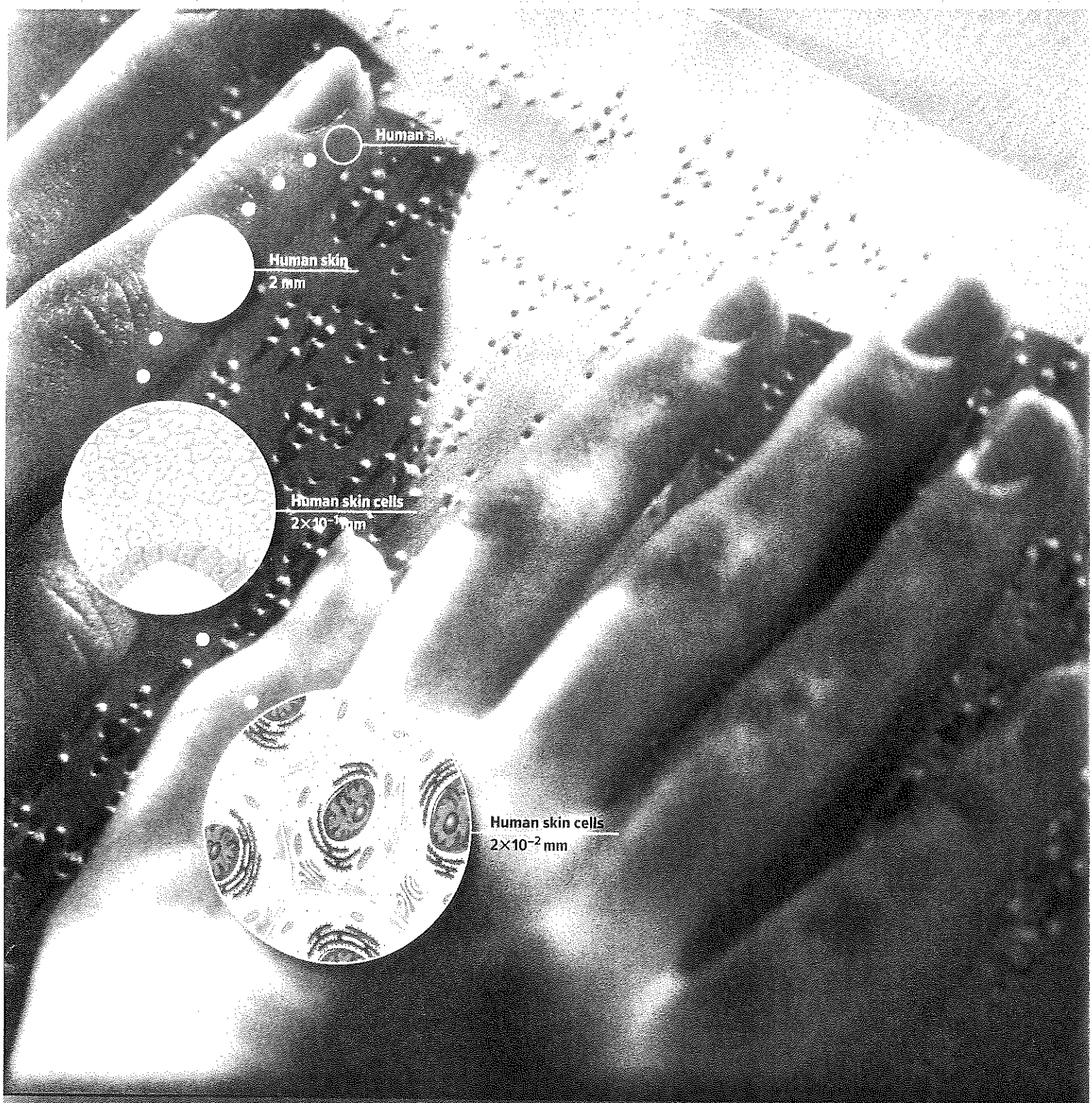


THEME FOCUS **Cause and Effect**
Cellular processes allow cells to respond to change in the environment.

BIG Idea **Cells are the structural and functional units of all living organisms.**

Cell Discovery and Theory

Reading Preview

Essential Questions

- How are the advances in microscope technology related to discoveries about cells?
- What are the similarities and differences between compound light microscopes and electron microscopes?
- What are the principles of the cell theory?
- What are the differences between a prokaryotic cell and a eukaryotic cell?

Review Vocabulary

organization: the orderly structure shown by living things

New Vocabulary

cell
cell theory
plasma membrane
organelle
eukaryotic cell
nucleus
prokaryotic cell

Multilingual eGlossary

Key Idea **The invention of the microscope led to the discovery of cells.**

Real-World Reading Link The different parts of your body might seem to have nothing in common. Your heart, for example, pumps blood throughout your body, while your skin protects and helps cool you. However, your body parts have one thing in common—they are composed of cells.

History of the Cell Theory

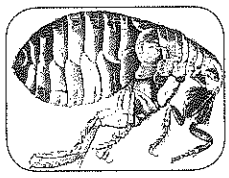
For centuries, scientists had no idea that the human body consists of trillions of cells. Cells are so small that their existence was unknown before the invention of the microscope. In 1665, as indicated in **Figure 1,** an English scientist named Robert Hooke made a simple microscope and looked at a piece of cork, the dead cells of oak bark. Hooke observed small, box-shaped structures, such as those shown in **Figure 2.** He called them cellulae (the Latin word meaning *small rooms*) because the boxlike cells of cork reminded him of the cells in which monks live at a monastery. It is from Hooke's work that we have the term *cell.* A **cell** is the basic structural and functional unit of all living organisms.

During the late 1600s, Dutch scientist Anton van Leeuwenhoek (LAY vun hook) designed his own microscope after he was inspired by a book written by Hooke. To his surprise, he saw living organisms in pond water, milk, and various other substances. The work of these scientists and others led to new branches of science and many new and exciting discoveries.

Figure 1

Microscopes in Focus

The invention of microscopes, improvements to the instruments, and new microscope techniques have led to the development of the cell theory and a better understanding of cells.



1665 Robert Hooke observes cork and names the tiny chambers that he sees *cells.* He publishes drawings of cells, fleas, and other minute bodies in his book *Micrographia.*

1830–1855 Scientists discover the cell nucleus (1833) and propose that both plants and animals are composed of cells (1839).

1500 | 1600 | 1700 | 1800

1590 Dutch lens grinders Hans and Zacharias Janssen invent the first compound microscope by placing two lenses in a tube.

1683 Dutch biologist Anton van Leeuwenhoek discovers single-celled, animal-like organisms, now called protozoans.

The cell theory Scientists continued observing the living microscopic world using glass lenses. In 1838, German scientist Matthias Schleiden carefully studied plant tissues and concluded that all plants are composed of cells. A year later, another German scientist, Theodor Schwann, reported that animal tissues also consisted of individual cells. Prussian physician Rudolph Virchow proposed in 1855 that all cells are produced from the division of existing cells. The observations and conclusions of these scientists and others are summarized as the cell theory. The **cell theory** is one of the fundamental ideas of modern biology and includes the following three principles:

1. All living organisms are composed of one or more cells.
2. Cells are the basic unit of structure and organization of all living organisms.
3. Cells arise only from previously existing cells, with cells passing copies of their genetic material on to their daughter cells.

Reading Check **Explain** Can cells appear spontaneously without genetic material from previous cells?

Microscope Technology

The discovery of cells and the development of the cell theory would not have been possible without microscopes. Improvements made to microscopes have enabled scientists to study cells in detail, as described in **Figure 1.**

Turn back to the opening pages of this chapter and compare the illustrations of the skin shown there. Note that the detail increases as the magnification and resolution–the ability of the microscope to make individual components visible–increase. Hooke and van Leewenhoek would not have been able to see the individual structures within human skin cells with their microscopes. Developments in microscope technology have given scientists the ability to study cells in greater detail than early scientists ever thought possible.

LM Magnification: 100×

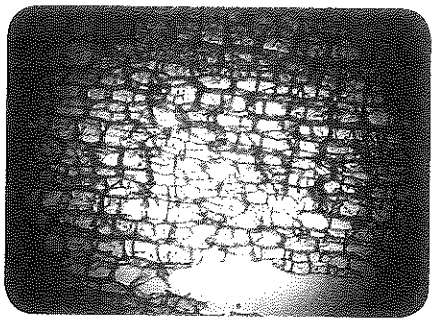


Figure 2 Robert Hooke used a basic light microscope to see what looked like empty chambers in a cork sample.
***Infer** what you think Hooke would have seen if these were living cells.*

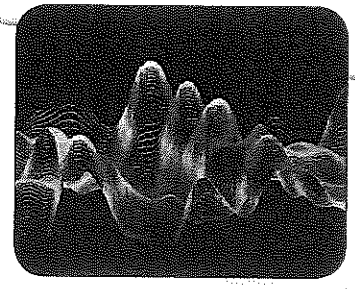
Launch Lab

Based on what you've read about cells, how would you now answer the analysis questions?

1880–1890 Louis Pasteur and Robert Koch, using compound microscopes, pioneered the study of bacteria.

1939 Ernest Everett Just writes the textbook *Biology of the Cell Surface* after years of studying the structure and function of cells.

1970 Lynn Margulis, a microbiologist, proposes the idea that some organelles found in eukaryotes were once free-living prokaryotes.



1981 The scanning tunneling microscope (STM) allows scientists to see individual atoms.

2008 3-dimensional structured illumination microscopy (3D-SIM) combines a 3-D view, high resolution, and multiple colors.

[(t)©Lester V. Bergman/Corbis; (b)SPL/Photo Researchers; (b)LBNL/SPL/Photo Researchers]

Compound light microscopes The modern compound light microscope consists of a series of glass lenses and uses visible light to produce a magnified image. Each lens in the series magnifies the image of the previous lens. For example, when two lenses each individually magnify 10 times, the total magnification is 100 times (10 × 10). Scientists often stain cells with dyes to see them better when using a light microscope because cells are so tiny, thin, and translucent. Over the years, scientists have developed various techniques and modifications for light microscopes, but the properties of visible light will always limit resolution with these microscopes. Objects cause light to scatter, which blurs images. The maximum magnification without blurring is around 1000×.

Electron microscopes As they began to study cells, scientists needed greater magnification to see the details of tiny parts of cells. During the second World War, in the 1940s, they developed the electron microscope. Instead of lenses, the electron microscope uses magnets to aim a beam of electrons at thin slices of cells. This type of electron microscope is called a transmission electron microscope (TEM) because electrons are passed, or transmitted, through a specimen to a fluorescent screen. Thick parts of the specimen absorb more electrons than thin parts, forming a black-and-white shaded image of the specimen. Transmission electron microscopes can magnify up to 500,000×, but the specimen must be dead, sliced very thin, and stained with heavy metals.

Over the past 65 years, many modifications have been made to the original electron microscopes. For example, the scanning electron microscope (SEM) is one modification that directs electrons over the surface of the specimen, producing a three-dimensional image. One disadvantage of using a TEM and an SEM is that only nonliving cells and tissues can be observed. Photomicrographs made with electron microscopes can be found online.

CAREERS IN BIOLOGY

Technology Representative
Companies that manufacture scientific equipment employ representatives to demonstrate and explain their products to the scientific community. A technology representative is an expert in these new technology products and brings this expertise to scientists who might use the products in the laboratory.

MiniLab 1

Discover Cells

MiniLab

How can you describe a new discovery? Imagine that you are a scientist looking through the eyepiece of some newfangled instrument called a microscope and you see a field of similarly shaped objects. You might recognize that the shapes that you see are not merely coincidence and random objects. Your whole idea of the nature of matter is changing as you view these objects.

Procedure

1. Read and complete the lab safety form.
2. Prepare a data table in which you will record observations and drawings for three slides.
3. View the **slide images** that your teacher projects for the class.
4. Describe and draw what you see. Be sure to include enough detail in your drawings to convey the information to other scientists who have not observed cells.

Analysis

1. **Describe** what analogies or terms could explain the images in your drawings.
2. **Explain** how you could show Hooke, with twenty-first-century technology, that his findings were valid.

Another type of microscope, the scanning tunneling electron microscope (STM), involves bringing the charged tip of a probe extremely close to the specimen so that the electrons "tunnel" through the small gap between the specimen and the tip. This instrument has enabled scientists to create three-dimensional computer images of objects as small as atoms. Unlike TEM and SEM, STM can be used with live specimens. **Figure 3** shows DNA, the cell's genetic material, magnified with a scanning tunneling electron microscope.

The atomic force microscope (AFM) measures various forces between the tip of a probe and the cell surface. To learn more about AFM, read the *Cutting Edge Biology* feature at the end of this chapter.

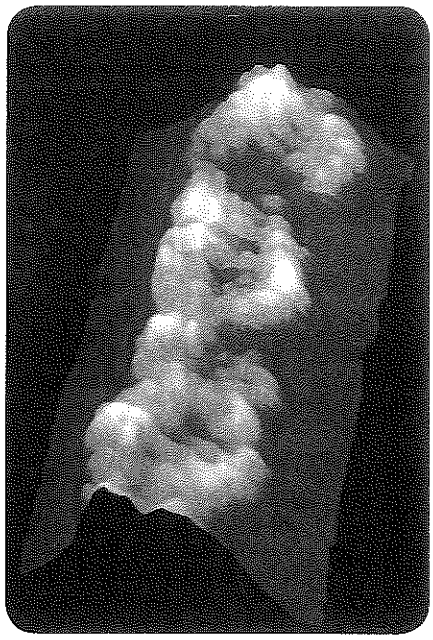
Basic Cell Types

You have learned, according to the cell theory, that cells are the basic units of all living organisms. By observing your own body and the living things around you, you might infer that cells must exist in various shapes and sizes. You also might infer that cells differ based on the functions they perform for an organism. However, all cells have at least one physical trait in common: they all have a structure called a plasma membrane. A **plasma membrane**, labeled in **Figure 4,** is a special boundary that helps control what enters and leaves the cell. Each of your skin cells has a plasma membrane, as do the cells of a rattlesnake. This critical structure is described in detail in the next section.

Cells generally have a number of functions in common. For example, most cells have genetic material in some form that provides instructions for making substances that the cell needs. Cells also break down molecules to generate energy. Scientists have grouped cells into two broad categories. These categories are prokaryotic (pro kar ee AW tik) cells and eukaryotic (yew kar ee AW tik) cells. **Figure 4** shows TEM photomicrographs of these two cell types. The images of the prokayotic cell and eukaryotic cell have been enlarged so that you can compare the cell structures. Eukaryotic cells generally are one to one hundred times larger than prokaryotic cells.

Reading Check **Compare** the sizes of prokaryotic cells and eukaryotic cells.

False-Color STM Magnification: 2,000,000×

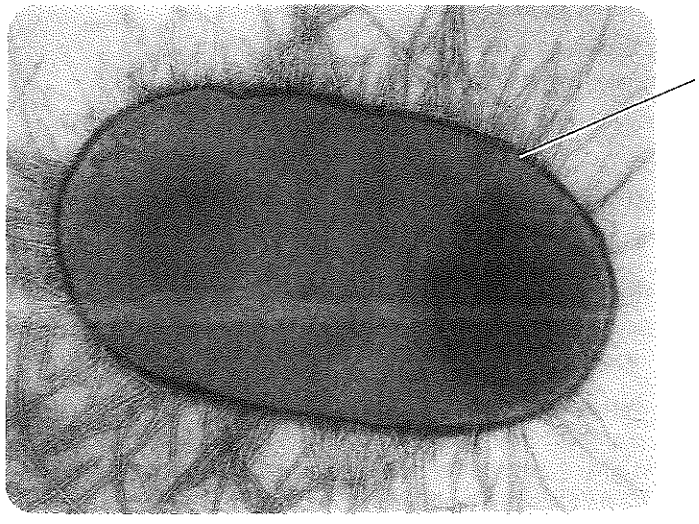


DNA

Figure 3 The scanning tunneling microscope (STM) provides images, such as this DNA molecule, in which cracks and depressions appear darker and raised areas appear lighter. Name *an application for which an STM might be used.*

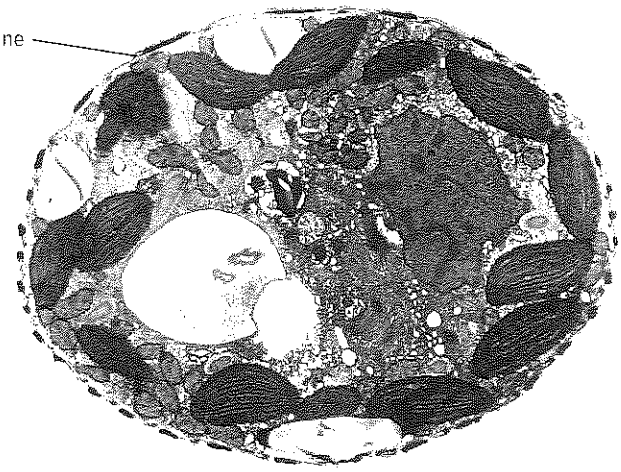
Video Lab

Color-Enhanced TEM Magnification: 15,000×



Prokaryotic cell

Color-Enhanced Magnification: unavailable



Eukaryotic cell

Figure 4 The prokaryotic cell on the left is smaller and appears less complex than the eukaryotic cell on the right. The prokaryotic cell has been enlarged for the purpose of comparing each cell's internal sturctures.

