Turn:**

Use the information in the chapter to perform the following tasks.

1. Find a simile to describe the endoplasmic reticulum.
2. Write a simile to describe the function of a mitochondrion.
**3.1 Cell Theory**

**KEY CONCEPT** Cells are the basic unit of life.

**VOCABULARY**
- cell theory
- cytoplasm
- organelle
- prokaryotic cell
- eukaryotic cell

**MAIN IDEAS**
- Early studies led to the development of the cell theory.
- Prokaryotic cells lack a nucleus and most internal structures of eukaryotic cells.

**Connect to Your World**
You and all other organisms are made of cells. As you saw on the previous page, a cell’s structure is closely related to its function. Today, we know that cells are the smallest unit of living matter that can carry out all processes required for life. But before the 1600s, people had many other ideas about the basis of life. Like many breakthroughs, the discovery of cells was aided by the development of new technology—in this case, the microscope.

**MAIN IDEA**
Early studies led to the development of the cell theory.

Almost all cells are too small to see without the aid of a microscope. Although glass lenses had been used to magnify images for hundreds of years, the early lenses were not powerful enough to reveal individual cells. The invention of the compound microscope in the late 1500s was an early step toward this discovery. The Dutch eyeglass maker Zacharias Janssen, who was probably assisted by his father, Hans, usually gets credit for this invention.

A compound microscope contains two or more lenses. Total magnification, the product of the magnifying power of each individual lens, is generally much more powerful with a compound microscope than with a single lens.

**Discovery of Cells**
In 1665, the English scientist Robert Hooke used the three-lens compound microscope shown in FIGURE 1.1 to examine thin slices of cork. Cork is the tough outer bark of a species of oak tree. He observed that cork is made of tiny, hollow compartments. The compartments reminded Hooke of small rooms found in a monastery, so he gave them the same name: cells. The plant cells he observed, shown in FIGURE 1.2 (top), were dead. Hooke was looking only at cell walls and empty space.

Around the same time, Anton van Leeuwenhoek, a Dutch tradesman, was studying new methods for making lenses to examine cloth. As a result of his research, his single-lens microscopes were much more powerful than Hooke’s crude compound microscope. In 1674, Leeuwenhoek became one of the first people to describe living cells when he observed numerous single-celled organisms swimming in a drop of pond water. Sketches of his “animalcules” are pictured in FIGURE 1.2 (bottom).
As people continued to improve the microscope over the next century and a half, it became sturdier, easier to use, and capable of greater magnification. This combination of factors led people to examine even more organisms. They observed a wide variety of cell shapes, and they observed cells dividing. Scientists began to ask important questions: Is all living matter made of cells? Where do cells come from?

**Cell Theory**

The German scientist Matthias Schleiden also used compound microscopes to study plant tissue. In 1838, he proposed that plants are made of cells. Schleiden discussed the results of his work with another German scientist, Theodor Schwann, who was struck by the structural similarities between plant cells and the animal cells he had been studying. Schwann concluded that all animals are made of cells. Shortly thereafter, in 1839, he published the first statement of the cell theory, concluding that all living things are made of cells and cell products. This theory helped lay the groundwork for all biological research that followed. However, it had to be refined over the years as additional data led to new conclusions. For example, Schwann stated in his publication that cells form spontaneously by free-cell formation. As later scientists studied the process of cell division, they realized that this part of Schwann’s idea was wrong. In 1855, Rudolf Virchow, another German scientist, reported that all cells come from preexisting cells. These early contributors are shown in Figure 1.3.

This accumulated research can be summarized in the cell theory, one of the first unifying concepts developed in biology. The major principles of the **cell theory** are the following:

- All organisms are made of cells.
- All existing cells are produced by other living cells.
- The cell is the most basic unit of life.

**Summarize** Explain the three major principles of cell theory in your own words.  

**FIGURE 1.3 Contributors to Cell Theory**

<table>
<thead>
<tr>
<th>HOEK</th>
<th>LEEUWENHOEK</th>
<th>SCHLEIDEN</th>
<th>SCHWANN</th>
<th>VIRCHOW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1665</strong> Hooke was the first to identify cells, and he named them.</td>
<td><strong>1674</strong> Because he made better lenses, Leeuwenhoek observed cells in greater detail.</td>
<td><strong>1838</strong> Schleiden was the first to note that plants are made of cells.</td>
<td><strong>1839</strong> Schwann concluded that all living things are made of cells.</td>
<td><strong>1855</strong> Virchow proposed that all cells come from other cells.</td>
</tr>
</tbody>
</table>

**FIGURE 1.2** Hooke observed the cell walls of dead plant cells (top). In contrast, Leeuwenhoek observed and drew microscopic life, which he called “animalcules,” in pond water (bottom).
Prokaryotic cells lack a nucleus and most internal structures of eukaryotic cells.

The variety of cell types found in living things is staggering. Your body alone is made of trillions of cells of many different shapes, sizes, and functions. They include long, thin, nerve cells that transmit sensory information, as well as short, blocky, skin cells that cover and protect the body. Despite this variety, the cells in your body share many characteristics with one another and with the cells that make up every other organism. In general, cells tend to be microscopic in size and have similar building blocks. They are also enclosed by a membrane that controls the movement of materials into and out of the cell.

Within the membrane, a cell is filled with cytoplasm. **Cytoplasm** is a jellylike substance that contains dissolved molecular building blocks—such as proteins, nucleic acids, minerals, and ions. In some types of cells, the cytoplasm also contains **organelles**, which are structures specialized to perform distinct processes within a cell. Most organelles are surrounded by a membrane. In many cells, the largest and most visible organelle is the nucleus, which stores genetic information.

As shown in **FIGURE 1.4**, cells can be separated into two broad categories based on their internal structures: prokaryotic cells and eukaryotic cells.

- **Prokaryotic cells** (pro-KAR-ee-AHT-ihk) do not have a nucleus or other membrane-bound organelles. Instead, the cell’s DNA is suspended in the cytoplasm. Most prokaryotes are microscopic, single-celled organisms.

- **Eukaryotic cells** (yoo-KAR-ee-AHT-ihk) have a nucleus and other membrane-bound organelles. The nucleus, the largest organelle, encloses the genetic information. Eukaryotes may be multicellular or single-celled organisms.

**FIGURE 1.4** In prokaryotic cells, such as this bacterium (top), DNA is suspended in the cytoplasm. In eukaryotic cells, such as this protozoan (bottom), the nuclear envelope separates DNA from the cytoplasm. (colored TEMs; magnifications: protozoan 3200×; bacterium 19,000×)

**VISUAL VOCAB**

- **Prokaryotic cells** do not have a nucleus or other membrane-bound organelles.
- **Eukaryotic cells** have a nucleus and other membrane-bound organelles.

