Chapter 8

Cells and Their Environment

Preview

Why It Matters

Cells interact with their environment to exchange nutrients and wastes and to coordinate activities over long distances.

Did you know that cells drink? This blood capillary cell wraps its cell membrane around the surrounding fluid and takes in a big gulp.

The lumen (blue) is the hollow part of a capillary.

A row of vesicles forms in the upper cell membrane (purple) and moves toward the bottom of the capillary. These vesicles help transport serum.

Section 1

Cell Membrane

Key Ideas	Key Terms	Why It Matters
❯ How does the cell membrane help a cell maintain homeostasis? ❯ How does the cell membrane restrict the exchange of substances? ❯ What are some functions of membrane proteins?	**phospholipid** **lipid bilayer**	A simple defect in a cell membrane protein can make a life-or-death difference. In people who have cystic fibrosis, the cell membrane is does not work properly.

Every cell is surrounded by a cell membrane. The cell membrane protects the cell and helps move substances and messages in and out of the cell. By regulating transport, the membrane helps the cell maintain constancy and order.

Homeostasis

All living things respond to their environments. For example, we sweat when we are hot and shiver when we are cold. These reactions help our bodies maintain homeostasis. Recall that homeostasis is the maintenance of stable internal conditions in a changing environment. Individual cells, as well as organisms, must maintain homeostasis in order to live. ❯ **One way that a cell maintains homeostasis is by controlling the movement of substances across the cell membrane.**

Like the swimmer and the jellyfish in **Figure 1,** cells are suspended in a fluid environment. Even the cell membrane is fluid. It is made up of a "sea" of lipids in which proteins float. By allowing some materials but not others to enter the cell, the cell membrane acts as a gatekeeper. In addition, it provides structural support to the cytoplasm, recognizes foreign material, and communicates with other cells. These functions also contribute to maintaining homeostasis.

❯ **Reading Check** ***What are some roles of the cell membrane? (See the Appendix for answers to Reading Checks.)***

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Topic: Homeostasis
Code: HX80753

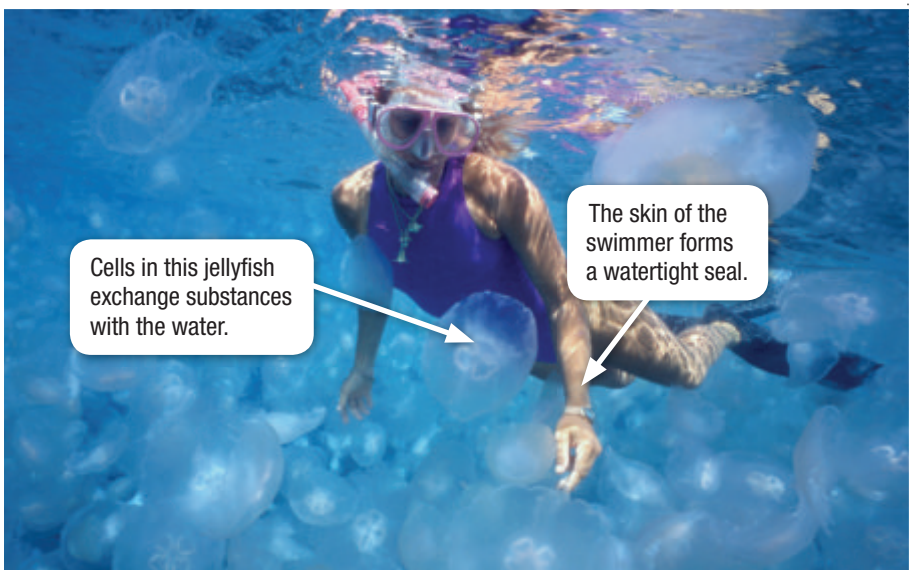


Figure 1 The cells of the jellyfish exchange materials more freely with the sea water than do the cells of the swimmer.

phospholipid (FAHS foh LIP id) a lipid that contains phosphorus and that is a structural component in cell membranes

lipid bilayer (LIP id BIE LAY uhr) the basic structure of a biological membrane, composed of two layers of phospholipids

Lipid Bilayer

The cell membrane is made of a "sea" of phospholipids. As **Figure 2** shows, a **phospholipid** is a specialized lipid made of a phosphate "head" and two fatty acid "tails." The phosphate head is polar and is attracted to water. In contrast, the fatty acid tails are nonpolar and are repelled by water.

Structure Because there is water inside and outside the cell, the phospholipids form a double layer called the **lipid bilayer.** The nonpolar tails, repelled by water, make up the interior of the lipid bilayer. The polar heads are attracted to the water, so they point toward the surfaces of the lipid bilayer. One layer of polar heads faces the cytoplasm, while the other layer is in contact with the cell's immediate surroundings.

Barrier Only certain substances can pass through the lipid bilayer. **› The phospholipids form a barrier through which only small, nonpolar substances can pass.** Ions and most polar molecules are repelled by the nonpolar interior of the lipid bilayer.