BrainPOP

Refer again to **Figure 4** and compare the types of cells to see why scientists place them into two broad categories that are based on internal structures. Both have a plasma membrane, but one cell contains many distinct internal structures called **organelles**–specialized structures that carry out specific cell functions.

Eukaryotic cells contain a nucleus and other organelles that are bound by membranes, also referred to as membrane-bound organelles. The **nucleus** is a distinct central organelle that contains the cell's genetic material in the form of DNA. Organelles enable cell functions to take place in different parts of the cell at the same time. Most organisms are made up of eukaryotic cells and are called eukaryotes. However, some unicellular organisms, such as some algae and yeast, also are eukaryotes.

Prokaryotic cells are defined as cells without a nucleus or other membrane-bound organelles. As you can see in **Figure 4,** prokaryotic cells are simpler than eukaryotic cells. Most unicellular organisms, such as bacteria, are prokaryotic cells. Thus, they are called prokaryotes. Many scientists think that prokaryotes are similar to the first organisms that lived on Earth.

Origin of cell diversity Scientists continue to investigate why there are two basic types of cells. The answer might be that eukaryotic cells evolved from prokaryotic cells millions of years ago. According to the endosymbiont theory, a symbiotic relationship involves one prokaryotic cell living inside of another and both cells benefiting from the relationship.

Imagine how organisms would be different if the eukaryotic form had not evolved. Because eukaryotic cells are larger and have distinct organelles, these cells have developed specific functions. Having specific functions has led to cell diversity, and thus more diverse organisms that can adapt better to their environments. Lifeforms more complex than bacteria might not have evolved without eukaryotic cells.

VOCABULARY

WORD ORIGIN

Eukaryote
eu- prefix; from Greek, meaning *true*

Prokaryote
pro- prefix; from Greek, meaning *before*
-kary from Greek, meaning *nucleus*

Section 1 Assessment

Section Summary

- Microscopes have been used as tools for scientific study since the late 1500s.
- Scientists use different types of microscopes to study cells.
- The cell theory summarizes three principles.
- There are two broad groups of cell types: prokaryotic cells and eukaryotic cells.

Understand Main Ideas

1. **Explain** how the development and improvement of microscopes changed the study of living organisms.
2. **Compare and contrast** a compound light microscope and an electron microscope.
3. **Summarize** the cell theory.
4. **Differentiate** the plasma membrane and the organelles.

Think Critically

5. **Describe** how you would determine whether the cells of a newly discovered organism were prokaryotic or eukaryotic.

MATH in Biology

6. If the overall magnification of a series of two lenses is 30×, and one lens magnifies 5×, what is the magnification of the other lens? Calculate the total magnification if the 5× lens is replaced by a 7× lens.

Online Quiz

Reading Preview

Essential Questions

- How does a cell's plasma membrane function?
- What are the roles of proteins, carbohydrates, and cholesterol in the plasma membrane?

Review Vocabulary

ion: an atom or group of atoms with a positive or negative electric charge

New Vocabulary

selective permeability
phospholipid bilayer
transport protein
fluid mosaic model

Multilingual eGlossary

The Plasma Membrane

MAIN Idea **The plasma membrane helps to maintain a cell's homeostasis.**

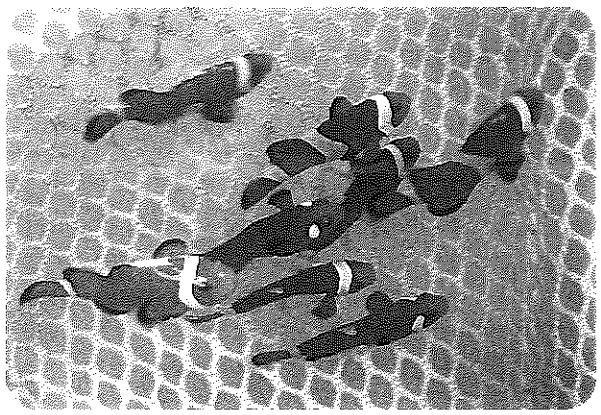
Real-World Reading Link When you approach your school, you might pass through a gate in a fence that surrounds the school grounds. The fence prevents people who should not be there from entering, and the gate allows students, staff, and parents to enter. Similarly, prokaryotic cells and eukaryotic cells have structures that maintain control of their internal environments.

Function of the Plasma Membrane

Recall that the process of maintaining balance in an organism's internal environment is called homeostasis. Homeostasis is essential to the survival of a cell. One of the structures that is primarily responsible for homeostasis is the plasma membrane. The plasma membrane is a thin, flexible boundary between a cell and its environment that allows nutrients into the cell and allows waste and other products to leave the cell. All prokaryotic cells and eukaryotic cells have a plasma membrane to separate them from the watery environments in which they exist.

A key property of the plasma membrane is **selective permeability** (pur mee uh BIH luh tee), by which a membrane allows some substances to pass through while keeping others out. Consider a fish net as an analogy of selective permeability. The net shown in **Figure 5** has holes that allow water and other substances in the water to pass through, but not the fish. Depending on the size of the holes in the net, some kinds of fish might pass through, while others are caught. The diagram in **Figure 5** illustrates selective permeability of the plasma membrane. The arrows show that substances enter and leave the cell through the plasma membrane. Control of how, when, and how much of these substances enter and leave a cell relies on the structure of the plasma membrane.

Reading Check **Define** the term *selective permeability.*



Jill Barton/AP Images

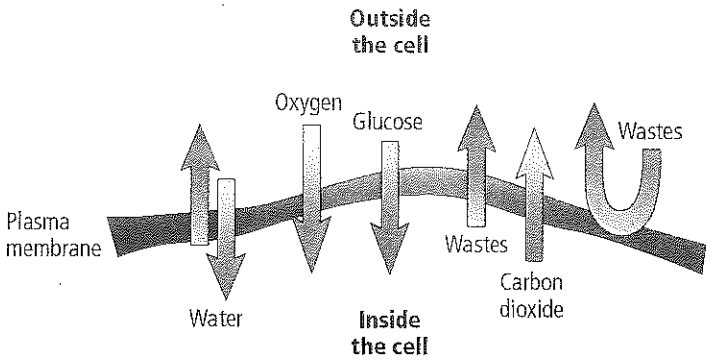


Figure 5
Left: The fish net selectively captures fish while allowing water and other debris to pass through. **Right:** Similarly, the plasma membrane selects substances entering and leaving the cell.

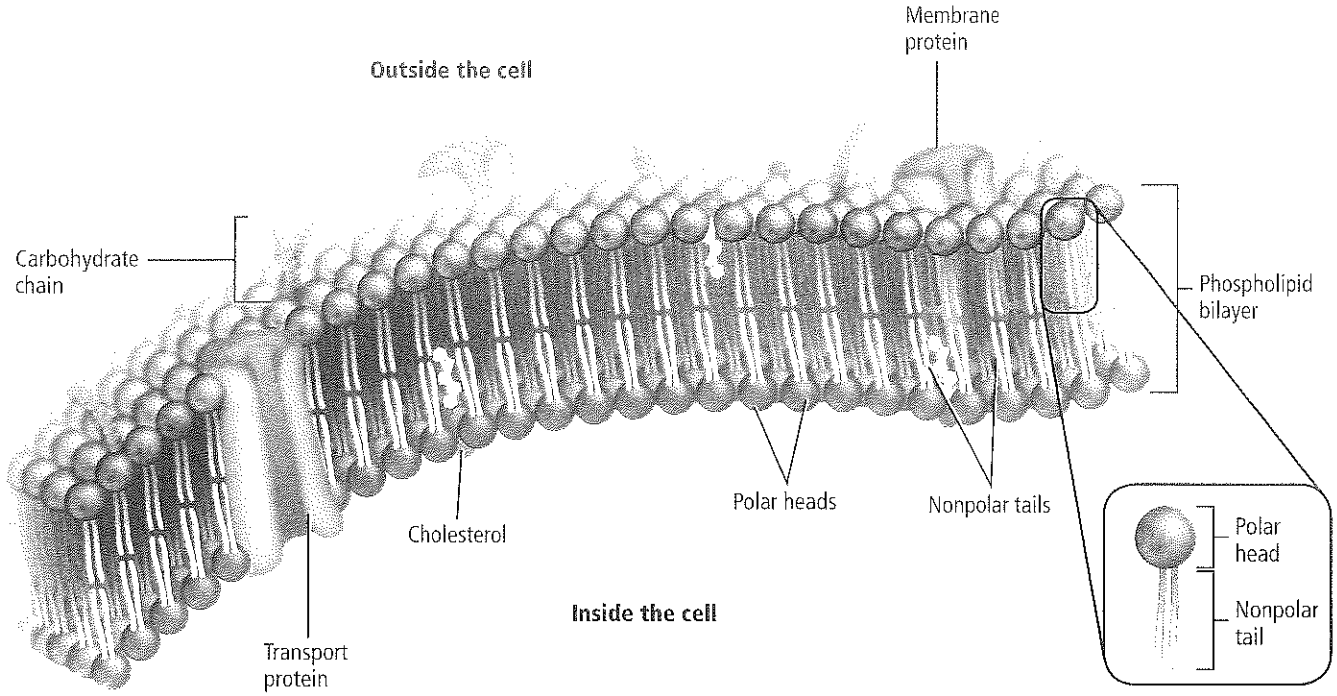


Figure 6 The phospholipid bilayer looks like a sandwich, with the polar heads facing the outside and the nonpolar tails facing the inside. **Infer** *how hydrophobic substances cross a plasma membrane.*

Structure of the Plasma Membrane

Connection to Chemistry Most of the molecules in the plasma membrane are lipids. Lipids are large molecules that are composed of glycerol and three fatty acids. If a phosphate group replaces a fatty acid, a phospholipid forms. A phospholipid (fahs foh LIH pid) is a molecule that has a glycerol backbone, two fatty acid chains, and a phosphate-containing group. The plasma membrane is composed of a **phospholipid bilayer,** in which two layers of phospholipids are arranged tail-to-tail, as shown in **Figure 6.** In the plasma membrane, phospholipids arrange themselves in a way that allows the plasma membrane to exist in the watery environment.

The phospholipid bilayer Notice in **Figure 6** that each phospholipid is diagrammed as a head with two tails. The phosphate group in each phospholipid makes the head polar. The polar head is attracted to water because water also is polar. The two fatty acid tails are nonpolar and are repelled by water.

The two layers of phospholipid molecules resemble a sandwich, with the fatty acid tails forming the interior of the plasma membrane and the phospholipid heads facing the watery environments found inside and outside the cell, as shown in **Figure 6.** This bilayer structure is critical for the formation and function of the plasma membrane. The phospholipids are arranged in such a way that the polar heads can be closest to the water molecules and the nonpolar tails can be farthest away from the water molecules.

When many phospholipid molecules come together in this manner, a barrier is created that is polar at its surfaces and nonpolar in the middle. Water-soluble substances will not move easily through the plasma membrane because they are stopped by the nonpolar middle. Therefore, the plasma membrane can separate the environment inside the cell from the environment outside the cell.

Vocabulary

Polar

Science usage: having an unequal distribution of charge
The positive end of a polar molecule attracts the negative end of a polar molecule.

Common usage: relating to a geographic pole or region
The polar ice cap in Greenland is, on average, 1.6 km thick.

Other components of the plasma membrane Moving with and among the phospholipids in the plasma membrane are cholesterol, proteins, and carbohydrates. When found on the outer surface of the plasma membrane, proteins called receptors transmit signals to the inside of the cell. Proteins at the inner surface anchor the plasma membrane to the cell's internal support structure, giving the cell its shape. Other proteins span the entire membrane and create tunnels through which certain substances enter and leave the cell. These **transport proteins** move needed substances or waste materials through the plasma membrane and therefore contribute to the selective permeability of the plasma membrane.

Reading Check **Describe** the benefit of the bilayer structure of the plasma membrane.

Locate the cholesterol molecules in **Figure 6.** Nonpolar cholesterol is repelled by water and is positioned among the phospholipids. Cholesterol helps to prevent the fatty-acid tails of the phospholipid bilayer from sticking together, which contributes to the fluidity of the plasma membrane. Although avoiding a high-cholesterol diet is recommended, cholesterol plays a critical role in plasma membrane structure and it is an important substance for maintaining homeostasis in a cell.

Other substances in the membrane, such as carbohydrates attached to proteins, stick out from the plasma membrane to define the cell's characteristics and help cells identify chemical signals. For example, carbohydrates in the membrane might help disease-fighting cells recognize and attack a potentially harmful cell.

Study Tip

Question Session Work with a partner and ask each other questions about the plasma membrane. Discuss each other's answers. Ask as many questions as you think of while taking turns.

DATA ANALYSIS LAB 1

Based on Real Data*

Interpret the Diagram

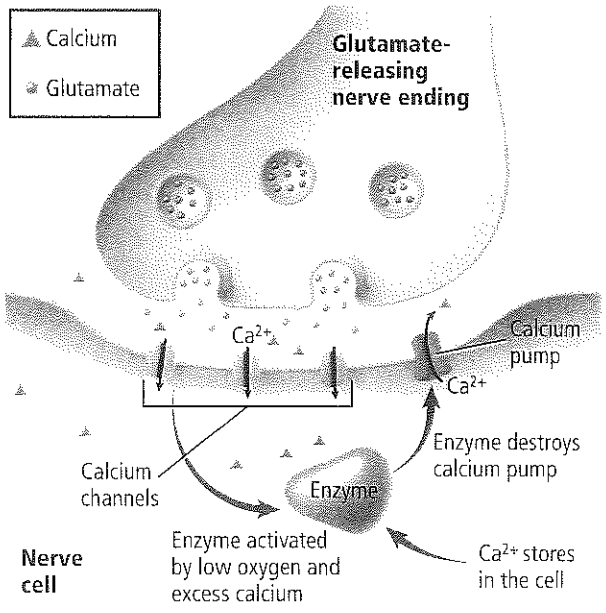
How are protein channels involved in the death of nerve cells after a stroke? A stroke occurs when a blood clot blocks the flow of oxygen-containing blood in a portion of the brain. Nerve cells in the brain that release glutamate are sensitive to the lack of oxygen and release a flood of glutamate when oxygen is low. During the glutamate flood, the calcium pump is destroyed. This affects the movement of calcium ions into and out of nerve cells. When cells contain excess calcium, homeostasis is disrupted.

Think Critically

1. **Interpret** how the glutamate flood destroys the calcium pump.
2. **Predict** what would happen if Ca^{2+} levels were lowered in the nerve cell during a stroke.

*Data obtained from: Choi, D.W. 2005. Neurodegeneration: cellular defences destroyed. *Nature* 433: 696–698.

Data and Observations



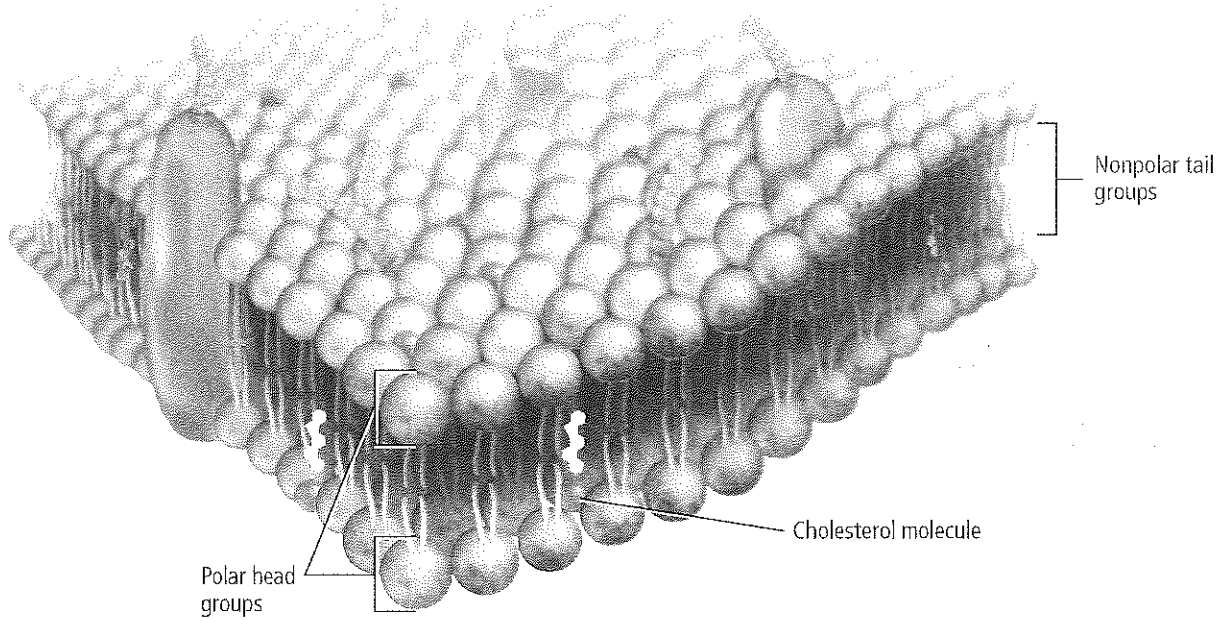


Figure 7 The fluid mosaic model refers to a plasma membrane with substances that can move around within the membrane.