**SELF-CHECK**

**GO ONLINE**

**Formative Assessment**

**REVIEWING MAIN IDEAS**

1. How did improvements in the microscope help scientists form the **cell theory**?  **TEKS 3F**
2. How do **prokaryotic** and **eukaryotic cells** differ?  **TEKS 4A**

**CRITICAL THINKING**

3. **Analyze** Today, scientists can study human cells grown in petri dishes. Explain how this technique builds on the work of early scientists.  **TEKS 3F**
4. **Compare** In what way are cells similar to atoms?

**CONNECT TO MEDICINE**

5. Suppose a certain poison kills human cells by blocking pores in the nuclear membrane. Explain why it would or would not kill bacteria.
Cell Organelles

<table>
<thead>
<tr>
<th>KEY CONCEPT</th>
<th>Eukaryotic cells share many similarities.</th>
</tr>
</thead>
</table>

**MAIN IDEAS**
- Cells have an internal structure.
- Several organelles are involved in making and processing proteins.
- Other organelles have various functions.
- Plant cells have cell walls and chloroplasts.

**Connect to Your World**
Your body is highly organized. It contains organs that are specialized to perform particular tasks. For example, your skin receives sensory information and helps prevent infection. Your intestines digest food, your kidneys filter wastes, and your bones protect and support other organs. On a much smaller scale, your cells have a similar division of labor. They contain specialized structures that work together to respond to stimuli and efficiently carry out other necessary processes.

**MAIN IDEA**
**Cells have an internal structure.**

Like your body, eukaryotic cells are highly organized structures. They are surrounded by a protective membrane that receives messages from other cells. They contain membrane-bound organelles that perform specific cellular processes, divide certain molecules into compartments, and help regulate the timing of key events. But the cell is not a random jumble of suspended organelles and molecules. Rather, certain organelles and molecules are anchored to specific sites, which vary by cell type. If the membrane were removed from a cell, the contents wouldn’t collapse and ooze out in a big puddle. How does a cell maintain this framework?

Each eukaryotic cell has a **cytoskeleton**, which is a flexible network of proteins that provide structural support for the cell. It is made of small protein subunits that form long threads, or fibers, that crisscross the entire cell, as shown in **FIGURE 2.1**. Three main types of fibers make up the cytoskeleton and allow it to serve a wide range of functions.

- **Microtubules** are long, hollow tubes. They give the cell its shape and act as “tracks” for the movement of organelles. When cells divide, microtubules form fibers that pull half of the DNA into each new cell.
- **Intermediate filaments**, which are somewhat smaller than microtubules, give a cell its strength.
- **Microfilaments**, the smallest of the three, are tiny threads that enable cells to move and divide. They play an important role in muscle cells, where they help the muscle contract and relax.

**FIGURE 2.1** The cytoskeleton supports and shapes the cell. The cytoskeleton includes microtubules (green) and microfilaments (red). (epifluorescence microscopy; magnification 750×)
Eukaryotic cells have highly organized structures, including membrane-bound organelles. Plant and animal cells share many of the same types of organelles, but both also have organelles that are unique to their needs.

**PLANT CELL**

**FOUND IN PLANT CELLS**
- chloroplast
- central vacuole
- cell wall

**FOUND IN BOTH**
- cytoskeleton
- vesicle
- nucleus
- nucleolus
- endoplasmic reticulum (rough)
- ribosome
- centrosome
- endoplasmic reticulum (smooth)
- cell membrane
- Golgi apparatus
- mitochondrion
- vacuole

**ANIMAL CELL**

**FOUND IN ANIMAL CELLS**
- centriole
- lysosome

**FOUND IN BOTH**
- cytoskeleton
- vesicle
- nucleus
- nucleolus
- endoplasmic reticulum (rough)
- ribosome
- centrosome
- endoplasmic reticulum (smooth)
- cell membrane
- Golgi apparatus
- mitochondrion
- vacuole

**CRITICAL VIEWING**

What differences do you observe between animal and plant cells?
Cytoplasm, which you read about in Section 1, is itself an important contributor to cell structure. In eukaryotes, it fills the space between the nucleus and the cell membrane. The fluid portion, excluding the organelles, is called cytosol and consists mostly of water. The makeup of cytoplasm shows that water is necessary for maintaining cell structure. This is only one of many reasons that water is an essential component for life, however. Many chemical reactions occur in the cytoplasm, where water acts as an important solvent.

The remainder of this chapter highlights the structure and function of the organelles found in eukaryotic cells. As **Figure 2.2** shows, plant and animal cells use many of the same types of organelles to carry out basic functions. Both cell types also have organelles that are unique to their needs.

**Infer** What problems might a cell experience if it had no cytoskeleton?

**Main Idea**

Several organelles are involved in making and processing proteins.

Much of the cell is devoted to making proteins. Proteins are made of 20 types of amino acids that have unique characteristics of size, polarity, and acidity. They can form very long or very short protein chains that fold into different shapes. And multiple protein chains can interact with each other. This almost limitless variety of shapes and interactions makes proteins very powerful. Proteins carry out many critical functions, so they need to be made correctly.

**Nucleus**

The **nucleus** (NOO-klee-uhs) is the storehouse for most of the genetic information, or DNA (deoxyribonucleic acid), in your cells. DNA contains genes that are instructions for making proteins. There are two major demands on the nucleus: (1) DNA must be carefully protected, and (2) DNA must be available for use at the proper times. Molecules that would damage DNA need to be kept out of the nucleus. But many proteins are involved in turning genes on and off, and they need to access the DNA at certain times. The special structure of the nucleus helps it meet both demands.

The nucleus is composed of the cell's DNA enclosed in a double membrane called the nuclear envelope. Each membrane in the nuclear envelope is similar to the membrane surrounding the entire cell. As **Figure 2.3** shows, the nuclear envelope is pierced with holes called pores that allow large molecules to pass between the nucleus and cytoplasm.

The nucleus also contains the nucleolus. The nucleolus is a dense region where tiny organelles essential for making proteins are assembled. These organelles, called ribosomes, are a combination of proteins and RNA molecules. They are discussed on the next page, and a more complete description of their structure and function is given in the chapter From DNA to Proteins.
**Endoplasmic Reticulum and Ribosomes**

A large part of the cytoplasm of most eukaryotic cells is filled by the endoplasmic reticulum, shown in Figure 2.4. The *endoplasmic reticulum* (end-uh-PLAZ-mihk rih-TIHK-yuh-luhm), or the ER, is an interconnected network of thin, folded membranes. The composition is very similar to that of the cell membrane and nuclear membranes. The ER membranes form a maze of enclosed spaces. The interior of this maze is called the lumen. Numerous processes, including the production of proteins and lipids, occur both on the surface of the ER and inside the lumen. The ER must be large enough to accommodate all these processes. How does it fit inside a cell?