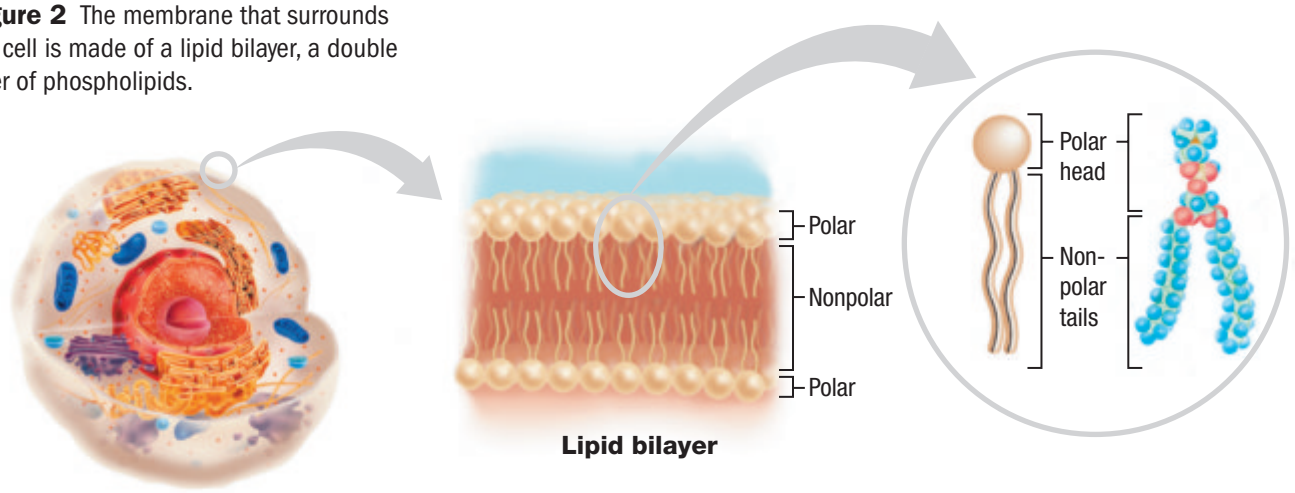
Membrane Proteins

Various proteins can be found in the cell membrane. Some proteins face inside the cell, and some face outside. Other proteins may stretch across the lipid bilayer and face both inside and outside.

Proteins in Lipids What holds these proteins in the membrane? Recall that proteins are made of amino acids. Some amino acids are polar, and others are nonpolar. Nonpolar portions of a protein are attracted to the interior of the lipid bilayer but are repelled by water on either side of the membrane. In contrast, polar parts of the protein are attracted to the water on both sides of the lipid bilayer. These opposing attractions help hold the protein in the membrane.

› Reading Check ***Why can't ions pass through the lipid bilayer?***

Figure 2 The membrane that surrounds the cell is made of a lipid bilayer, a double layer of phospholipids.



The lipid bilayer is the foundation of the cell membrane.

The arrangement of phospholipids in the lipid bilayer makes the cell membrane selectively permeable.

A phospholipid's "head" is polar, and its two fatty acid "tails" are nonpolar.