Animation

Together, the phospholipids in the bilayer create a "sea" in which other molecules can float, like apples floating in a barrel of water. This "sea" concept is the basis for the **fluid mosaic model** of the plasma membrane. The phospholipids can move sideways within the membrane, just as apples move around in water. At the same time, other components in the membrane, such as proteins, also move among the phospholipids. Because there are different substances in the plasma membrane, a pattern, or mosaic, is created on the surface. You can see this pattern in **Figure 7.** The components of the plasma membrane are in constant motion, sliding past one another.

Section 2 Assessment

Section Summary

- Selective permeability is a property of the plasma membrane that allows it to control what enters and leaves the cell.
- The plasma membrane is made up of two layers of phospholipid molecules.
- Cholesterol and transport proteins aid in the function of the plasma membrane.
- The fluid mosaic model describes the plasma membrane.

Understand Main Ideas

1. **Describe** how the plasma membrane helps maintain homeostasis in a cell.
2. **Explain** how the inside of a cell remains separate from its environment.
3. **Diagram** the plasma membrane and label each component.
4. **Identify** the molecules in the plasma membrane that provide basic membrane structure, cell identity, and membrane fluidity.

Think Critically

5. **Explain** what effect more cholesterol in the plasma membrane will have on the membrane.

WRITING in Biology

6. Using what you know about the term *mosaic*, write a paragraph describing another biological mosaic.

Online Quiz

Section 3

Reading Preview

Essential Questions

- What are the structures of a typical eukaryotic cell, and what are their functions?
- What are the similarities and differences between plant and animal cells?

Review Vocabulary

enzyme: a protein that speeds up the rate of a chemical reaction

New Vocabulary

cytoplasm
cytoskeleton
ribosome
nucleolus
endoplasmic reticulum
Golgi apparatus
vacuole
lysosome
centriole
mitochondrion
chloroplast
cell wall
cilium
flagellum

Multilingual eGlossary

Structures and Organelles

MAIN Idea **Eukaryotic cells contain organelles that allow the specialization and the separation of functions within the cell.**

Real-World Reading Link Suppose you start a company to manufacture hiking boots. Each pair of boots could be made individually by one person, but it would be more efficient to use an assembly line. Similarly, eukaryotic cells have specialized structures that perform specific tasks, much like a factory.

Cytoplasm and Cytoskeleton

You just have investigated the part of a cell that functions as the boundary between the inside and outside environments. The environment inside the plasma membrane is a semifluid material called **cytoplasm.** In a prokaryotic cell, all of the chemical processes of the cell, such as breaking down sugar to generate the energy used for other functions, take place directly in the cytoplasm. Eukaryotic cells perform these processes within organelles in their cytoplasm. At one time, scientists thought that cell organelles floated in a sea of cytoplasm.

More recently, cell biologists have discovered that organelles do not float freely in a cell, but are supported by a structure within the cytoplasm similar to the structure shown in **Figure 8.** The **cytoskeleton** is a supporting network of long, thin protein fibers that form a framework for the cell and provide an anchor for the organelles inside the cells. The cytoskeleton also has a function in cell movement and other cellular activities.

The cytoskeleton is made of substructures called microtubules and microfilaments. Microtubules are long, hollow protein cylinders that form a rigid skeleton for the cell and assist in moving substances within the cell. Microfilaments are thin protein threads that help give the cell shape and enable the entire cell or parts of the cell to move. Microtubules and microfilaments rapidly assemble and disassemble and slide past one another. This allows cells and organelles to move.

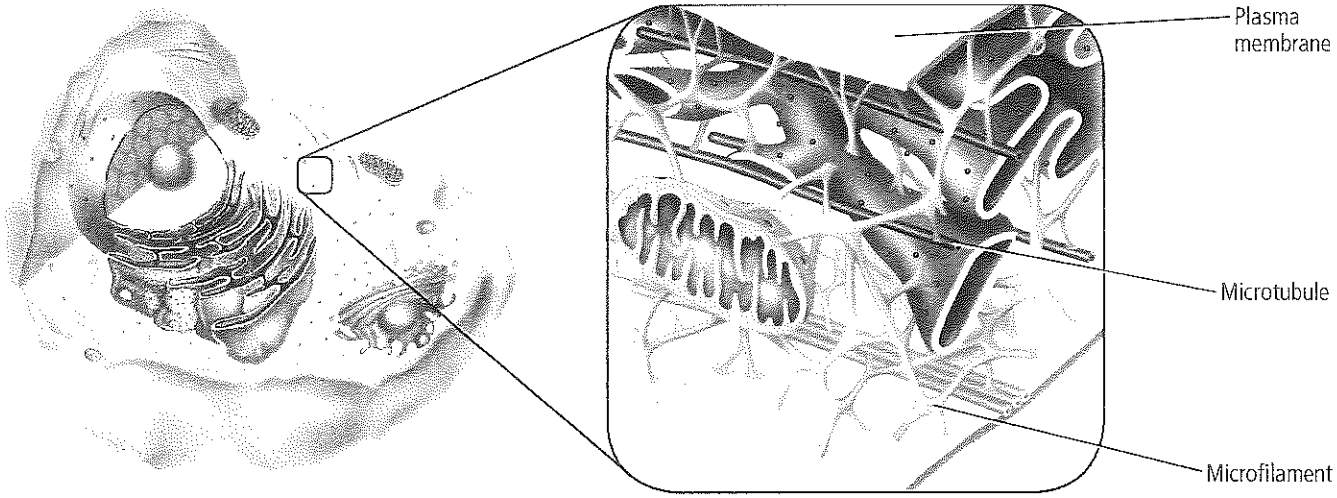
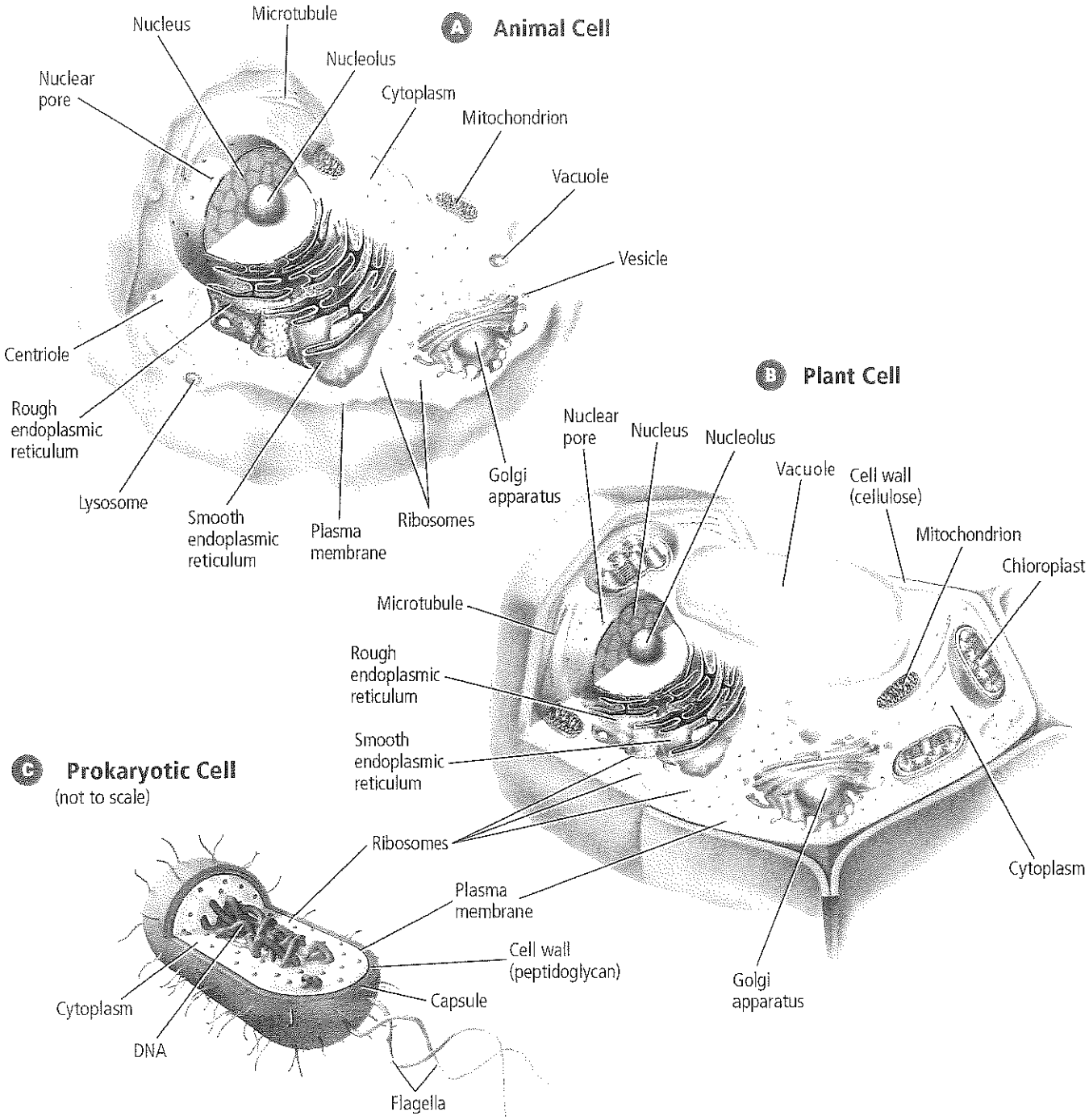


Figure 8 Microtubules and microfilaments make up the cytoskeleton.

Visualizing Cells

Figure 9

Compare the illustrations of a plant cell, animal cell, and prokaryotic cell. Some organelles are found only in plant cells; others are found only in animal cells. Prokaryotic cells do not have membrane-bound organelles.



Animation

Cell Structures

In a factory, there are separate areas set up for performing different tasks. Eukaryotic cells also have separate areas for tasks. Membrane-bound organelles make it possible for different chemical processes to take place at the same time in different parts of the cytoplasm. Organelles carry out essential cell processes, such as protein synthesis, energy transformation, digestion of food, excretion of wastes, and cell division. Each organelle has a unique structure and function. You can compare organelles to a factory's offices, assembly lines, and other important areas that keep the factory running. As you read about the different organelles, refer to the diagrams of plant and animal cells in **Figure 9** to see the organelles of each type.

The nucleus Just as a factory needs a manager, a cell needs an organelle to direct the cell processes. The nucleus, shown in **Figure 10,** is the cell's managing structure. It contains most of the cell's DNA, which stores information used to make proteins for cell growth, function, and reproduction.

The nucleus is surrounded by a double membrane called the nuclear envelope. The nuclear envelope is similar to the plasma membrane, except the nuclear membrane has nuclear pores that allow larger-sized substances to move in and out of the nucleus. Chromatin, which is a complex DNA attached to protein, is spread throughout the nucleus.

Reading Check **Describe** the role of the nucleus.

Ribosomes One of the functions of a cell is to produce proteins. The organelles that help manufacture proteins are called **ribosomes.** Ribosomes are made of two components–RNA and protein–and are not bound by a membrane like other organelles are. Within the nucleus is the site of ribosome production called the **nucleolus,** shown in **Figure 10.**

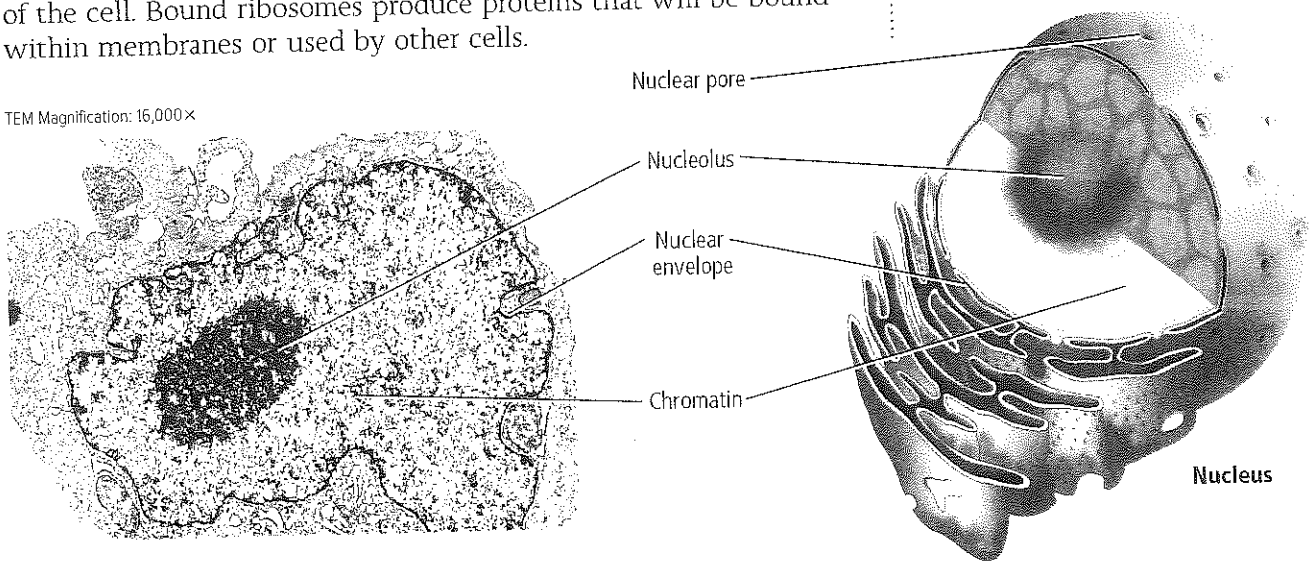
Cells have many ribosomes that produce a variety of proteins that are used by the cell or are moved out and used by other cells. Some ribosomes float freely in the cytoplasm, while others are bound to another organelle called the endoplasmic reticulum. Free-floating ribosomes produce proteins for use within the cytoplasm of the cell. Bound ribosomes produce proteins that will be bound within membranes or used by other cells.

VOCABULARY

Cytoplasm
Cytoskeleton
cyte- prefix; from Greek, meaning *cell*

BrainPOP

Figure 10 The nucleus of a cell is a three-dimensional shape. The photomicrograph shows a cross section of a nucleus. **Infer** ***why all of the cross sections of a nucleus are not identical.***



Dr. Gopal Murti/Science Source

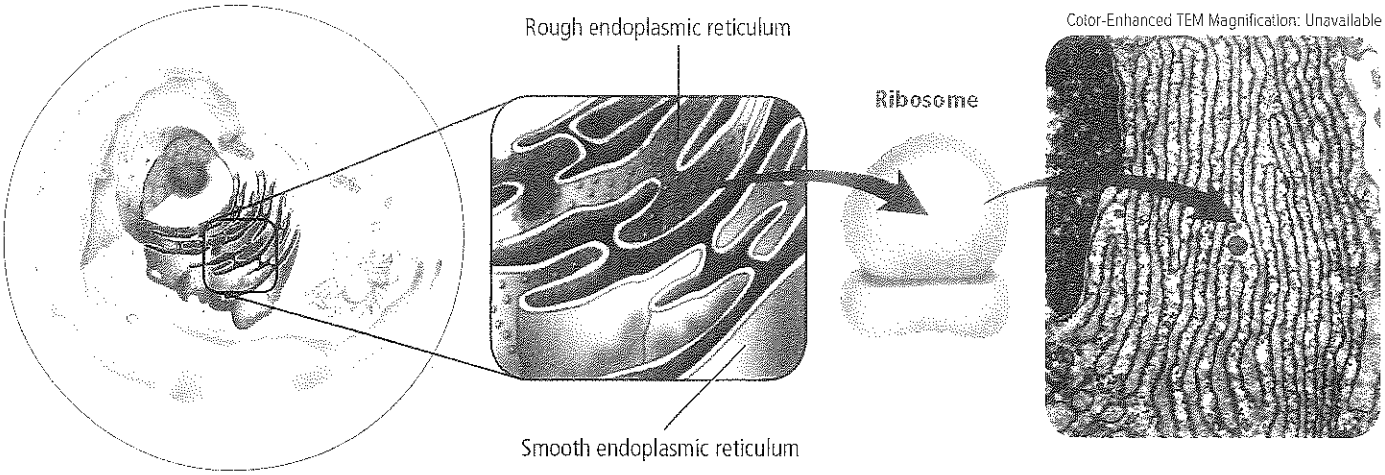


Figure 11 Ribosomes are simple structures made of RNA and protein that may be attached to the surface of the rough endoplasmic reticulum. They look like bumps on the endoplasmic reticulum.