The ER membrane has many creases and folds. If you have ever gone camping, you probably slept in a sleeping bag that covered you from head to foot. The next morning, you stuffed it back into a tiny little sack. How does the entire sleeping bag fit inside such a small sack? The surface area of the sleeping bag does not change, but the folds allow it to take up less space. Likewise, the ER's many folds enable it to fit within the cell.

In some regions, the ER is studded with *ribosomes* (RY-buh-sohmz), tiny organelles that link amino acids together to form proteins. Ribosomes are both the site of protein synthesis and active participants in the process. Ribosomes are themselves made of proteins and RNA. After assembly in the nucleolus, ribosomes pass through the nuclear pores into the cytoplasm, where most protein synthesis occurs.

Surfaces of the ER that are covered with ribosomes are called rough ER because they look bumpy when viewed with an electron microscope. As a protein is being made on these ribosomes, it enters the lumen. Inside the lumen, the protein may be modified by having sugar chains added to it, which can help the protein fold or give it stability.

Not all ribosomes are bound to the ER; some are suspended in the cytoplasm. In general, proteins made on the ER are either incorporated into the cell membrane or secreted. In contrast, proteins made on suspended ribosomes are typically used in chemical reactions occurring within the cytoplasm.

Surfaces of the ER that do not contain ribosomes are called smooth ER. Smooth ER makes lipids and performs a variety of other specialized functions, such as breaking down drugs and alcohol.

**Golgi Apparatus**

From the ER, proteins generally move to the Golgi apparatus, shown in Figure 2.5. The *Golgi apparatus* (GOHL-jee) consists of closely layered stacks of membrane-enclosed spaces that process, sort, and deliver proteins. Its membranes contain enzymes that make additional changes to proteins. The Golgi apparatus also packages proteins. Some of the packaged proteins are stored within the Golgi apparatus for later use. Some are transported to other organelles within the cell. Still others are carried to the membrane and secreted outside the cell.
Vesicles
Cells need to separate reactants for various chemical reactions until it is time for them to be used. Vesicles (VEHS-ih-kuhlz), shown in Figure 2.6, are a general name used to describe small, membrane-bound sacs that divide some materials from the rest of the cytoplasm and transport these materials from place to place within the cell. Vesicles are generally short-lived and are formed and recycled as needed.

After a protein has been made, part of the ER pinches off to form a vesicle surrounding the protein. Protected by the vesicle, the protein can be safely transported to the Golgi apparatus. There, any necessary modifications are made, and the protein is packaged inside a new vesicle for storage, transport, or secretion.

Compare and Contrast  How are the nucleus and a vesicle similar and different in structure and function?

MAIN IDEA
Other organelles have various functions.

Mitochondria
Mitochondria (my-tuh-KAHN-dree-uh) supply energy to the cell. Mitochondria (singular, mitochondrion) are bean shaped and have two membranes, as shown in Figure 2.7. The inner membrane has many folds that greatly increase its surface area. Within these inner folds and compartments, a series of chemical reactions converts molecules from the food you eat into usable energy. You will learn more about this process in Cells and Energy.

Unlike most organelles, mitochondria have their own ribosomes and DNA. This fact suggests that mitochondria were originally free-living prokaryotes that were taken in by larger cells. The relationship must have helped both organisms to survive.

Vacuole
A vacuole (VAK-yoo-ohl) is a fluid-filled sac used for the storage of materials needed by a cell. These materials may include water, food molecules, inorganic ions, and enzymes. Most animal cells contain many small vacuoles. The central vacuole, shown in Figure 2.8, is a structure unique to plant cells. It is a single, large vacuole that usually takes up most of the space inside a plant cell. It is filled with a watery fluid that strengthens the cell and helps to support the entire plant. When a plant wilts, its leaves shrivel because there is not enough water in each cell’s central vacuole to support the leaf’s normal structure. The central vacuole may also contain other substances, including toxins that would harm predators, waste products that would harm the cell itself, and pigments that give color to cells—such as those in the petals of a flower.
Lysosomes

Lysosomes (LY-suh-soh-mz), shown in Figure 2.9, are membrane-bound organelles that contain enzymes. They defend a cell from invading bacteria and viruses. They also break down damaged or worn-out cell parts. Lysosomes tend to be numerous in animal cells. Their presence in plant cells is still questioned by some scientists, but others assert that plant cells do have lysosomes, though fewer than are found in animal cells.

Recall that all enzymes are proteins. Initially, lysosomal enzymes are made in the rough ER in an inactive form. Vesicles pinch off from the ER membrane, carry the enzymes, and then fuse with the Golgi apparatus. There, the enzymes are activated and packaged as lysosomes that pinch off from the Golgi membrane. The lysosomes can then engulf and digest targeted molecules. When a molecule is broken down, the products pass through the lysosomal membrane and into the cytoplasm, where they are used again.

Lysosomes provide an example of the importance of membrane-bound structures in the eukaryotic cell. Because lysosomal enzymes can destroy cell components, they must be surrounded by a membrane that prevents them from destroying necessary structures. However, the cell also uses other methods to protect itself from these destructive enzymes. For example, the enzymes do not work as well in the cytoplasm as they do inside the lysosome.

Centrosome and Centrioles

The centrosome is a small region of cytoplasm that produces microtubules. In animal cells, it contains two small structures called centrioles. Centrioles (SEHN-tree-ohlz) are cylinder-shaped organelles made of short microtubules arranged in a circle. The two centrioles are perpendicular to each other, as shown in Figure 2.10. Before an animal cell divides, the centrosome, including the centrioles, doubles and the two new centrosomes move to opposite ends of the cell. Microtubules grow from each centrosome, forming spindle fibers. These fibers attach to the DNA and appear to help divide it between the two cells.

Centrioles were once thought to play a critical role in animal cell division. However, experiments have shown that animal cells can divide even if the centrioles are removed, making their role questionable. In addition, although centrioles are found in some algae, they are not found in plants.

Centrioles also organize microtubules to form cilia and flagella. Cilia look like little hairs; flagella look like a whip or a tail. Their motion forces liquids past a cell. For single cells, this movement results in swimming. For cells anchored in tissue, this motion sweeps liquid across the cell surface.

Compare In what ways are lysosomes, vesicles, and the central vacuole similar?

Plant cells have cell walls and chloroplasts.

Plant cells have two features not shared by animal cells: cell walls and chloroplasts. Cell walls are structures that provide rigid support. Chloroplasts are organelles that help a plant convert solar energy to chemical energy.
Cell Walls
In plants, algae, fungi, and most bacteria, the cell membrane is surrounded by a strong cell wall, which is a rigid layer that gives protection, support, and shape to the cell. The cell walls of multiple cells, as shown in Figure 2.11, can adhere to each other to help support an entire organism. For instance, much of the wood in a tree trunk consists of dead cells whose cell walls continue to support the entire tree.

Cell wall composition varies and is related to the different needs of each type of organism. In plants and algae, the cell wall is made of cellulose, a polysaccharide. Because molecules cannot easily diffuse across cellulose, the cell walls of plants and algae have openings, or channels. Water and other molecules small enough to fit through the channels can freely pass through the cell wall. In fungi, cell walls are made of chitin, and in bacteria, they are made of peptidoglycan.

Chloroplasts
Chloroplasts (kLAWR-uh-PLASTS) are organelles that carry out photosynthesis, a series of complex chemical reactions that convert solar energy into energy-rich molecules the cell can use. Photosynthesis will be discussed more fully in Cells and Energy. Like mitochondria, chloroplasts are highly compartmentalized. They have both an outer membrane and an inner membrane. They also have stacks of disc-shaped sacs within the inner membrane, shown in Figure 2.12. These sacs, called thylakoids, contain chlorophyll, a light-absorbing molecule that gives plants their green color and plays a key role in photosynthesis. Like mitochondria, chloroplasts also have their own ribosomes and DNA. Scientists have hypothesized that they, too, were originally free-living prokaryotes that were taken in by larger cells.

Both chloroplasts and mitochondria are present in plant cells, where they work together to capture and convert energy. Chloroplasts are found in the cells of certain other organisms as well, including green algae.

Analyze Would it be accurate to say that a chloroplast makes energy for a plant cell? Explain your answer.
Defining Variables

The operational definition of a dependent variable is a description of what is to be observed and measured in an experiment and what that measurement represents. It is important for scientists to include in their reports the operational definition of the dependent variable so that different scientists repeating the experiment will collect and record data in exactly the same way.

Model

Chloroplasts are organelles that can have a variety of pigments. Only chloroplasts that contain chlorophyll, a type of pigment, can carry out photosynthesis. The rate of photosynthesis increases as the number of chloroplasts with chlorophyll increases. Students wanted to determine if the rate of photosynthesis was greater in summer or fall. They collected leaves from many trees in both summer and fall and counted the number of chloroplasts with chlorophyll.

In this experiment, the number of chloroplasts with chlorophyll is what is being measured. The operational definition is the number of chloroplasts with chlorophyll in the leaf. This number represents the rate at which a plant can carry out photosynthesis.

<table>
<thead>
<tr>
<th>Tree</th>
<th>Leaf Chloroplasts with Chlorophyll (no./cell)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Summer</td>
</tr>
<tr>
<td>Birch</td>
<td>192</td>
</tr>
<tr>
<td>Linden</td>
<td>182</td>
</tr>
<tr>
<td>Maple</td>
<td>183</td>
</tr>
<tr>
<td>Weeping willow</td>
<td>177</td>
</tr>
</tbody>
</table>

Practice

Form an Operational Definition

Some studies suggest that drinking cranberry juice may help prevent the development of urinary tract infections caused by bacterial cells, which are prokaryotes. Researchers hypothesize that a chemical in cranberry juice may stop the bacteria from attaching to cells in the wall of the urinary bladder. Researchers grew eukaryotic bladder cells in culture and exposed them to a solution containing bacteria. The cells were then treated with a solution of different juices or water to determine if the juices interfered with bacterial attachment. The results are shown in the graph.

1. **Apply** What is the operational definition of the dependent variable in this experiment?
2. **Conclude** Which juices may be effective in preventing urinary tract infections?
The cell membrane is a barrier that separates a cell from the external environment.

**Main Ideas**
- Cell membranes are composed of two phospholipid layers.
- Chemical signals are transmitted across the cell membrane.

**Connect to Your World**

Think about how the products you buy are packaged—a pint of berries, perhaps, or a tube of toothpaste. The berries are probably in a plastic container that has holes to allow air circulation. The toothpaste is in a tube strong enough to be squeezed without ripping. Both containers protect their contents but do so in different ways. Like these products, the cell needs protection, but it must also be able to respond to its surroundings. It is constantly taking in and getting rid of various molecules. The structure of the cell membrane allows it to perform all those functions.

**Main Idea**

Cell membranes are composed of two phospholipid layers.

The **cell membrane**, or the plasma membrane, forms a boundary between a cell and the outside environment and controls the passage of materials into and out of a cell. The cell membrane consists of a double layer of phospholipids interspersed with a variety of other molecules. A **phospholipid** is a molecule composed of three basic parts:

- a charged phosphate group
- glycerol
- two fatty acid chains

Together, the glycerol and the phosphate group form the “head” of a phospholipid; the fatty acids form the “tail.” Because the head bears a charge, it is polar. Recall that water molecules are also polar. Therefore, the polar head of the phospholipid forms hydrogen bonds with water molecules. In contrast, the fatty acid tails are nonpolar and cannot form hydrogen bonds with water. As a result, the nonpolar tails are attracted to each other and repelled by water.

Because the membrane touches the cytoplasm inside the cell and the watery fluid outside the cell, the properties of polar heads and nonpolar tails cause the phospholipids to arrange themselves in layers, like a sandwich.

**Visual Vocab**

A **phospholipid** is composed of three basic parts:

- charged phosphate group
- glycerol
- two fatty acid chains
The polar heads are like the bread. They form the outer surfaces of the membrane, where they interact with the watery environment both outside and inside a cell. The nonpolar tails are like the filling. They are sandwiched between the layers of polar heads, where they are protected from the watery environment.

**FIGURE 3.1** shows other molecules embedded within the phospholipid layers. They give the membrane properties and characteristics it would not otherwise have. These molecules serve diverse functions. Here are a few examples:

- Cholesterol molecules strengthen the cell membrane.
- Some proteins extend through one or both phospholipid layers and help materials cross the membrane. Other proteins are key components of the cytoskeleton. Different cell types have different membrane proteins.
- Carbohydrates attached to membrane proteins serve as identification tags, enabling cells to distinguish one type of cell from another.

---

**FIGURE 3.1 Cell Membrane**

The cell membrane is made of two phospholipid layers embedded with other molecules, such as proteins, carbohydrates, and cholesterol.