Endoplasmic reticulum The **endoplasmic reticulum** (en duh PLAZ mihk • rih TIHK yuh lum), also called ER, is a membrane system of folded sacs and interconnected channels that serves as the site for protein and lipid synthesis. The pleats and folds of the ER provide a large amount of surface area where cellular functions can take place. The area of ER where ribosomes are attached is called rough endoplasmic reticulum. Notice in **Figure 11** that the rough ER appears to have bumps on it. These bumps are the attached ribosomes that will produce proteins for export to other cells.

Figure 11 also shows that there are areas of the ER that do not have ribosomes attached. The area of ER where no ribosomes are attached is called smooth endoplasmic reticulum. Although the smooth ER has no ribosomes, it does perform important functions for the cell. For example, the smooth ER provides a membrane surface where a variety of complex carbohydrates and lipids, including phospholipids, are synthesized. Smooth ER in the liver detoxifies harmful substances.

Virtual Lab

DATA ANALYSIS LAB 2

Based on Real Lab Data*

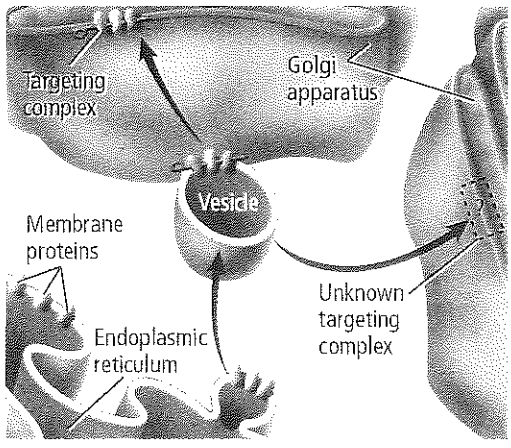
Interpret the Data

How is vesicle traffic from the ER to the Golgi apparatus regulated? Some proteins are synthesized by ribosomes on the endoplasmic reticulum (ER). The proteins are processed in the ER, and vesicles containing these proteins pinch off and migrate to the Golgi apparatus. Scientists currently are studying the molecules that are involved in fusing these vesicles to the Golgi apparatus.

Think Critically

1. **Interpret the diagram** by naming two complexes on the Golgi apparatus that might be involved in vesicle fusion.
2. **Hypothesize** an explanation for vesicle transport based on what you have read about cytoplasm and the cytoskeleton.

Data and Observations



*Data obtained from: Brittle, E. E., and Waters, M. G. 2000. ER-to-golgi traffic—this bud's for you. *Science* 289: 403–404.

MedImage/Science Source

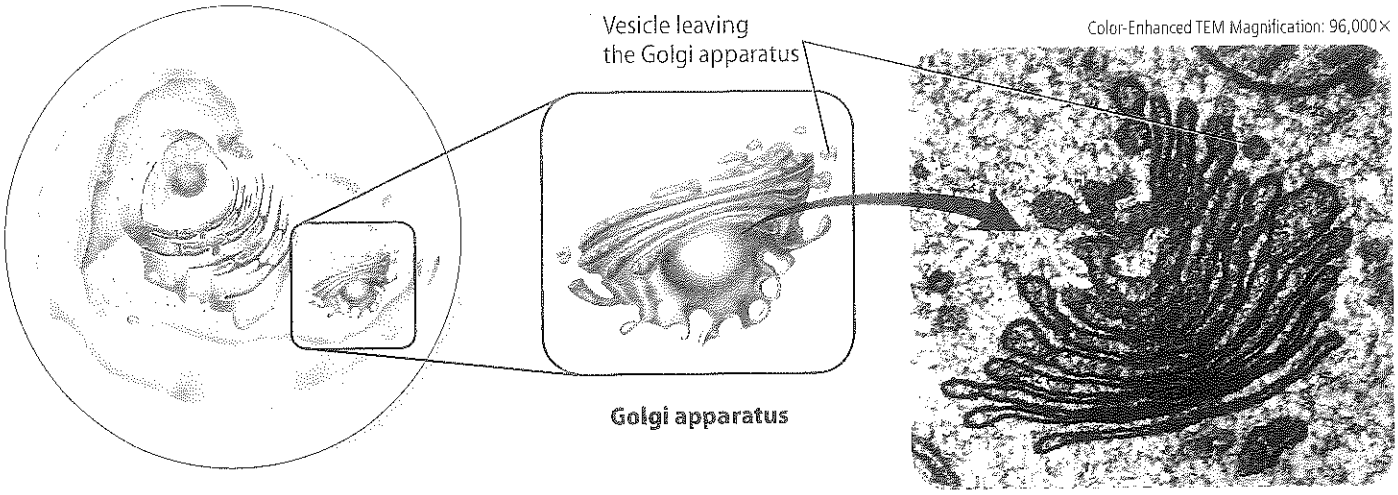
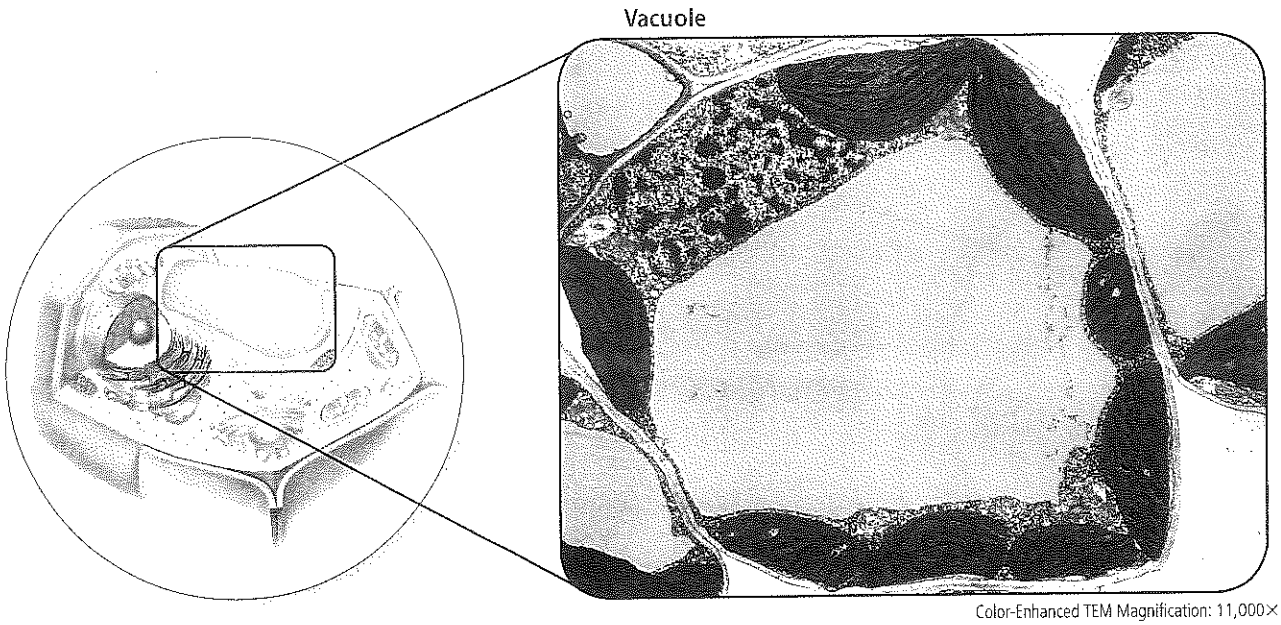


Figure 12 Flattened stacks of membranes make up the Golgi apparatus.

Golgi apparatus After hiking boots are made in a factory, they must be organized into pairs, boxed, and shipped. Similarly, after proteins are made in the endoplasmic reticulum, some might be transferred to the Golgi (GAWL jee) apparatus, illustrated in **Figure 12.** The **Golgi apparatus** is a flattened stack of membranes that modifies, sorts, and packages proteins into sacs called vesicles. Vesicles then can fuse with the cell's plasma membrane to release proteins to the environment outside the cell. Observe the vesicle in **Figure 12.**

Vacuoles A factory needs a place to store materials and waste products. Similarly, cells have membrane-bound vesicles called vacuoles for temporary storage of materials within the cytoplasm. A **vacuole,** such as the plant vacuole shown in **Figure 13,** is a sac used to store food, enzymes, and other materials needed by a cell. Some vacuoles store waste products. Interestingly, animal cells usually do not contain vacuoles. If animal cells do have vacuoles, they are much smaller than those in plant cells.

Figure 13 Plant cells have large membrane-bound storage compartments called vacuoles.



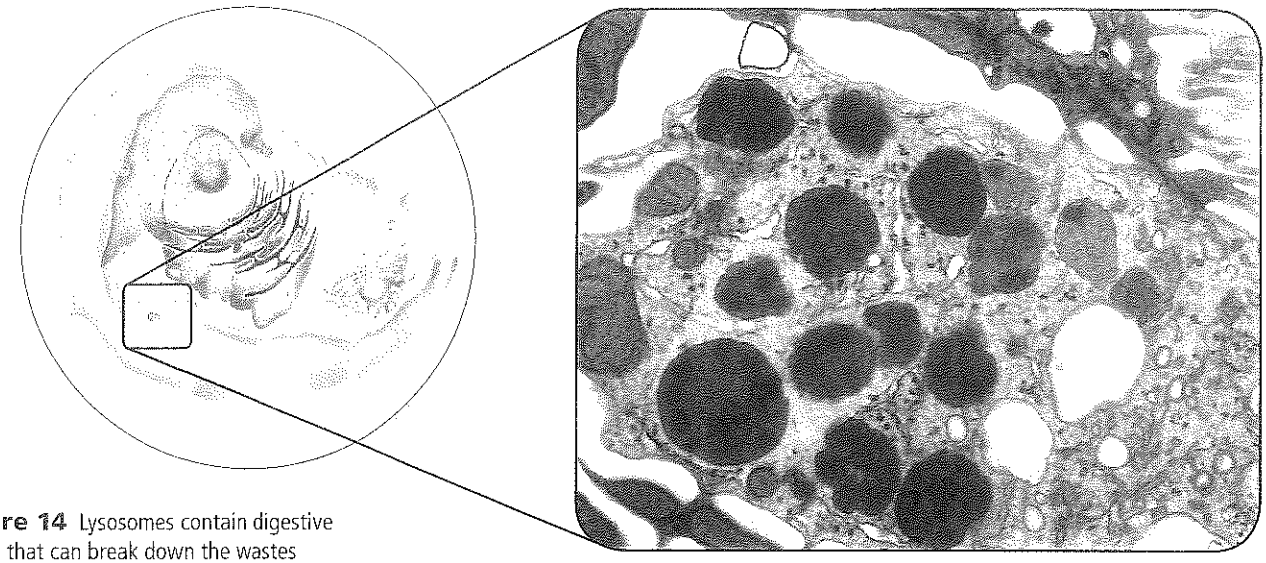
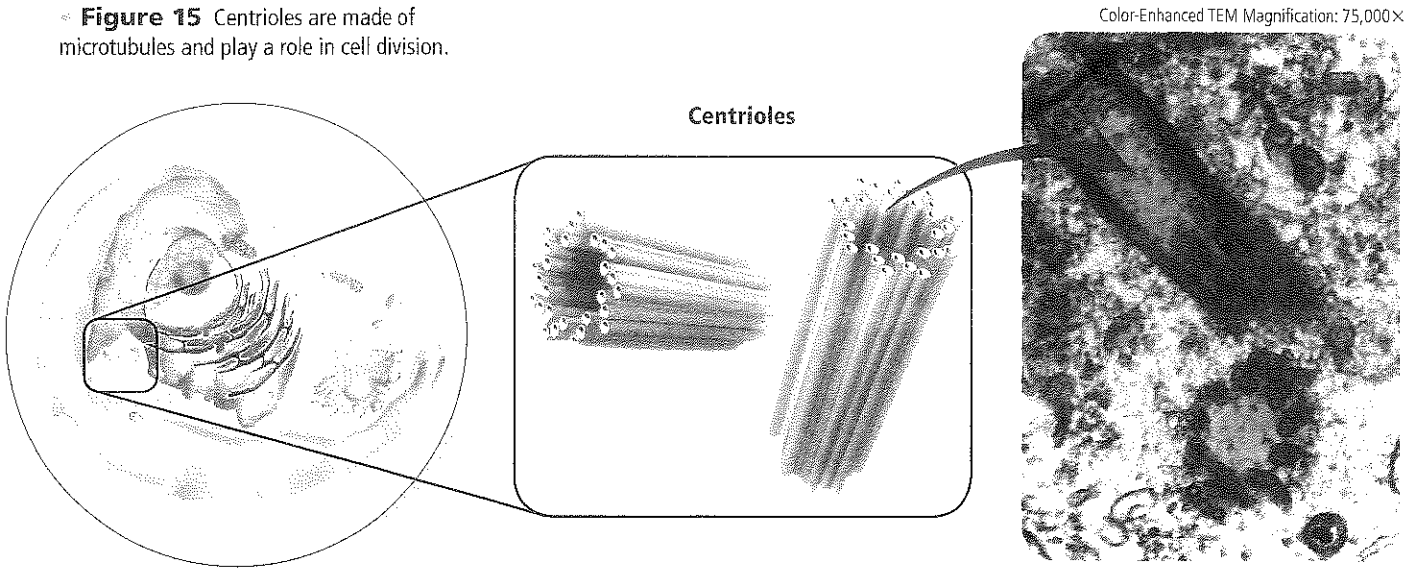


Figure 14 Lysosomes contain digestive enzymes that can break down the wastes contained in vacuoles.

Lysosomes Factories and cells also need cleanup crews. In a cell, there are **lysosomes,** shown in **Figure 14,** which are vesicles that contain substances that digest excess or worn-out organelles and food particles. Lysosomes also digest bacteria and viruses that have entered the cell. The membrane surrounding a lysosome prevents the digestive enzymes inside from destroying the cell. Lysosomes can fuse with vacuoles and dispense their enzymes into the vacuoles. These enzymes digest the wastes inside.

Centrioles Previously in this section, you read about microtubules and the cytoskeleton. Groups of microtubules form another structure called a centriole (SEN tree ol). **Centrioles,** shown in **Figure 15,** are organelles made of microtubules that function during cell division. Centrioles are located in the cytoplasm of animal cells and most protists and usually are near the nucleus.

Figure 15 Centrioles are made of microtubules and play a role in cell division.



(t)EM Research Services, Newcastle University; (b) Biophoto Associates/Science Source

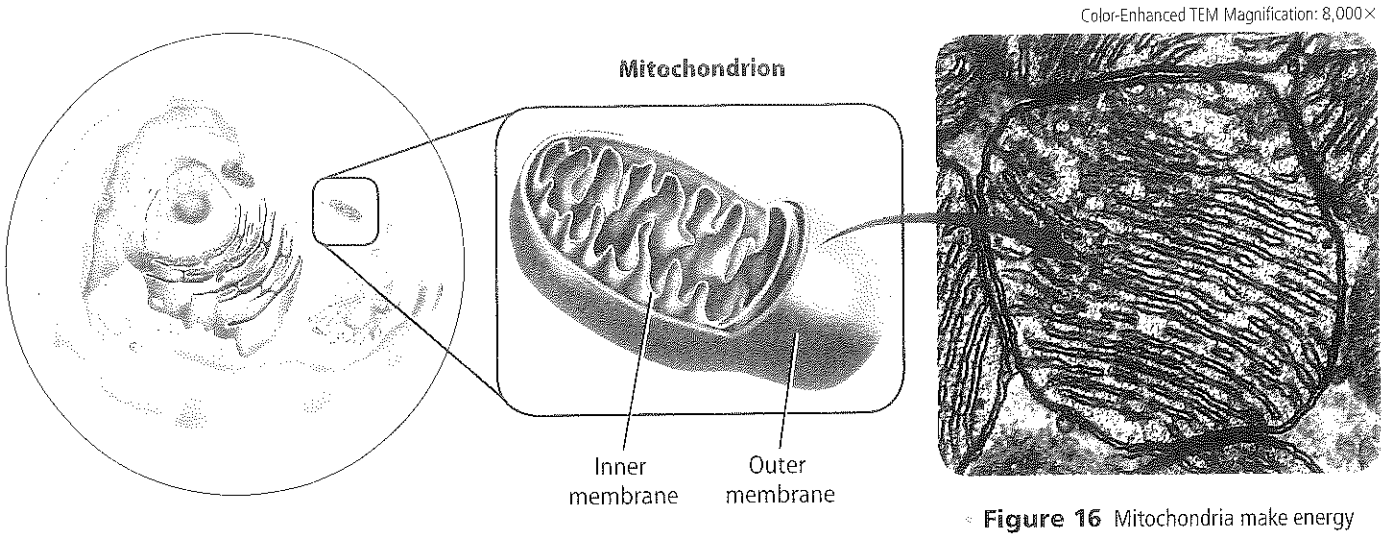


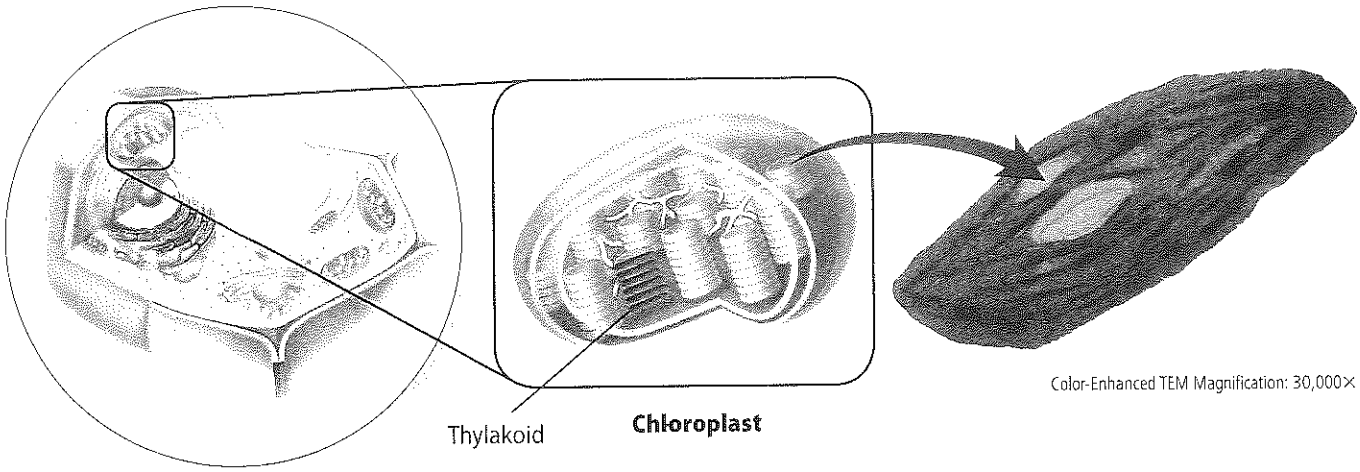
Figure 16 Mitochondria make energy available to the cell.
Describe *the membrane structure of a mitochondrion.*

Mitochondria Imagine now that a boot factory has its own generator that produces the electricity it needs. Cells also have energy generators called **mitochondria** (mi tuh KAHN dree uh; singular, mitochondrion), which convert fuel particles (mainly sugars) into usable energy. **Figure 16** shows that a mitochondrion has an outer membrane and a highly folded inner membrane that provides a large surface area for breaking the bonds in sugar molecules. The energy produced from that breakage is stored in the bonds of other molecules and later used by the cell. For this reason, mitochondria often are referred to as the "powerhouses" of cells.