Infer Note that cholesterol is located between the fatty acid chains. Do you think cholesterol is polar or nonpolar? Explain your answer.

---

**Fluid Mosaic Model**

Scientists have developed the **fluid mosaic model**, which describes the arrangement of the molecules that make up a cell membrane. This model of cell membrane structure takes its name from two characteristics. First, the cell membrane is flexible, not rigid. The phospholipids in each layer can move from side to side and slide past each other. As a result, the membrane behaves like a fluid, similar to a film of oil on the surface of water. However, proteins embedded in the membrane do not flip vertically. If one part of a protein is outside the membrane, it will stay outside the membrane. Second, the variety of molecules studding the membrane is similar to the arrangement of colorful tiles with different textures and patterns that make up a mosaic.
Selective Permeability

The cell membrane has the property of selective permeability, which means it allows some, but not all, materials to cross. Selective permeability is illustrated in FIGURE 3.2. The terms semipermeable and selectively permeable also refer to this property. As an example, outdoor clothing is often made of semipermeable fabric. The material is waterproof yet breathable. Molecules of water vapor from sweat are small enough to exit the fabric, but water droplets are too large to enter.

Selective permeability enables a cell to maintain homeostasis in spite of unpredictable, changing conditions outside the cell. Because a cell needs to maintain certain conditions to carry out its functions, it must control the import and export of certain molecules and ions. Thus, even if ion concentrations change drastically outside a cell, these ions won’t necessarily interfere with vital chemical reactions inside a cell.

Molecules cross the membrane in several ways. Some of these methods require the cell to expend energy; others do not. How a particular molecule crosses the membrane depends on the molecule's size, polarity, and concentration inside versus outside the cell. In general, small nonpolar molecules easily pass through the cell membrane, small polar molecules are transported via proteins, and large molecules are moved in vesicles.

Connect  Describe a semipermeable membrane with which you are already familiar.
Chemical signals are transmitted across the cell membrane.

Recall that cell membranes may secrete molecules and may contain identifying molecules, such as carbohydrates. All these molecules can act as signals to communicate with other cells. How are these signals recognized?

A receptor is a protein that detects a signal molecule and performs an action in response. It recognizes and binds to only certain molecules, ensuring that the right cell gets the right signal at the right time. The molecule a receptor binds to is called a ligand. When a receptor and a ligand bind, they change shape. This change is critical because it affects how a receptor interacts with other molecules. Two major types of receptors are present in your cells.

**Intracellular Receptor**

A molecule may cross the cell membrane and bind to an intracellular receptor, as shown in Figure 3.3. The word *intracellular* means “within, or inside, a cell.” Molecules that cross the membrane are generally nonpolar and may be relatively small. Many hormones fit within this category. For example, aldosterone can cross most cell membranes. However, it produces an effect only in cells that have the right type of receptor, such as kidney cells. When aldosterone enters a kidney cell, it binds to an intracellular receptor. The receptor-ligand complex enters the nucleus, interacts with the DNA, and turns on certain genes. As a result, specific proteins are made that help the kidneys absorb sodium ions and retain water, both of which are important for maintaining normal blood pressure.

**Membrane Receptor**

A molecule that cannot cross the membrane may bind to a receptor in the cell membrane, as shown in Figure 3.4. The receptor then sends the message to the cell interior. Although the receptor binds to a signal molecule outside the cell, the entire receptor changes shape—even the part inside the cell. As a result, it causes molecules inside the cell to respond. These molecules, in turn, start a complicated chain of events inside the cell that tells the cell what to do. For instance, band 3 protein is a membrane receptor in red blood cells. When activated, it triggers processes that carry carbon dioxide from body tissues to the lungs.

**Contrast** How do intracellular receptors differ from membrane receptors?

![Figure 3.3 Intracellular receptors are located inside the cell. They are bound by molecules that can cross the membrane.](image1)

![Figure 3.4 Membrane receptors bind to molecules that cannot enter the cell. When bound, the receptor transmits the signal inside the cell by changing shape.](image2)

### 3.3 Formative Assessment

**REVIEWING MAIN IDEAS**

1. Why do **phospholipids** form a double layer?
2. Explain how membrane **receptors** transmit messages across the **cell membrane**.

**CRITICAL THINKING**

3. **Compare** Describe the similarities between enzymes and receptors.
4. **Infer** If proteins were rigid, why would they make poor receptors?

**HUMAN BIOLOGY**

5. Insulin helps cells take up sugar from the blood. Explain the effect on blood sugar levels if insulin receptors stopped working.

---

84 Unit 2: Cells
Materials move across membranes because of concentration differences.

Diffusion and osmosis are types of passive transport.

Some molecules diffuse through transport proteins.

Connect to Your World

If you have ever been stuck in traffic behind a truck full of pigs, you know that “unpleasant” fails to fully describe the situation. That is because molecules travel from the pigs to receptors in your nose, and your brain interprets those molecules to be a really bad odor. Or, perhaps you have tie-dyed a T-shirt and have seen dye molecules spread throughout the pot of water, turning it neon green or electric blue. Why does that happen? Why don’t the molecules stay in one place?

Diffusion and osmosis are types of passive transport.

Cells almost continually import and export substances. If they had to expend energy to move every molecule, cells would require an enormous amount of energy to stay alive. Fortunately, some molecules enter and exit a cell without requiring the cell to work. As FIGURE 4.1 shows, passive transport is the movement of molecules across a cell membrane without energy input from the cell. It may also be described as the diffusion of molecules across a membrane.

Diffusion

Diffusion is the movement of molecules in a fluid or gas from a region of higher concentration to a region of lower concentration. It results from the natural motion of particles, which causes molecules to collide and scatter. Concentration is the number of molecules of a substance in a given volume, and it can vary from one region to another. A concentration gradient is the difference in the concentration of a substance from one location to another. Molecules diffuse down their concentration gradient—that is, from a region of higher concentration to a region of lower concentration.

In the tie-dye example, dye molecules are initially at a high concentration in the area where they are added to the water. Random movements of the dye and water molecules cause them to bump into each other and mix. Thus, the dye molecules move from an area of higher concentration to an area of lower concentration. Eventually, they are evenly spread throughout the solution. This means the molecules have reached a dynamic equilibrium. The concentration of dye molecules is the same throughout the solution (equilibrium), but the molecules continue to move (dynamic).
In cells, diffusion plays an important role in moving substances across the membrane. Small lipids and other nonpolar molecules, such as carbon dioxide and oxygen, easily diffuse across the membrane. For example, most of your cells continually consume oxygen, which means that the oxygen concentration is almost always higher outside a cell than it is inside a cell. As a result, oxygen generally diffuses into a cell without the cell's expending any energy.