Chloroplasts Factory machines need electricity that is generated by burning fossil fuels or by collecting energy from alternative sources, such as the Sun. Plant cells have their own way of using solar energy. In addition to mitochondria, plants and some other eukaryotic cells contain **chloroplasts,** which are organelles that capture light energy and convert it to chemical energy through a process called photosynthesis. Examine **Figure 17** and notice that inside the inner membrane are many small, disk-shaped compartments called thylakoids. It is there that the energy from sunlight is trapped by a pigment called chlorophyll. Chlorophyll gives leaves and stems their green color.

Chloroplasts belong to a group of plant organelles called plastids, some of which are used for storage. Some plastids store starches or lipids. Others, such as chromoplasts, contain red, orange, or yellow pigments that trap light energy and give color to plant structures such as flowers and leaves.

Figure 17 In plants, chloroplasts capture and convert light energy to chemical energy.



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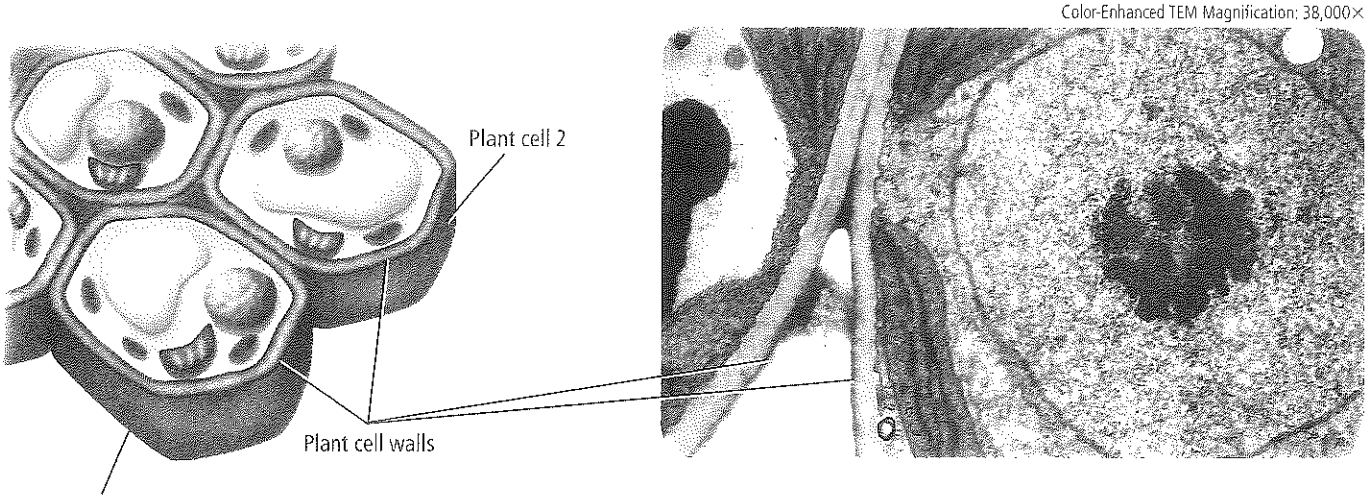

Figure 18 The illustration shows plant cells and their cell walls. Compare this to the transmission electron micrograph showing the cell walls of adjacent plant cells.

Cell wall Another structure associated with plant cells is the cell wall, shown in **Figure 18.** The **cell wall** is a thick, rigid, mesh of fibers that surrounds the outside of the plasma membrane, protects the cell, and gives it support. Rigid cell walls allow plants to stand at various heights—from blades of grass to California redwood trees. Plant cell walls are made of a carbohydrate called cellulose, which gives the cell walls their inflexible characteristics. **Table 1** summarizes cell walls and various other cell structures.

Cilia and flagella Some eukaryotic cell surfaces have structures called cilia and flagella that project outside the plasma membrane. As shown in **Figure 19, cilia** (singular, cilium) are short, numerous projections that look like hairs. The motion of cilia is similar to the motion of oars in a rowboat. **Flagella** (singular, flagellum) are longer and less numerous than cilia. These projections move with a whiplike motion. Cilia and flagella are composed of microtubules arranged in a 9 + 2 configuration, in which nine pairs of microtubules surround two single microtubules. Typically, a cell has one or two flagella.

Prokaryotic cilia and flagella contain cytoplasm and are enclosed by the plasma membrane. These structures are made of complex proteins. While both structures are used for cell movement, cilia are also found on stationary cells.

Figure 19 The hairlike structures in the photomicrograph are cilia, and the tail-like structures are flagella. Both structures function in cell movement.

Infer *where in the body of an animal you would predict cilia might be found.*

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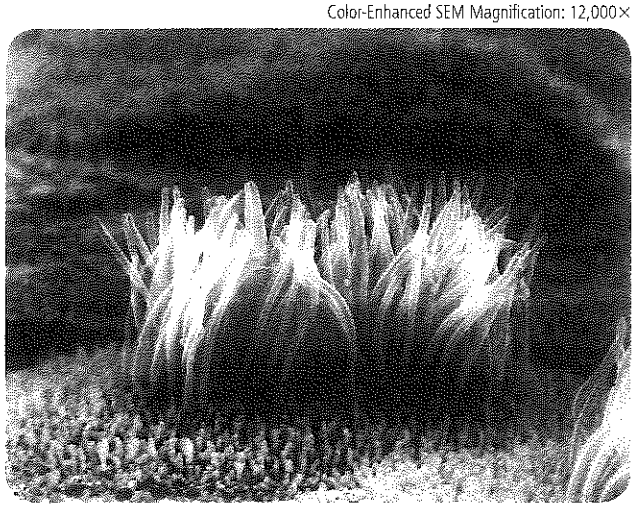

Cilia on the surface of a *Paramecium*

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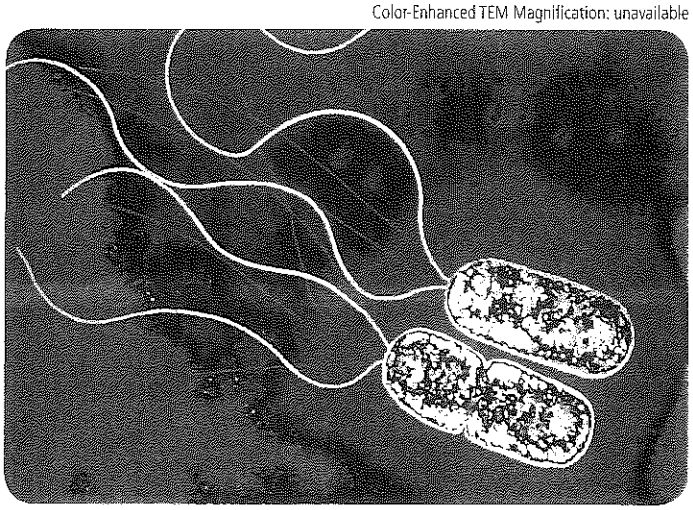
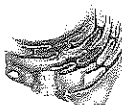
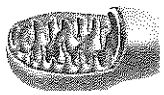


Bacteria with flagella

Table 1 Summary of Cell Structures

Interactive Table

Cell Structure	Example	Function	Cell Type
Cell wall		An inflexible barrier that provides support and protects the plant cell	Plant cells, fungi cells, and some prokaryotes
Centrioles		Organelles that occur in pairs and are important for cell division	Animal cells and most protist cells
Chloroplast		A double-membrane organelle with thylakoids containing chlorophyll; where photosynthesis takes place	Plant cells and some protist cells
Cilia		Projections from cell surfaces that aid in locomotion and feeding; also used to sweep substances along surfaces	Some animal cells, protist cells, and prokaryotes
Cytoskeleton		A framework for the cell within the cytoplasm	All eukaryotic cells
Endoplasmic reticulum		A highly folded membrane that is the site of protein synthesis	All eukaryotic cells
Flagella		Projections that aid in locomotion and feeding	Some animal cells, prokaryotes, and some plant cells
Golgi apparatus		A flattened stack of tubular membranes that modifies proteins and packages them for distribution outside the cell	All eukaryotic cells
Lysosome		A vesicle that contains digestive enzymes for the breakdown of excess or worn-out cellular substances	Animal cells and rare in plant cells
Mitochondrion		A membrane-bound organelle that makes energy available to the rest of the cell	All eukaryotic cells
Nucleus		The control center of the cell that contains coded directions for the production of proteins and cell division	All eukaryotic cells
Plasma membrane		A flexible boundary that controls the movement of substances into and out of the cell	All cells
Ribosome		Organelle that is the site of protein synthesis	All cells
Vacuole		A membrane-bound vesicle for the temporary storage of materials	Plant cells–one large; rarely animal cells–a few small

Comparing Cells

Table 1 summarizes the structures of eukaryotic plant cells and animal cells. Notice that plant cells contain chlorophyll; they can capture and transform energy from the Sun into a usable form of chemical energy. This is one of the main characteristics that distinguishes plants from animals. In addition, recall that animal cells usually do not contain vacuoles. If they do, vacuoles in animal cells are much smaller than vacuoles in plant cells. Also, animal cells do not have cell walls. Cell walls give plant cells protection and support.

Organelles at Work

With a basic understanding of the structures found within a cell, it becomes easier to envision how those structures work together to perform cell functions. Take, for example, the synthesis of proteins.

Protein synthesis begins in the nucleus with the information contained in the DNA. Genetic information is copied and transferred to another genetic molecule called RNA. Then RNA and ribosomes, which have been manufactured in the nucleolus, leave the nucleus through the pores of the nuclear membrane. Together, RNA and ribosomes manufacture proteins. Each protein made on the rough ER has a particular function; it might become a protein that forms a part of the plasma membrane, a protein that is released from the cell, or a protein transported to other organelles. Other ribosomes will float freely in the cytoplasm and also make proteins.

Most of the proteins made on the surface of the ER are sent to the Golgi apparatus. The Golgi apparatus packages the proteins in vesicles and transports them to other organelles or out of the cell. Other organelles use the proteins to carry out cell processes. For example, lysosomes use proteins, enzymes in particular, to digest food and waste. Mitochondria use enzymes to produce a usable form of energy for the cell.

After reading about the organelles in a cell, it becomes clear why people equate the cell to a factory. Each organelle has its job to do, and the health of the cell depends on all of the components working together.

CAREERS IN BIOLOGY

Science Communications Specialist Many publishers of scientific material hire communications specialists to write about research and its importance to the general public. This often is accomplished through press releases, ads, pamphlets, and targeted mailings.

Section 3 Assessment

Section Summary

- Eukaryotic cells contain membrane-bound organelles in the cytoplasm that perform cell functions.
- Ribosomes are the sites of protein synthesis.
- Mitochondria are the powerhouses of cells.
- Plant and animal cells contain many of the same organelles, while other organelles are unique to either plant cells or animal cells.

Understand Main Ideas

1. **Identify** the role of the nucleus in a eukaryotic cell.
2. **Summarize** the role of the endoplasmic reticulum.
3. **Create** a flowchart comparing the parts of a cell to an automobile production line.
4. **Compare and contrast** structures of plant and animal cells.

Think Critically

5. **Hypothesize** how lysosomes would be involved in changing a caterpillar into a butterfly.

WRITING in Biology

6. Categorize the structures and organelles in **Table 1** into lists based on cell type and then draw a concept map illustrating your organization.

Online Quiz

Section 4

Reading Preview

Essential Questions

- What are the processes of diffusion, facilitated diffusion, and active transport?
- What is the effect of a hypotonic, hypertonic, or isotonic solution on a cell?
- How do large particles enter and exit cells?

Review Vocabulary

homeostasis: the regulation of the internal environment of a cell or organism to maintain conditions suitable for life

New Vocabulary

diffusion
dynamic equilibrium
facilitated diffusion
osmosis
isotonic solution
hypotonic solution
hypertonic solution
active transport
endocytosis
exocytosis

Multilingual eGlossary

Cellular Transport

MAIN IDEA **Cellular transport moves substances within the cell and moves substances into and out of the cell.**

Real-World Reading Link Imagine studying in your room while cookies are baking in the kitchen. You probably did not notice when the cookies were put into the oven because you could not smell them. But, as the cookies baked, the movement of the aroma from the kitchen to your room happened through a process called diffusion.

Diffusion

Connection to Chemistry As the aroma of baking cookies makes its way to you, the particles are moving and colliding with each other in the air. This happens because the particles in gases, liquids, and solids are in random motion. Similarly, substances dissolved in water move constantly in random motion called Brownian motion. This random motion causes **diffusion,** which is the net movement of particles from an area where there are many particles of the substance to an area where there are fewer particles of the substance. The amount of a substance in a particular area is called concentration. Therefore, substances diffuse from areas of high concentration to low concentration. **Figure 20** illustrates the process of diffusion. Additional energy input is not required for diffusion because the particles already are in motion.

For example, if you drop red and blue ink into a container of water at opposite ends of the container, which is similar to the watery environment of a cell, the process of diffusion begins, as shown in **Figure 20(A).** In a short period of time, the ink particles have mixed as a result of diffusion to the point where a purple-colored blended area is visible. **Figure 20(B)** shows the initial result of this diffusion.

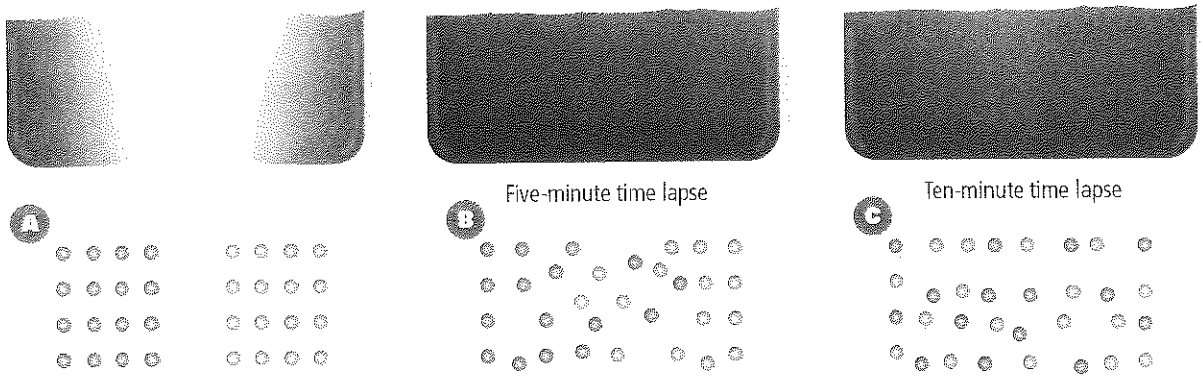


Figure 20 Diffusion causes the inks to move from high-ink concentration to low-ink concentration until the colors become evenly blended in the water.

VOCABULARY

Concentration
the amount of a component in a given area or volume
The concentration of salt in the aquarium was too high, causing the fishes to die.

Given more time, the ink particles continue to mix and, in this case, continue to form the uniform purple mixture shown in **Figure 20(C).** Mixing continues until the concentrations of red ink and blue ink are the same in all areas. The final result is the purple solution. After this point, the particles continue to move randomly, but no further change in concentration will occur. This condition, in which there is continuous movement but no overall change, is called **dynamic equilibrium.**

One of the key characteristics of diffusion is the rate at which diffusion takes place. Three main factors affect the rate of diffusion: concentration, temperature, and pressure. When concentration is high, diffusion occurs more quickly because there are more particles that collide. Similarly, when temperature or pressure increases, the number of collisions increases, thus increasing the rate of diffusion. Recall that at higher temperatures particles move faster, and at higher pressure the particles are closer together. In both cases, more collisions occur and diffusion is faster. The size and charge of a substance also affects the rate of diffusion.

FOLDABLES
Incorporate information from this section into your Foldable.

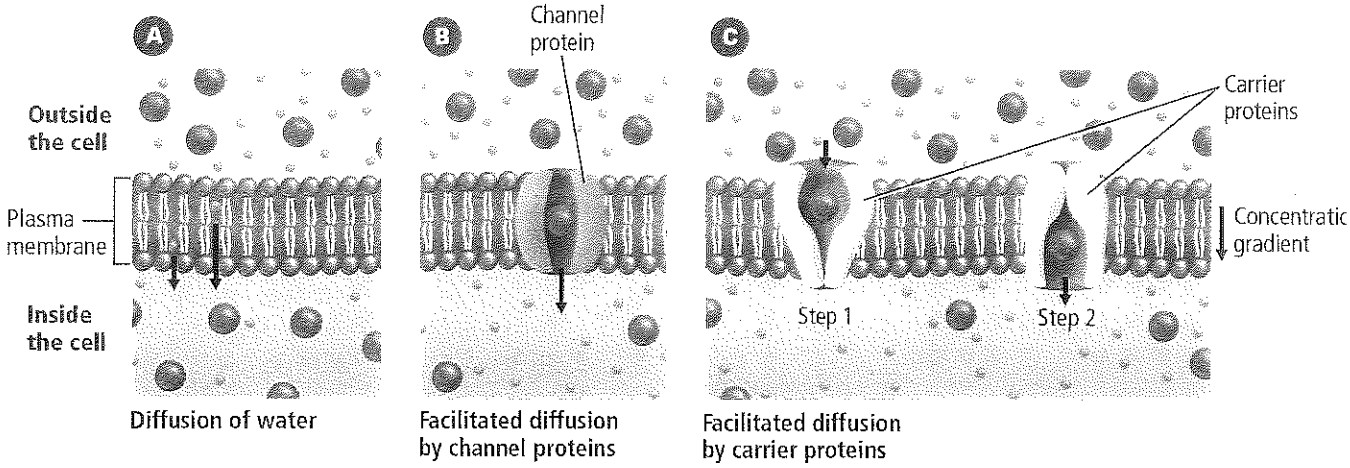
Diffusion across the plasma membrane In addition to water, cells need certain ions and small molecules, such as chloride ions and sugars, to perform cellular functions. Water can diffuse across the plasma membrane, as shown in **Figure 21(A),** but most other substances cannot. Another form of transport, called **facilitated diffusion,** uses transport proteins to move other ions and small molecules across the plasma membrane. By this method, substances move into the cell through a water-filled transport protein, called a channel protein, that opens and closes to allow the substance to diffuse through the plasma membrane, as shown in **Figure 21(B).** Another type of transport protein, called a carrier protein, also can help substances diffuse across the plasma membrane. Carrier proteins change shape as the diffusion process continues to help move the particle through the membrane, as illustrated in **Figure 21(C).**

Diffusion of water and facilitated diffusion of other substances require no additional input of energy because the particles are moving from an area of high concentration to an area of lower concentration. This is also known as passive transport. You will learn later in this section about a form of cellular transport that does require energy input.

Reading Check **Describe** how sodium (Na^+) ions get into cells.

Figure 21 Although water moves freely through the plasma membrane, other substances cannot pass through the phospholipid bilayer on their own. Such substances enter the cell by facilitated transport.

Animation



Osmosis: Diffusion of Water

Water is a substance that passes freely into and out of a cell through the plasma membrane. The diffusion of water across a selectively permeable membrane is called **osmosis** (ahs MOH sus). Regulating the movement of water across the plasma membrane is an important factor in maintaining homeostasis within the cell.

How osmosis works Recall that in a solution, a substance called the solute is dissolved in a solvent. Water is the solvent in a cell and its environment. Concentration is a measure of the amount of solute dissolved in a solvent. The concentration of a solution decreases when the amount of solvent increases.

Examine **Figure 22,** showing a U-shaped tube containing solutions with different sugar concentrations separated by a selectively permeable membrane. What will happen if the solvent (water) can pass through the membrane but the solute (sugar) cannot?

Water molecules diffuse toward the side with the greater sugar concentration–the right side. As water moves to the right, the concentration of the sugar solution decreases. The water continues to diffuse until dynamic equilibrium occurs–the concentration of the solutions is the same on both sides. Notice in **Figure 22** that the result is an increase in solution level on the right side. During dynamic equilibrium, water molecules continue to diffuse back and forth across the membrane. But, the concentrations on each side no longer change.

Reading Check **Compare and contrast** diffusion and osmosis.

Mini Lab 2

MiniLab

Investigate Osmosis

What will happen to cells placed in a strong salt solution? Regulating the flow and amount of water into and out of a cell is critical to the survival of that cell. Osmosis is one method used to regulate a cell's water content.

Procedure

1. Read and complete the lab safety form.
2. Prepare a control **slide** using **onion epidermis, water,** and **iodine stain** as directed by your teacher.
3. Prepare a test slide using onion epidermis, **salt water,** and iodine stain as directed by your teacher.
4. Predict the effect, if any, that the salt solution will have on the onion cells in the test slide.
5. View the control slide using a **compound microscope** under low power and sketch several onion cells.
6. View the test slide under the same magnification and sketch your observations.

Analysis

1. **Analyze and conclude** whether your prediction was correct or incorrect. Explain.
2. **Explain** Use the process of osmosis to explain what you observe.

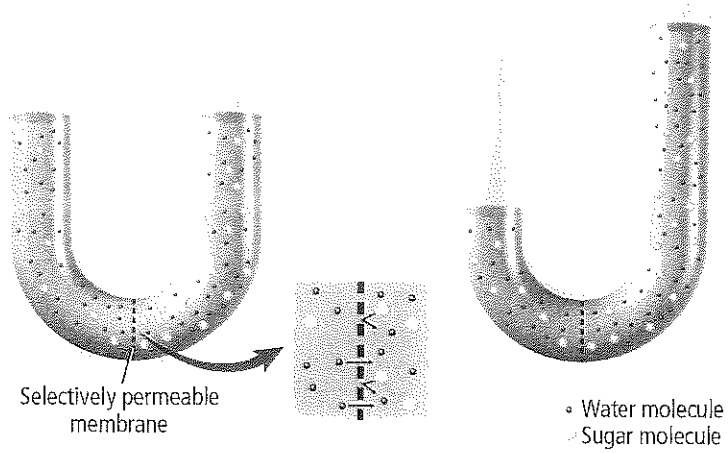
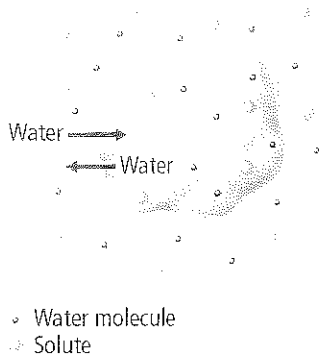


Figure 22 Before osmosis, the sugar concentration is greater on the right side. After osmosis, the concentrations are the same on both sides.
Name *the term for this phenomenon.*



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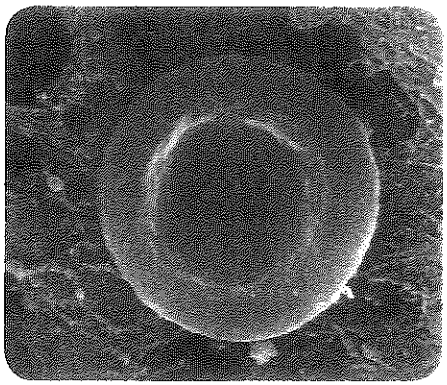

Animal cell

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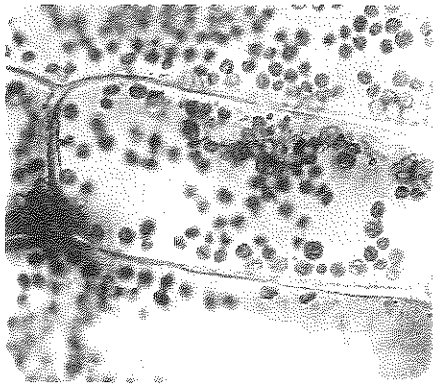


Plant cells

Figure 23 In an isotonic solution, water molecules move into and out of the cell at the same rate, and cells retain their normal shape. The animal cell and the plant cells have their normal shapes in an isotonic solution.

Animation

Cells in an isotonic solution When a cell is in a solution that has the same concentration of water and solutes–ions, sugars, proteins, and other substances–as its cytoplasm, the cell is said to be in an **isotonic solution.** *Iso-* comes from the Greek word meaning *equal.* Water still moves through the plasma membrane, but water enters and leaves the cell at the same rate. The cell is at equilibrium with the solution, and there is no net movement of water. The cells retain their normal shape, as shown in **Figure 23.** Most cells in organisms are in isotonic solutions, such as blood.

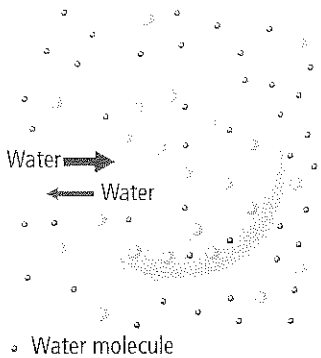
Cells in a hypotonic solution If a cell is in a solution that has a lower concentration of solute, the cell is said to be in a **hypotonic solution.** *Hypo-* comes from the Greek word meaning *under.* There is more water outside of the cell than inside. As a result of osmosis, the net movement of water through the plasma membrane is into the cell, as illustrated in **Figure 24.** Pressure generated as water flows through the plasma membrane is called osmotic pressure. In an animal cell, as water moves into the cell, the pressure increases and the plasma membrane swells. If the solution is extremely hypotonic, the plasma membrane might be unable to withstand this pressure and the cell might burst.

Because they have a rigid cell wall that supports them, plant cells do not burst when in a hypotonic solution. As the pressure inside a cell increases, the plant's central vacuole fills with water, pushing the plasma membrane against the cell wall, shown in the plant cells in **Figure 24.** Instead of bursting, the plant cell becomes firmer. Grocers use this process to keep produce looking fresh by misting fruits and vegetables with water.

APPLYING PRACTICES

Plan and Conduct an Investigation Go to the resources tab in ConnectED to find the Applying Practices worksheet *Investigating Osmosis.*

Figure 24 In a hypotonic solution, water enters a cell by osmosis, causing the cell to swell. Animal cells may continue to swell until they burst. Plant cells swell beyond their normal size as internal pressure increases.



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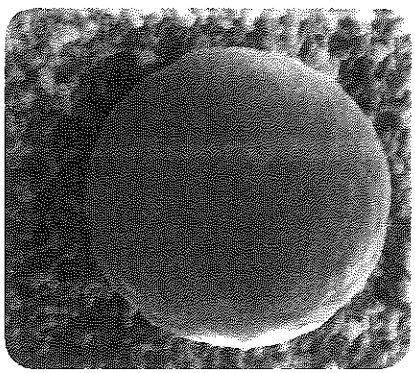
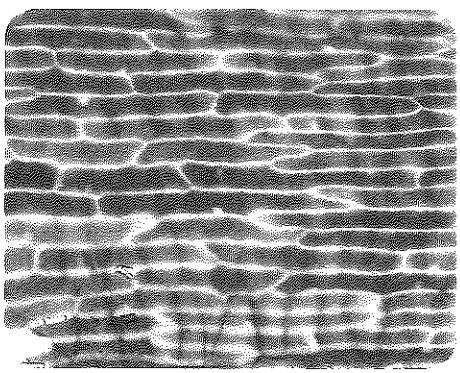


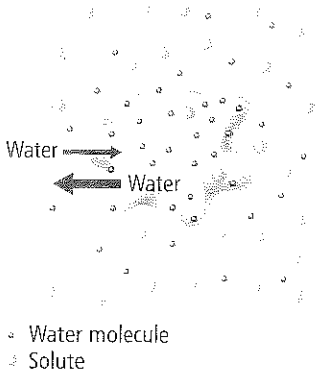
Animal cell

LM Magnification: 250×

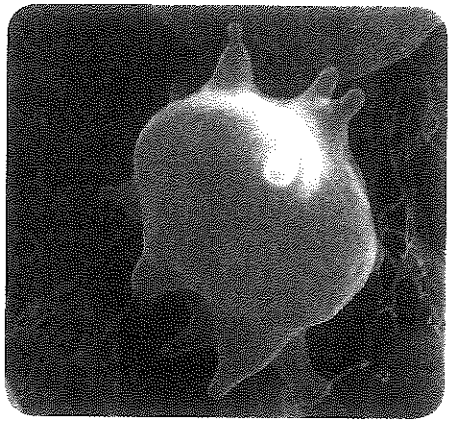


Plant cells

(t)David M. Phillips / Science Source; (tr)Ed Reschke/Peter Arnold/Getty Images; (b)David M. Phillips / Science Source; (br)Michael Abbey/Photo Researchers

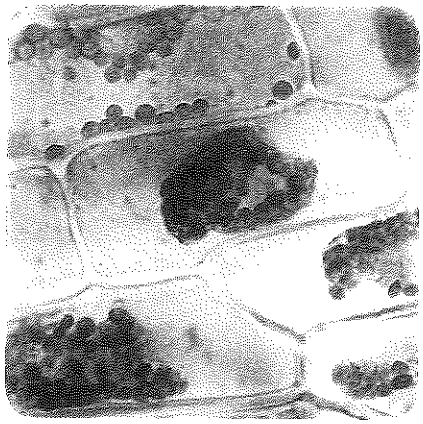


Color-Enhanced SEM Magnification: 15,000×



Animal cells

LM Magnification: 250×



Plant cells

Figure 25 In a hypertonic solution, water leaves a cell by osmosis, causing the cell to shrink. Animal cells shrivel up as they lose water. As plant cells lose internal pressure, the plasma membrane shrinks away from the cell wall.

Cells in a hypertonic solution When a cell is placed in a **hypertonic solution,** the concentration of the solute outside of the cell is higher than it is inside. *Hyper-* comes from the Greek word meaning *above.* During osmosis, the net movement of water is out of the cell, as illustrated in **Figure 25.** Animal cells in a hypertonic solution shrivel because of decreased pressure in the cells. Plant cells in a hypertonic solution lose water, mainly from the central vacuole. The plasma membrane shrinks away from the cell wall. Loss of water in a plant cell causes wilting.

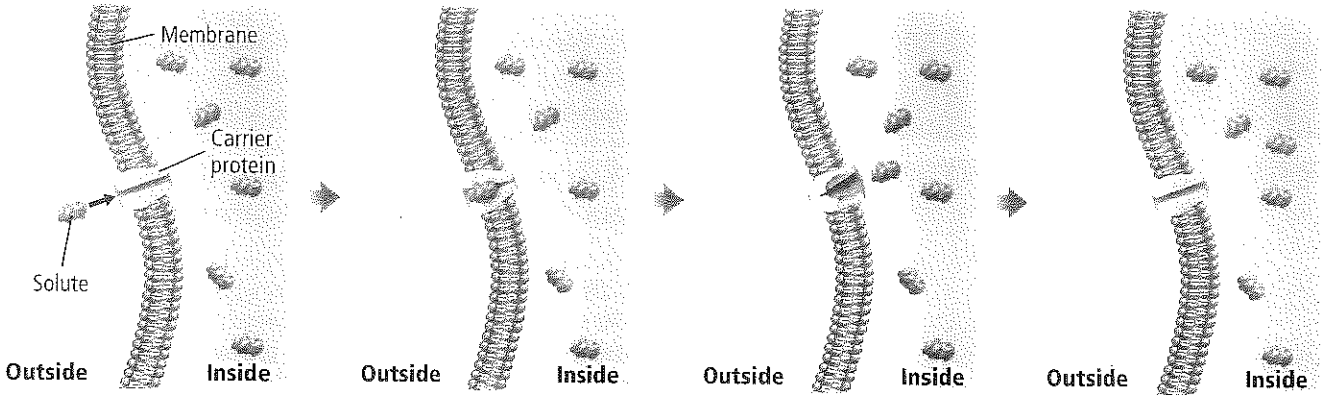
Reading Check **Compare and contrast** the three types of solutions.