**Osmosis**

Water molecules, of course, also diffuse. They move across a semipermeable membrane from an area of higher water concentration to an area of lower water concentration. This process is called osmosis. It is important to recognize that the higher the concentration of dissolved particles in a solution, the lower the concentration of water molecules in the same solution. So, if you put 1 teaspoon of salt in a cup of water and 10 teaspoons of salt in a different cup of water, the first cup would have the higher water concentration.

A solution may be described as isotonic, hypertonic, or hypotonic relative to another solution. Note that these terms are comparisons; they require a point of reference, as shown in **FIGURE 4.3**. For example, you may be taller than your coach or taller than you were two years ago, but you are never just taller. Likewise, a solution may be described as isotonic only in comparison with another solution. To describe it as isotonic by itself would be meaningless.

1. **A solution is isotonic** to a cell if it has the same concentration of dissolved particles as the cell. Water molecules move into and out of the cell at an equal rate, so the cell's size remains constant.
2. **A hypertonic** solution has a higher concentration of dissolved particles than a cell. This means water concentration is higher inside the cell than outside. Thus, water flows out of the cell, causing it to shrivel or even die.

**FIGURE 4.3 Effects of Osmosis**

Osmosis is the diffusion of water across a semipermeable membrane from an area of higher water concentration to an area of lower water concentration.

1. **ISOTONIC SOLUTION**
   - isotonic
   - A solution is isotonic to a cell if it has the same concentration of solutes as the cell. Equal amounts of water enter and exit the cell, so its size stays constant.

2. **HYPERTONIC SOLUTION**
   - hypertonic
   - A hypertonic solution has more solutes than a cell. Overall, more water exits a cell in a hypertonic solution, causing the cell to shrivel or even die.

3. **HYPOTONIC SOLUTION**
   - hypotonic
   - A hypotonic solution has fewer solutes than a cell. Overall, more water enters a cell in a hypotonic solution, causing the cell to expand or even burst.

**Apply** How would adding salt to the isotonic solution above affect the cell?
A hypotonic solution has a lower concentration of dissolved particles than a cell. This means water molecules are more concentrated outside the cell than inside. Water diffuses into the cell. If too much water enters a cell, the cell membrane could potentially expand until it bursts.

Some animals and single-celled organisms can survive in hypotonic environments. Their cells have adaptations for removing excess water. In plants, the rigid cell wall prevents the membrane from expanding too much. Remember from Section 2 that pressure exerted on the cell wall by fluid inside the central vacuole provides structural support for each cell and for the plant as a whole.

Apply  What will happen to a houseplant if you water it with salt water (a hypertonic solution)?  TEKS 4B

**MAIN IDEA  TEKS 4B, 9A**

Some molecules diffuse through transport proteins.

Some molecules cannot easily diffuse across a membrane. They may cross more easily through transport proteins—openings formed by proteins that pierce the cell membrane. Facilitated diffusion is the diffusion of molecules across a membrane through transport proteins. The word facilitate means “to make easier.” Transport proteins make it easier for molecules to enter or exit a cell. But the process is still a form of passive transport. The molecules move down a concentration gradient, requiring no energy expenditure by the cell.

There are many types of transport proteins. Most types allow only certain ions or molecules to pass. As FIGURE 4.4 shows, some transport proteins are simple channels, or tunnels, through which particles such as ions can pass. Others act more like enzymes. When bound, the protein changes shape, allowing the molecule to travel the rest of the way into the cell.

**Explain**  Why are transport proteins needed in the cell membrane?  TEKS 4B, 9A

---

### Formative Assessment

#### REVIEWING MAIN IDEAS

1. Explain what a **concentration gradient** is and what it means for a molecule to diffuse down its concentration gradient.  **TEKS 4B**
2. Explain why **facilitated diffusion** does not require energy from a cell.  **TEKS 4B**

#### CRITICAL THINKING

3. **Apply**  A cell is bathed in fluid. However, you notice that water is flowing out of the cell. In what kind of solution is this cell immersed: isotonic, hypertonic, or hypotonic?  **TEKS 4B, 9A**
4. **Compare**  How are receptors and transport proteins similar?  **TEKS 4B, 9A**

#### CONNECT TO HEALTH

5. When a person becomes dehydrated due to the loss of fluids and solutes, saline solution (water and salts) is infused into the bloodstream by medical personnel. Why is saline solution used instead of pure water?  **TEKS 4B**
Virtual Tour of Animal Cell
Explore the features of cell organelles.

Organelle Dysfunction
What happens when an organelle does not function as it should? Review a patient’s symptoms, research them, and diagnose her illness. Explore how the health of an entire person can depend on just one organelle.

Get Through a Cell Membrane
Move materials into and out of a cell to maintain homeostasis.
Active Transport, Endocytosis, and Exocytosis

**Vocabulary**
- Active transport
- Endocytosis
- Phagocytosis
- Exocytosis

**Key Concept**
Cells use energy to transport materials that cannot diffuse across a membrane.

**Main Ideas**
- Proteins can transport materials against a concentration gradient.
- Endocytosis and exocytosis transport materials across the membrane in vesicles.

**Connect to Your World**
If you want to go up to the second floor of the mall, you’re going to need help beating gravity. You could take an escalator, which uses energy to move you against gravity, much like transport proteins involved in active transport use energy to move molecules against a gradient. Alternatively, you might take the elevator, entering on the first floor and hopping out when the doors open on the second. In endocytosis and exocytosis, vesicles act like that elevator, surrounding molecules on one side of a membrane and releasing them into the other.

**Main Idea**
Proteins can transport materials against a concentration gradient.

You just learned that some transport proteins let materials diffuse into and out of a cell down a concentration gradient. Many other transport proteins, often called pumps, move materials against a concentration gradient. **Active transport** drives molecules across a membrane from a region of lower concentration to a region of higher concentration. This process, shown in Figure 5.1, uses transport proteins powered by chemical energy. Cells use active transport to get needed molecules regardless of the concentration gradient and to maintain homeostasis.

Before we discuss active transport proteins, let’s look at transport proteins in general. All transport proteins span the membrane, and most change shape when they bind to a target molecule or molecules. Some transport proteins bind to only one type of molecule. Others bind to two different types. Some proteins that bind to two types of molecules move both types in the same direction. Others move the molecules in opposite directions.
The key feature of active transport proteins is that they can use chemical energy to move a substance against its concentration gradient. Most use energy from a molecule called ATP, either directly or indirectly. For example, nerve cells, or neurons, need to have a higher concentration of potassium ions and a lower concentration of sodium ions than the fluid outside the cell. The sodium-potassium pump uses energy directly from the breakdown of ATP. It pumps three sodium ions out of the cell for every two potassium ions it pumps in. The proton pump, another transport protein, uses energy from the breakdown of ATP to move hydrogen ions (or protons) out of the cell. This action forms a concentration gradient of hydrogen ions (H+), which makes the fluid outside the cell more positively charged than the fluid inside. In fact, this gradient is a form of stored energy that is used to power other active transport proteins. In plant cells, this gradient causes yet another protein to transport sucrose into the cell—an example of indirect active transport.

**Synthesize** In what ways are active transport proteins similar to enzymes?

### Main Idea TEKS 4B

**Endocytosis and exocytosis transport materials across the membrane in vesicles.**

A cell may also use energy to move a large substance or a large amount of a substance in vesicles. Transport in vesicles lets substances enter or exit a cell without crossing through the membrane.

**Endocytosis**

Endocytosis (en-doh-sy-TOH-sih) is the process of taking liquids or fairly large molecules into a cell by engulfing them in a membrane. In this process, the cell membrane makes a pocket around a substance. The pocket breaks off inside the cell and forms a vesicle, which then fuses with a lysosome or a similar type of vesicle. Lysosomal enzymes break down the vesicle membrane and its contents (if necessary), which are then released into the cell.

**Phagocytosis** (fag-uh-sy-TOH-sih) is a type of endocytosis in which the cell membrane engulfs large particles. The word literally means “cell eating.” Phagocytosis plays a key role in your immune system. Some white blood cells called macrophages help your body fight infection. They find foreign materials, such as bacteria, and engulf and destroy them.
1. How do transport proteins that are pumps differ from those that are channels?  

2. How do endocytosis and exocytosis differ from diffusion?  

3. Apply Small lipid molecules are in high concentration outside a cell. They slowly cross the membrane into the cell. What term describes this action? Does it require energy?  

4. Apply Ions are in low concentration outside a cell. They move rapidly into the cell via protein molecules. What term describes this action? Does it require energy?  

5. Suppose molecules were unable to diffuse into and out of cells. How might life be different if cells had to use active transport to move every substance? Explain your reasoning.

**Exocytosis**  
**Exocytosis** (ehk-soh-sy-TOH-sihs), the opposite of endocytosis, is the release of substances out of a cell by the fusion of a vesicle with the membrane. During this process, a vesicle forms around materials to be sent out of the cell. The vesicle then moves toward the cell’s surface, where it fuses with the membrane and releases its contents.

Exocytosis happens all the time in your body. In fact, you couldn’t think or move a muscle without it. When you want to move your big toe, for example, your brain sends a message that travels through a series of nerve cells to reach your toe. This message, or nerve impulse, travels along each nerve cell as an electrical signal, but it must be converted to a chemical signal to cross the tiny gap that separates one nerve cell from the next. These chemicals are stored in vesicles within the nerve cells. When a nerve impulse reaches the end of a cell, it causes the vesicles to fuse with the cell membrane and release the chemicals outside the cell. There they attach to the next nerve cell, which triggers a new electrical impulse in that cell.

Hypothesize What might happen if vesicles in your neurons were suddenly unable to fuse with the cell membrane?  

**Virtual Investigation**  
Transport Across Cell Membrane

**Formative Assessment**

**Reviewing Main Ideas**

1. How do transport proteins that are pumps differ from those that are channels?  

2. How do endocytosis and exocytosis differ from diffusion?  

**Critical Thinking**

3. Apply Small lipid molecules are in high concentration outside a cell. They slowly cross the membrane into the cell. What term describes this action? Does it require energy?  

4. Apply Ions are in low concentration outside a cell. They move rapidly into the cell via protein molecules. What term describes this action? Does it require energy?  

**Connect to Diffusion**

5. Suppose molecules were unable to diffuse into and out of cells. How might life be different if cells had to use active transport to move every substance? Explain your reasoning.
**3 Summary**

**KEY CONCEPTS**

**3.1 Cell Theory**
Cells are the basic unit of life. The contributions of many scientists led to the discovery of cells and the development of the cell theory. The cell theory states that all organisms are made of cells, all cells are produced by other living cells, and the cell is the most basic unit of life.

**3.2 Cell Organelles**
Eukaryotic cells share many similarities. They have a nucleus and other membrane-bound organelles that perform specialized tasks within the cell. Many of these organelles are involved in making proteins. Plant and animal cells share many of the same types of organelles, but both also have organelles that are specific to the cells’ unique functions.

**3.3 Cell Membrane**
The cell membrane is a barrier that separates a cell from the external environment. It is made of a double layer of phospholipids and a variety of embedded molecules. Some of these molecules act as signals; others act as receptors. The membrane is selectively permeable, allowing some but not all materials to cross.

**3.4 Diffusion and Osmosis**
Materials move across membranes because of concentration differences. Diffusion is the movement of molecules in a fluid or gas from a region of higher concentration to a region of lower concentration. It does not require a cell to expend energy; it is a form of passive transport. Osmosis is the diffusion of water. Net water movement into or out of a cell depends on the concentration of the solution.

**3.5 Active Transport, Endocytosis, and Exocytosis**
Cells use energy to transport materials that cannot diffuse across a membrane. Active transport is the movement of molecules across a membrane from a region of lower concentration to a region of higher concentration—against a concentration gradient. The processes of endocytosis and exocytosis move substances in vesicles and also require energy.

**READING TOOLBOX**

**Main Idea Web** Plant and animal cells, though similar, each have some unique features. Identify how these cell types differ by placing plant cell characteristics on the left side of the main idea web and animal cell characteristics on the right.

**Concept Map** Fill in a concept map like the one below to summarize what you know about forms of transport.

- Materials move across the cell membrane with or without energy added.
- Active transport requires energy.
- Passive transport does not require energy.
- Endocytosis and exocytosis involve vesicles and energy.
Reviewing Vocabulary

**Labeling Diagrams**

In your science notebook, write the vocabulary term that matches each numbered item below.

1. __________
2. __________
3. __________
4. __________
5. __________
6. __________
7. __________
8. __________

**Labeling Diagrams**

Describe one similarity and one difference between the two terms in each of the following pairs.

9. **eukaryotic, prokaryotic**
10. **cell wall, cell membrane**
11. **diffusion, facilitated diffusion**

**Greek and Latin Word Origins**

12. The word *organelle* is the diminutive, or “tiny,” form of the Latin word for organs of the body. How is an organelle like a tiny organ?