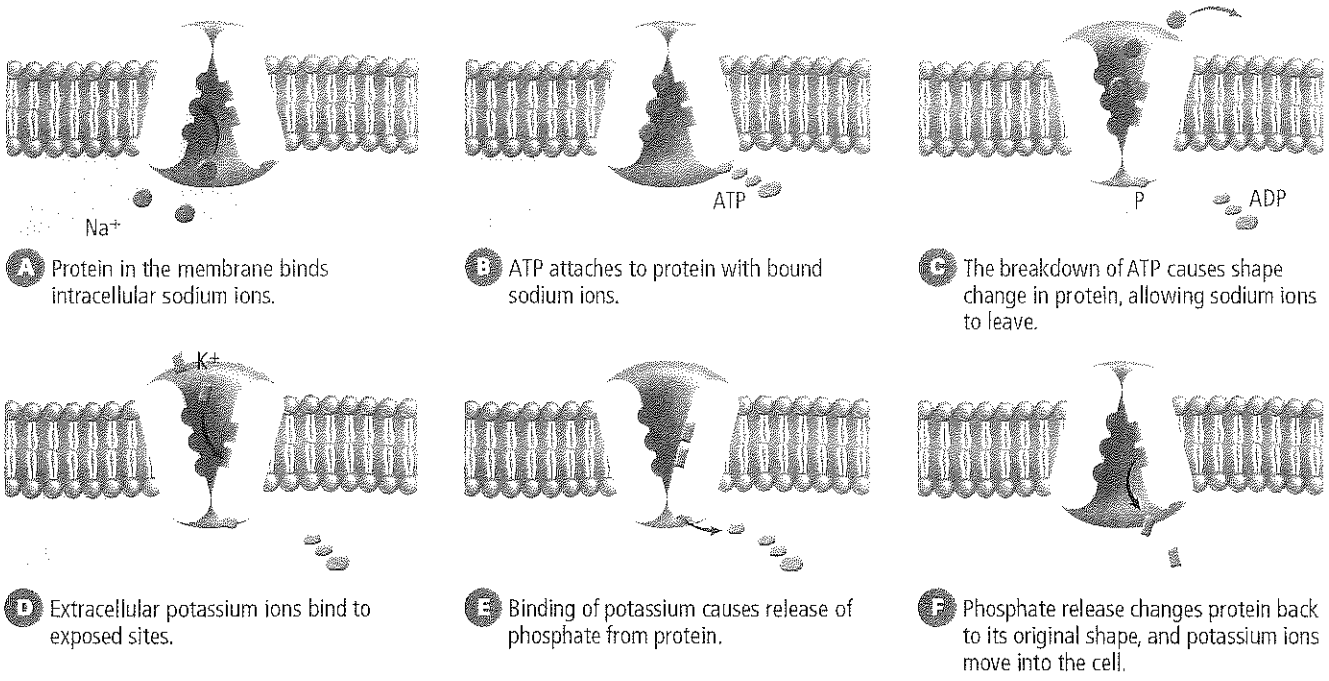
Active Transport

Sometimes substances must move from a region of lower concentration to a region of higher concentration against the passive movement from higher to lower concentration. This movement of substances across the plasma membrane against a concentration gradient requires energy; therefore, it is called **active transport. Figure 26** illustrates how active transport occurs with the aid of carrier proteins, commonly called pumps. Some pumps move one type of substance in only one direction, while others move two substances either across the membrane in the same direction or in opposite directions. Because of active transport, the cell maintains the proper balance of substances it needs. Active transport helps maintain homeostasis.

Figure 26 Carrier proteins pick up and move substances across the plasma membrane against the concentration gradient and into the cell.

Explain *why active transport requires energy.*





A Protein in the membrane binds intracellular sodium ions.

B ATP attaches to protein with bound sodium ions.

C The breakdown of ATP causes shape change in protein, allowing sodium ions to leave.

D Extracellular potassium ions bind to exposed sites.

E Binding of potassium causes release of phosphate from protein.

F Phosphate release changes protein back to its original shape, and potassium ions move into the cell.

Figure 27 Some cells use elaborate pumping systems, such as the Na^+/K^+ ATPase pump shown here, to help move substances through the plasma membrane.

Animation

Personal Tutor

Na^+/K^+ ATPase pump One common active transport pump is called the sodium-potassium ATPase pump. This pump is found in the plasma membrane of animal cells. The pump maintains the level of sodium ions (Na^+) and potassium ions (K^+) inside and outside the cell. This protein pump is an enzyme that catalyzes the breakdown of an energy-storing molecule. The pump uses the energy to transport three sodium ions out of the cell while moving two potassium ions into the cell. The high level of sodium on the outside of the cell creates a concentration gradient. Follow the steps in **Figure 27** to see the action of the Na^+/K^+ ATPase pump.

The activity of the Na^+/K^+ ATPase pump can result in yet another form of cellular transport. Substances, such as sugar molecules, must come into the cell from the outside, where the concentration of the substance is lower than it is inside. This requires energy. Recall, however, that the Na^+/K^+ ATPase pump moves Na^+ out of the cell, which creates a low concentration of Na^+ inside the cell. In a process called coupled transport, the Na^+ ions that have been pumped out of the cell can couple with sugar molecules and be transported into the cell through a membrane protein called a coupled channel. The sugar molecule, coupled to a Na^+ ion, enters the cell by facilitated diffusion of the sodium, as shown in **Figure 28.** As a result, sugar enters the cell without spending any additional cellular energy.

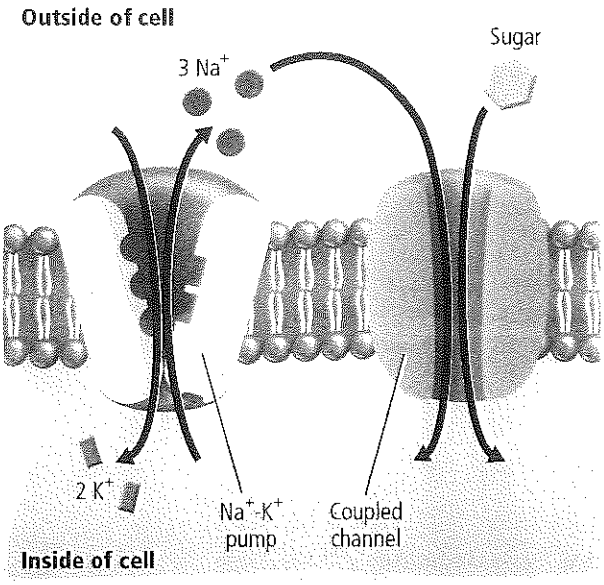


Figure 28 Substances "piggy-back" their way into or out of a cell by coupling with another substance that uses an active transport pump.
Compare and contrast ***active and passive transport across the plasma membrane.***

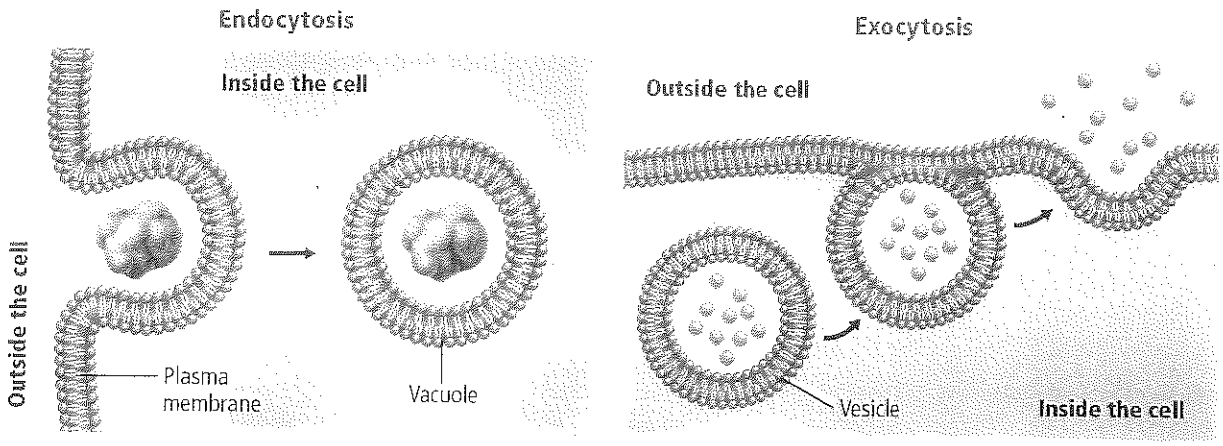


Figure 29
Left: Large substances can enter a cell by endocytosis.
Right: Substances can be deposited outside the cell by exocytosis.

Transport of Large Particles

Some substances are too large to move through the plasma membrane by diffusion or transport proteins and must get inside the cell by a different process. **Endocytosis** is the process by which a cell surrounds a substance in the outside environment, enclosing the substance in a portion of the plasma membrane. The membrane then pinches off and leaves the substance inside the cell. The substance shown on the left in **Figure 29** is engulfed and enclosed by a portion of the cell's plasma membrane. The membrane then pinches off inside of the cell, and the resulting vacuole, with its contents, moves to the inside of the cell.

Exocytosis is the secretion of materials at the plasma membrane. The illustration on the right in **Figure 29** shows that exocytosis is the reverse of endocytosis. Cells use exocytosis to expel wastes and to secrete substances, such as hormones, produced by the cell. Both endocytosis and exocytosis require the input of energy. Cells maintain homeostasis by moving substances into and out of the cell. Some transport processes require additional energy input, while others do not. Together, the different types of transport allow a cell to interact with its environment while maintaining homeostasis.

Section 4 Assessment

Section Summary

- Cells maintain homeostasis using passive and active transport.
- Concentration, temperature, and pressure affect the rate of diffusion.
- Cells must maintain homeostasis in all types of solutions, including isotonic, hypotonic, and hypertonic.
- Some large molecules are moved into and out of the cell using endocytosis and exocytosis.

Understand Main Ideas

1. **List and describe** the types of cellular transport.
2. **Describe** how the plasma membrane controls what goes into and comes out of a cell.
3. **Sketch** a before and an after diagram of an animal cell placed in a hypotonic solution.
4. **Contrast** how facilitated diffusion is different from active transport.

Think Critically

5. **Describe** Some organisms that normally live in pond water contain water pumps. These pumps continually pump water out of the cell. Describe a scenario that might reverse the action of the pump.
6. **Summarize** the role of the phospholipid bilayer in cellular transport in living cells.

Online Quiz

CUTTING-EDGE BIOLOGY

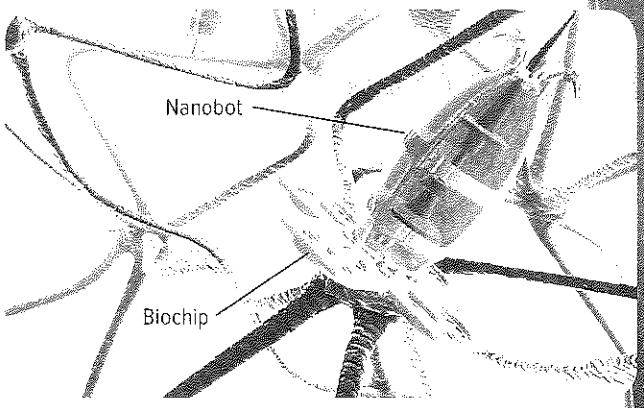
EXPLORING NANOTECHNOLOGY

Imagine that cancer cells could be detected and destroyed one by one, or that a new drug could be tested on a single cell to evaluate its clinical performance. Advances in technologies that allow scientists to focus on individual cells might make these scenarios a reality in the near future.

Nanotechnology (na no tek NAW luh jee) is the branch of science that deals with the development and use of devices on the nanometer scale. A nanometer (nm) is one billionth of a meter (10^{-9} m). To put this scale into perspective, consider that most human cells are between 10,000 and 20,000 nm in diameter. Nanotechnology is a fast-growing branch of science that likely will leave its mark on everything from electronics to medicine.

Atomic force microscopes At the National Institute of Advanced Industrial Science and Technology in Hyogo, Japan, researchers are using nanotechnology in the form of an atomic force microscope (AFM) to operate on single cells. The microscope is actually used as a "nanoneedle." The AFM creates a visual image of a cell using a microscopic sensor that scans the cell. Then the probe of the AFM, sharpened into a needle tip that is approximately 200 nm in diameter, can be inserted into the cell without damaging the cell membrane.

Some scientists envision many applications for this technique. The nanoneedle might help scientists study how a cell responds to a new drug or how the chemistry of a diseased cell differs from that of a healthy cell. Another application for the nanoneedle might be to insert DNA strands directly into the nucleus of a cell to test new gene therapy techniques that might correct genetic disorders.



This computer-generated image shows a nanobot armed with a biochip. Someday, a biochip, which is an electronic device that contains organic materials, might repair a damaged nerve cell.

Lasers Nanotechnology applications, perhaps in the form of nanosurgery, could be used to investigate how cells work or to destroy individual cancer cells without harming nearby healthy cells. Researchers at Harvard University have developed a laser technique that allows them to manipulate a specific component of the cell's internal parts without causing damage to the cell membrane or other cell structures. Imagine having the capability to perform extremely delicate surgery on a cellular level!

In the future, nanotechnology might be our first line of defense to treat cancer. It also might become the standard technique to test new drugs or even become a favored treatment used in gene therapy.

WRITING in Biology

Review Write an overview of one technology related to medicine and healthcare that you find interesting. Describe its advantages and challenges. You may include a presentation with your overview.

WebQuest

BIOLAB

WHICH SUBSTANCES WILL PASS THROUGH A SELECTIVELY PERMEABLE MEMBRANE?

Background: **All membranes in cells are selectively permeable. In this lab, you will examine the movement of some biologically important molecules through a dialysis membrane that is analogous to the plasma membrane. Because a dialysis membrane has tiny pores, it is permeable only for tiny molecules.**

Question: *Which substances pass through a dialysis membrane?*

Materials

cellulose dialysis tubing (2)
400-mL beakers (2)
string
scissors
distilled water
small plastic dishpan
starch solution
albumin solution
glucose solution
NaCl solution
iodine solution (tests starch)
anhydrous Benedict's reagent (tests glucose)
silver nitrate solution (tests NaCl)
biuret reagent (tests albumin)
10-mL graduated cylinder
test tubes (2)
test-tube rack
funnel
wax pencil
eye droppers

Safety Precautions

Procedure

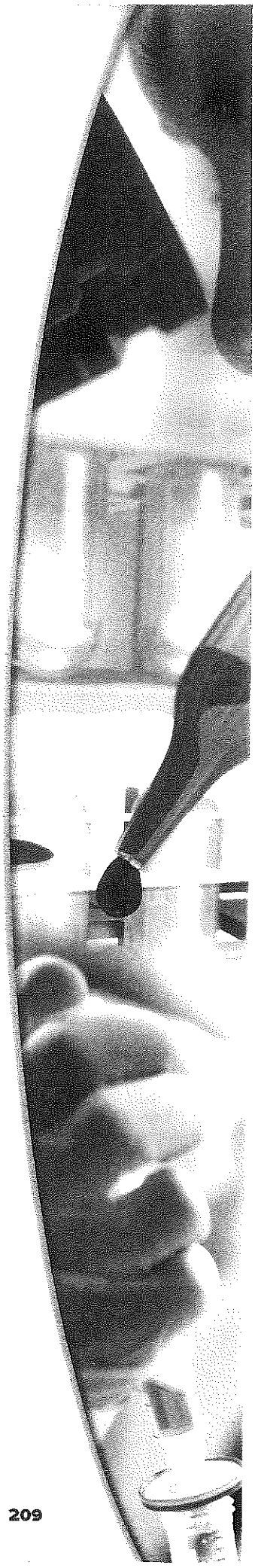
1. Read and complete the lab safety form.
2. Construct a data table as instructed by your teacher. Predict which substances will pass through the dialysis membrane.
3. Collect two lengths of dialysis tubing, two 400-mL beakers, and the two solutions that you have been assigned to test.
4. Label the beakers with the type of solution that you place in the dialysis tubing.
5. With a partner, prepare and fill one length of dialysis tubing with one solution. Rinse the outside of the bag thoroughly. Place the filled tubing bag into a beaker that contains distilled water.
6. Repeat Step 5 using the second solution.
7. After 45 minutes, transfer some of the water from each beaker into separate test tubes.
8. Add a few drops of the appropriate test reagent to the water.
9. Record your results and determine whether your prediction was correct. Compare your results with those of other groups in your class and record the results for the two solutions that you did not test.
10. **Cleanup and Disposal** Wash and return all reusable materials. Dispose of test solutions and used dialysis tubing as directed by your teacher. Wash your hands thoroughly after using any chemical reagent.

Analyze and Conclude

1. **Evaluate** Did your test molecules pass through the dialysis tubing? Explain.
2. **Think Critically** What characteristics of a plasma membrane give it more control over the movement of molecules than the dialysis membrane has?
3. **Error Analysis** How could failing to rinse the dialysis tube bags with distilled water prior to placing them in the beaker cause a false positive test for the presence of a dissolved molecule? What other sources of error might lead to inaccurate results?

POSTER SESSION

Communicate A disease called cystic fibrosis occurs when plasma membranes lack a molecule that helps transport chloride ions. Research this disease and present your finding to your class using a poster.



Chapter 7 Study Guide

THEME FOCUS Cause and Effect Cellular processes allow cells to respond to change in the environment.

BIG Idea Cells are the structural and functional units of all living things.

Section 1 Cell Discovery and Theory

cell (p. 182)
cell theory (p. 183)
plasma membrane (p. 185)
eukaryotic cell (p. 186)
nucleus (p. 186)
organelle (p. 186)
prokaryotic cell (p. 186)

Key Idea The invention of the microscope led to the discovery of cells.

- Microscopes have been used as tools for scientific study since the late 1500s.
- Scientists use different types of microscopes to study cells.
- The cell theory summarizes three principles.
- There are two broad groups of cell types: prokaryotic cells and eukaryotic cells.
- Eukaryotic cells each contain a nucleus and organelles.

Section 2 Plasma Membrane

selective permeability (p. 187)
phospholipid bilayer (p. 188)
transport protein (p. 189)
fluid mosaic model (p. 190)

Key Idea The plasma membrane helps to maintain a cell's homeostasis.

- Selective permeability is the property of the plasma membrane that allows it to control what enters and leaves the cell.
- The plasma membrane is made up of two layers of phospholipid molecules.
- Cholesterol and transport proteins aid in the function of the plasma membrane.
- The fluid mosaic model describes the plasma membrane.

Section 3 Structures and Organelles

cytoplasm (p. 191)
cytoskeleton (p. 191)
nucleolus (p. 193)
ribosome (p. 193)
endoplasmic reticulum (p. 194)
Golgi apparatus (p. 195)
vacuole (p. 195)
centriole (p. 196)
lysosome (p. 196)
chloroplast (p. 197)
mitochondrion (p. 197)
cell wall (p. 198)
cilium (p. 198)
flagellum (p. 198)

Key Idea Eukaryotic cells contain organelles that allow the specialization and the separation of functions within the cell.

- Eukaryotic cells contain membrane-bound organelles in the cytoplasm that perform cell functions.
- Ribosomes are the sites of protein synthesis.
- Mitochondria are the powerhouses of cells.
- Plant and animal cells contain many of the same organelles, while other organelles are unique to either plant cells or animal cells.

Section 4 Cellular Transport

diffusion (p. 201)
dynamic equilibrium (p. 202)
facilitated diffusion (p. 202)
osmosis (p. 203)
hypotonic solution (p. 204)
isotonic solution (p. 204)
active transport (p. 205)
hypertonic solution (p. 205)
endocytosis (p. 207)
exocytosis (p. 207)

Key Idea Cellular transport moves substances within the cell and moves substances into and out of the cell.

- Cells maintain homeostasis using passive and active transport.
- Concentration, temperature, and pressure affect the rate of diffusion.
- Cells must maintain homeostasis in all types of solutions, including isotonic, hypotonic, and hypertonic.
- Some large molecules are moved into and out of the cell using endocytosis and exocytosis.

Vocabulary eGames

Chapter 7 Assessment

Section 1

Vocabulary Review

Each of the following sentences is false. Make each sentence true by replacing the italicized word with a vocabulary term from the Study Guide page.

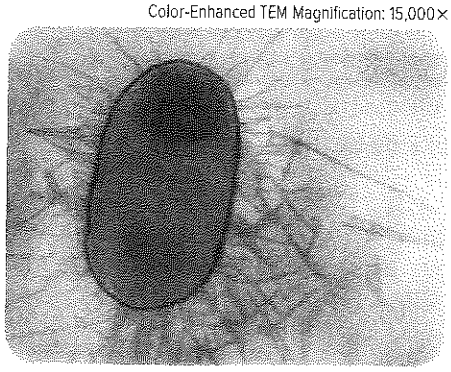
1. The *nucleus* is a structure that surrounds a cell and helps control what enters and exits the cell.
2. A(n) *prokaryote* has membrane-bound organelles.
3. *Organelles* are basic units of all organisms.

Understand Main Ideas

4. If a microscope has a series of three lenses that magnify individually 5×, 5×, and 7×, what is the total magnification of the microscope?
   A. 25× C. 17×
   B. 35× D. 175×
5. Which is not part of the cell theory?
   A. The basic unit of life is the cell.
   B. Cells came from preexisting cells.
   C. All living organisms are composed of cells.
   D. Cells contain membrane-bound organelles.

Use the photo to answer question 6.

Color-Enhanced TEM Magnification: 15,000×



6. The photomicrograph shows which kind of cell?
   A. prokaryotic cell C. animal cell
   B. eukaryotic cell D. plant cell

Constructed Response

7. **THINK IDEA** Explain how the development of the microscope changed how scientists studied living organisms.
8. **Short Answer** Compare and contrast prokaryotic cells and eukaryotic cells.

Think Critically

9. Why might a microscopist, who specializes in the use of microscopes to examine specimens, use a light microscope instead of an electron microscope?
10. **Analyze** A material is found in an asteroid that might be a cell. What criteria must the material meet to be considered a cell?

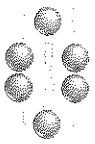
Section 2

Vocabulary Review

Complete the sentences below using vocabulary terms from the Study Guide page.

11. A _____ is the basic structure that makes up the plasma membrane.
12. _____ proteins move needed substances or waste materials through the plasma membrane.
13. _____ is the property that allows only some substances in and out of a cell.

Understand Main Ideas

14. Which of the following orientations of phospholipids best represents the phospholipid bilayer of the plasma membrane?
   A. 
   C. 
   B. 
   D. 
15. Which situation would increase the fluidity of a phospholipid bilayer?
   A. decreasing the temperature
   B. increasing the number of proteins
   C. increasing the number of cholesterol molecules
   D. increasing the number of unsaturated fatty acids

Online Test Practice

Chapter 7 Assessment

Constructed Response

16. MAIN IDEA Explain how the plasma membrane maintains homeostasis within a cell.

17. **Open Ended** Explain what a mosaic is and then explain why the term *fluid mosaic model* is used to describe the plasma membrane.

18. **Short Answer** How does the orientation of the phospholipids in the bilayer allow a cell to interact with its internal and external environments?

Think Critically

19. **Hypothesize** how a cell would be affected if it lost the ability to be selectively permeable.

20. **Predict** What might happen to a cell if it no longer could produce cholesterol?

Section 3

Vocabulary Review

Fill in each blank with the vocabulary term from the Study Guide page that matches the function definition.

21. _____ stores wastes

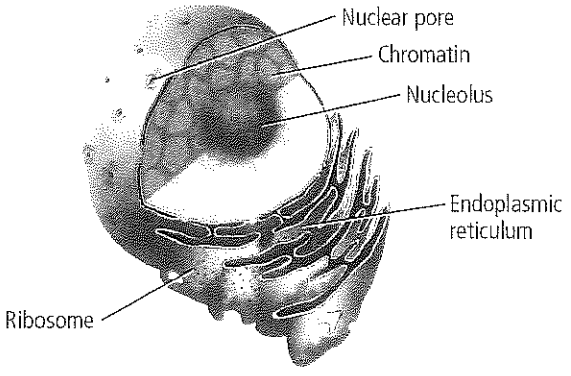
22. _____ produces ribosomes

23. _____ generates energy for a cell

24. _____ sorts proteins into vesicles

Understand Main Ideas

Use the diagram below to answer questions 25 and 26.



25. Which structure synthesizes proteins that will be used by the cell?
   A. chromatin
   B. nucleolus
   C. ribosome
   D. endoplasmic reticulum

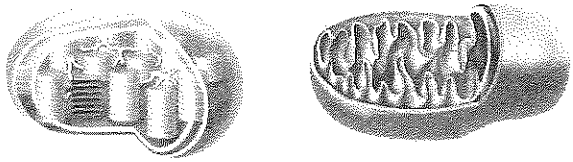
26. Which is the site of protein synthesis?
   A. nuclear pore
   B. endoplasmic reticulum
   C. chromatin
   D. nucleolus

27. In which structure would you expect to find a cell wall?
   A. human skin cell
   B. cell from an oak tree
   C. blood cell from a cat
   D. liver cell from a mouse

Constructed Response

28. **Short Answer** Describe why the cytoskeleton within the cytoplasm was a recent discovery.

29. **Short Answer** Compare the structures and functions of the mitochondrion and chloroplast below.



30. MAIN IDEA Suggest a reason why packets of proteins collected in a vacuole might merge with lysosomes.

Think Critically

31. THEME FOCUS Cause and Effect **Identify** a specific example in which the cell wall structure has aided the survival of a plant in its natural habitat.

32. **Infer** why plant cells that transport water against the force of gravity contain many more mitochondria than other plant cells do.

Section 4

Vocabulary Review

Explain the difference in the terms in each pair below. Then explain how the terms are related.

33. active transport, facilitated diffusion

34. endocytosis, exocytosis

35. hypertonic solution, hypotonic solution

Online Test Practice

Understand Main Ideas

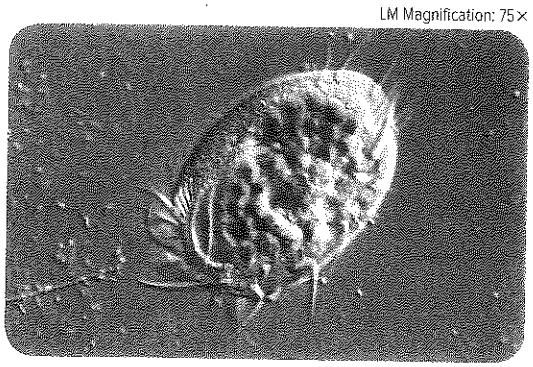
36. Which is not a factor that affects the rate of diffusion?
   A. conductivity
   B. concentration
   C. pressure
   D. temperature

37. Which type of transport requires energy input from the cell?
   A. active transport
   B. facilitated diffusion
   C. osmosis
   D. simple diffusion

Constructed Response

38. **Short Answer** Why is active transport an energy-utilizing process?

39. **Short Answer** Some protists that live in a hypotonic pond environment have cell membrane adaptations that slow water uptake. What adap-tations might this protist living in the hypertonic Great Salt Lake have?



40. THINK Summarize how cellular transport helps maintain homeostasis within a cell.

Think Critically

41. **Hypothesize** how oxygen crosses the plasma membrane if the concentration of oxygen is lower inside the cell than it is outside the cell.

42. **Analyze** Farming and watering that are done in very dry regions of the world leave salts that accumulate in the soil as water evaporates. Based on what you know about concentration gradients, why does increasing soil salinity have adverse effects on plant cells?

Summative Assessment

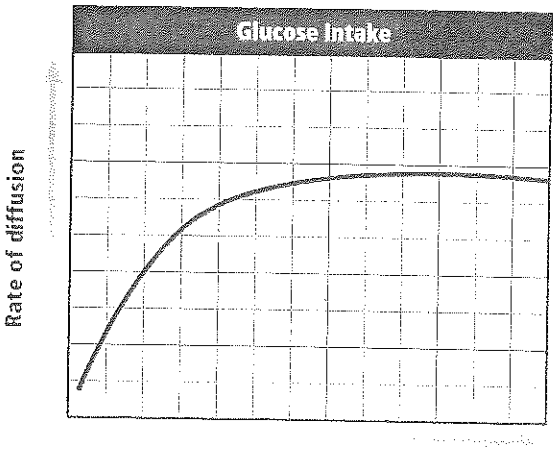
43. BIG IDEA Cells are the structural and functional units of living things. Create an analogy where "smaller parts" provide structure and funtion for a "whole." Relate it to cells and living things by giving specific examples.

44. Use what you have learned about osmosis and cellular transport to design an apparatus that would enable a freshwater fish to survive in a saltwater habitat.

45. WRITING Biology Create a poem that describes the functions of at least five cell organelles.

Document-Based Questions

The graph below describes the relationship between the amount of glucose entering a cell and the rate at which the glucose enters the cell with the help of carrier proteins. Use this graph to answer questions 46 and 47.



Data obtained from: Raven, P.H., and Johnson, G.B. 2002. *Biology*, 6th ed.: 99.

46. Summarize the relationship between the amount of glucose and the rate of diffusion.

47. Infer why the rate of diffusion tapers off with higher amounts of glucose. Make an illustration to explain your answer.

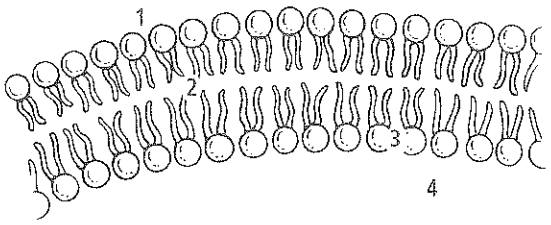
Online Test Practice

Standardized Test Practice

Cumulative

Multiple Choice

Use the illustration below to answer questions 1 and 2.



1. Which number in the illustration represents the location where you would expect to find water-insoluble substances?
   - A. 1
   - B. 2
   - C. 3
   - D. 4

2. Which is the effect of having the polar and non-polar ends of phospholipid molecules oriented as they are in the illustration?
   - A. It allows transport proteins to move easily through the membrane.
   - B. It controls the movement of substances across the membrane.
   - C. It helps the cell to maintain its characteristic shape.
   - D. It makes more room inside the phospholipid bilayer.

3. Which of these habitats would be best suited for a population of *r*-strategists?
   - A. desert
   - B. grassland
   - C. deciduous forest
   - D. tropical rain forest

4. Which adaptation helps plants survive in a tundra biome?
   - A. deciduous leaves that fall off as winter approaches
   - B. leaves that store water
   - C. roots that grow only a few centimeters deep
   - D. underground stems that are protected from grazing animals

5. Which is a nonrenewable resource?
   - A. clean water from freshwater sources
   - B. energy provided by the Sun
   - C. an animal species that has become extinct
   - D. a type of fish that is caught in the ocean

6. In which type of cell would you find a chloroplast?
   - A. prokaryote
   - B. animal
   - C. plant
   - D. fungus

Use this incomplete equation to answer questions 7 and 8.

$$CH_4 + 4Cl_2 \rightarrow \_\_HCl + \_\_CCl_4$$

7. The chemical equation above shows what can happen in a reaction between methane and chlorine gas. The coefficients have been left out in the product side of the equation. Which is the correct coefficient for HCl?
   - A. 1
   - B. 2
   - C. 4
   - D. 8

8. Which is the minimum number of chlorine (Cl) atoms needed for the reaction shown in the equation?
   - A. 1
   - B. 2
   - C. 4
   - D. 8

9. Why is *Caulerpa taxifolia* considered an invasive species in some coastal areas of North America?
   - A. It is dangerous to humans.
   - B. It is nonnative to the area.
   - C. It grows slowly and invades over time.
   - D. It outcompetes native species for resources.

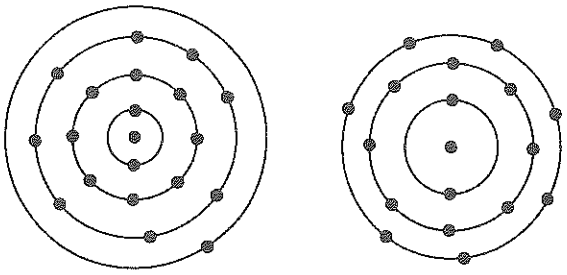
Short Answer

10. Use a flowchart to organize information about cell organelles and protein synthesis. For each step, analyze the role of the organelle in protein synthesis.

11. Compare and contrast the functions of carbohydrates, lipids, proteins, and nucleic acids.

12. State why the polarity of water molecules makes water a good solvent.

Use the figure below to answer question 13.



K
Atomic number 19

Cl
Atomic number 17

13. Use the figure to describe how the ionic compound potassium chloride (KCl) is formed.

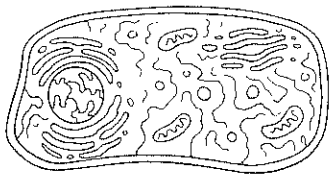
14. What might happen if cell membranes were not selectively permeable?

15. Choose a specific natural resource and develop a plan for the sustainable use of that resource.

16. What can you infer about the evolution of bacterial cells from studying their structure?

Extended Response

The illustration below shows a single animal cell in an isotonic solution. Use the illustration to answer question 17.



17. Describe what would happen to this cell in a hypertonic solution and in a hypotonic solution.

18. Explain why direct economic value is not the only important consideration of biodiversity.

19. Analyze why an electron microscope can produce higher magnification than a light microscope can.

20. Assess why transport proteins are needed to move certain substances across a cell membrane.

Essay Question

Recently, some international trade agreements have allowed scientists and companies to patent the discoveries they make about organisms and their genetic material. For instance, it is possible to patent seeds that have genes for disease resistance and plants that can be used in medicine or industry. Owners of patents now have greater control over the use of these organisms.

Using the information in the paragraph above, answer the following question in essay format.

21. Based on what you know about biodiversity, identify some pros and cons of a patent system. Write an essay exploring the pros and cons of patenting discoveries about organisms.

NEED EXTRA HELP?

If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Review Section . . .	7.2	7.2	4.1	3.1	5.3	7.3	6.2	6.8	5.2	7.3	6.4	6.3	6.1	7.2	5.3	7.1	7.4	5.1	7.1	7.4	5.2