13. The Greek word *karuon* means “nut.” The prefix *pro-* means “before,” and the prefix *eu-* means “true.” Thus, *prokaryote* means “before nut,” and *eukaryote* means “true nut.” How do these meanings relate to structural differences between these two cell types?

**Reviewing MAIN IDEAS**

14. According to the cell theory, what is required for an object to be considered alive?

15. What role do membranes play in prokaryotic cells? in eukaryotic cells? **TEKS** 4A

16. How do the cytoskeleton and the cytoplasm contribute to a cell’s shape?

17. You know that many organelles are involved in protein production. Briefly explain where proteins are made, modified, and packaged within a cell. **TEKS** 4B

18. Explain what mitochondria do and why evidence suggests that they might have descended from free-living prokaryotes in the evolutionary past.

19. If you were looking through a microscope at an unknown cell, how might you determine whether it was a plant cell or an animal cell?

20. Cells are surrounded by a watery fluid, and they contain cytoplasm. Explain how the structure of the lipid bilayer is related to these two watery environments. **TEKS** 9A

21. How are cells able to respond to signal molecules that are too large to enter the cytoplasm? **TEKS** 4B

22. How do transport proteins make it easier for certain molecules to diffuse across a membrane? **TEKS** 4B, 9A

23. Under what conditions would a molecule need to be actively transported across a membrane? **TEKS** 4B

24. Do you think that endocytosis and exocytosis can occur within the same cell? Explain your reasoning. **TEKS** 4B
Critical Thinking

25. **Summarize** How was the development of cell theory closely tied to advancements in technology? **TEKS 3F**

26. **Analyze** What structural features suggest that eukaryotic cells evolved from prokaryotic cells? **TEKS 4A**

27. **Synthesize** If vesicles are almost constantly pinching off from the ER to carry proteins to the Golgi apparatus, why does the ER not shrink and finally disappear?

28. **Compare and Contrast** You know that both vesicles and vacuoles are hollow compartments used for storage. How do they differ in function?

29. **Infer** When cells release ligands, they are sent through the bloodstream to every area of the body. Why do you think that only certain types of cells will respond to a particular ligand?

30. **Provide Examples** What are two ways in which exocytosis might help a cell maintain homeostasis? **TEKS 4B**

31. **Compare** How is facilitated diffusion similar to both passive transport and active transport? **TEKS 4B**

Interpreting Visuals
Use the diagram to answer the next three questions.

32. **Apply** What process is occurring in the diagram, and how do you know? **TEKS 4B**

33. **Predict** If the transport proteins that carry amino acids into this cell stopped working, how might the process shown be affected? **TEKS 4B**

34. **Infer** What might you conclude about the membrane structure of the final vesicle and the cell membrane?

Analyzing Data **Form an Operational Definition**
Use the text and table below to answer the next three questions. Reactive oxygen species, or ROS, are clusters of highly reactive oxygen atoms that can damage the body. As people age, the amount of ROS in the body increases, causing a condition called oxidative stress. In one study, researchers studied how the number of mitochondria might be involved in this situation.

- Muscle tissue was obtained from patients.
- Radioactive probes labeled the mitochondria.
- A machine counted the mitochondria per cell.

**Age and Muscle Cell Mitochondria**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age</th>
<th>Mitochondria per Muscle Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>47</td>
<td>2026</td>
</tr>
<tr>
<td>2</td>
<td>89</td>
<td>2987</td>
</tr>
<tr>
<td>3</td>
<td>65</td>
<td>2752</td>
</tr>
<tr>
<td>4</td>
<td>38</td>
<td>1989</td>
</tr>
</tbody>
</table>

35. **Apply** If the independent variable in this study is age, what is the operational definition of the dependent variable?

36. **Analyze** What do the data show about the relationship between age and number of mitochondria?

37. **Infer** What might the relationship between age and number of mitochondria indicate about the increase in ROS levels?

Making Connections

38. **Write an Analogy** The cell membrane regulates what can enter and exit a cell. In eukaryotes, it encloses a complex group of organelles that carry out special jobs. Make an analogy to describe the cell membrane and the variety of organelles and processes that take place inside it. Explain any limitations of your analogy. **TEKS 3E, 4B**

39. **Connect** On the chapter opener, you saw a picture of macrophages eating up bacteria. Identify the ways in which the cytoskeleton helps the macrophage carry out this job.
Record your answers on a separate piece of paper.

**MULTIPLE CHOICE**

**TEKS 2C**
1. The cell theory states that the cell is the most basic unit of life, all organisms are made of cells, and all cells come from cells. What makes the cell theory a scientific theory?
   A. It is based on a scientific publication that is read by scientists worldwide.
   B. It is based on the work of many scientists and leads to accurate predictions.
   C. It is based on ideas that have been proven true and that are not subject to revision.
   D. It is based on preliminary evidence but still needs to be confirmed with experiments.

**TEKS 2G, 4A**
2. A student observes four cells with a compound microscope and records her observations in the table shown.

<table>
<thead>
<tr>
<th>Observed Structures</th>
<th>Cell 1</th>
<th>Cell 2</th>
<th>Cell 3</th>
<th>Cell 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell Wall</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Nucleus</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Chloroplasts</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Mitochondrion</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

Based on these data, how should the cells be classified?
   A. Cells 1 and 3 are prokaryotic cells, and Cells 2 and 4 are eukaryotic cells.
   B. All four cells are prokaryotic cells.
   C. Cell 3 is a prokaryotic cell, and Cells 1, 2, and 4 are eukaryotic cells.
   D. All four cells are eukaryotic cells.

**TEKS 4B**
3. As the concentration of molecules outside a cell increases, more molecules will enter the cell because —
   A. the molecules are moving down their concentration gradient
   B. the molecules are moving from an area of low concentration to an area of high concentration
   C. energy is available to move them using active transport
   D. they have reached dynamic equilibrium

**THINK THROUGH THE QUESTION**

Are the molecules that are moving into the cell moving from an area of high concentration to low concentration, or vice versa?

**TEKS 4A, 4C**
4. Some viruses attack cells by inserting their own DNA into the host cells’ DNA. Why might it be simpler for these viruses to attack prokaryotic cells than eukaryotic cells?
   A. Prokaryotic cells have less DNA than do eukaryotic cells.
   B. Unlike eukaryotic cells, prokaryotic cells do not have a nucleus.
   C. The cell wall in prokaryotic cells is a less effective barrier.
   D. The rapid growth of prokaryotic cells generates more viruses.

**TEKS 4B**
5. The diagram below shows how glucose molecules move down a concentration gradient to enter a cell with the help of transport proteins.

What type of transport is shown above?
   A. facilitated diffusion
   B. active transport
   C. osmosis
   D. pinocytosis