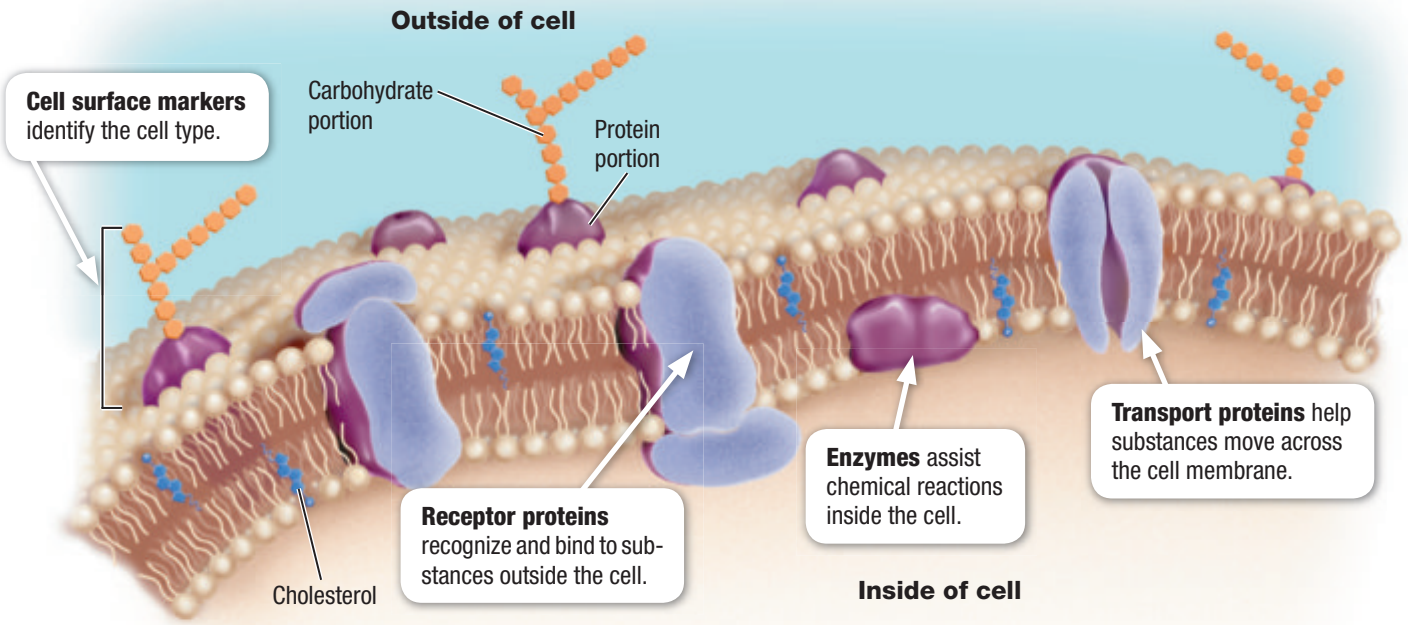


Figure 3 The cell membrane contains various proteins that have specialized functions.

Types of Proteins As **Figure 3** shows, membranes contain different types of proteins. **Proteins in the cell membrane include cell-surface markers, receptor proteins, enzymes, and transport proteins.**

- **Cell-Surface Markers** Like a name tag, a chain of sugars acts as a marker to identify each type of cell. Liver cells have a different chain of sugars from heart cells. These sugars (carbohydrates) are attached to the cell surface by proteins called *glycoproteins*. Glycoproteins help cells work together.
- **Receptor Proteins** Receptor proteins enable a cell to sense its surroundings by binding to certain substances outside the cell. When this happens, it causes changes inside the cell.
- **Enzymes** Many proteins in the cell membrane help with important biochemical reactions inside the cell.
- **Transport Proteins** Many substances that the cell needs cannot pass through the lipid bilayer. Transport proteins aid the movement of these substances into and out of the cell.

READING TOOLBOX

Four-Corner Fold Make a four-corner fold to compare four types of proteins found in the cell membrane.

Section 1 Review

KEY IDEAS

1. **Relate** the functions of the cell membrane to homeostasis.
2. **Describe** the types of substances that can pass through the lipid bilayer of the cell membrane.
3. **Outline** four functions of proteins within the cell membrane.

CRITICAL THINKING

4. **Applying Logic** What would happen if the cell membrane were fully permeable to all substances in the cell's environment?
5. **Predicting Outcomes** What would happen if the cell were exposed to a drug that disabled the transport proteins in the cell membrane?

ALTERNATIVE ASSESSMENT

6. **Making Models** Create a model of the lipid bilayer, including its associated proteins. Your model may be made of clay or household items. Present your model to the class. Indicate the role of each type of protein in maintaining homeostasis.

Section 2

Cell Transport

Key Ideas	Key Terms	Why It Matters
❯ What determines the direction in which passive transport occurs? ❯ Why is osmosis important? ❯ How do substances move against their concentration gradients?	equilibrium concentration gradient diffusion carrier protein osmosis sodium-potassium pump	The cell's membrane is a little like a country's border. Both barriers regulate who or what enters and who or what leaves.

The cell must move substances of varying size, electrical charge, and composition into and out of the cell. Substances may enter and leave the cell in a variety of ways. Sometimes the cell must use energy to move a substance across the cell membrane. In *active transport,* the cells is required to use energy to move a substance. In *passive transport,* the cell does not use energy.

Passive Transport

In a solution, randomly moving molecules tend to fill up a space. When the space is filled evenly, a state called **equilibrium** is reached. The amount of a particular substance in a given volume is called the *concentration* of the substance. When one area has a higher concentration than another area does, as **Figure 4** shows, a **concentration gradient** exists. Substances move from an area of higher concentration to an area of lower concentration. This movement down the concentration gradient is called **diffusion.**

The cell membrane separates the cytoplasm from the fluid outside the cell. Some substances enter and leave the cell by diffusing across the cell membrane. The direction of movement depends on the concentration gradient and does not require energy. ❯ **In passive transport, substances cross the cell membrane down their concentration gradient.** Some substances diffuse through the lipid bilayer. Others diffuse through transport proteins.

Figure 4 If people acted like molecules, they would fill up the space in this room evenly over time. ❯ **What area of this room has a high concentration of people?**

Simple Diffusion Small, nonpolar molecules can pass directly through the lipid bilayer. This type of movement is called *simple diffusion.* As **Figure 5** shows, oxygen diffuses into the cell through the lipid bilayer. The concentration of oxygen is higher outside the cell than it is inside. Thus, oxygen moves down its concentration gradient into the cell. In contrast, the concentration of carbon dioxide is often higher inside the cell than it is outside. So, carbon dioxide diffuses out of the cell. Natural steroid hormones, which are nonpolar and fat soluble, can also diffuse across the lipid bilayer.

Facilitated Diffusion Many ions and polar molecules that are important for cell function do not diffuse easily through the nonpolar lipid bilayer. During *facilitated diffusion,* transport proteins help these substances diffuse through the cell membrane. Two types of transport proteins are channel proteins and carrier proteins.

Channel Proteins Ions, sugars, and amino acids can diffuse through the cell membrane through channel proteins. These proteins, sometimes called *pores,* serve as tunnels through the lipid bilayer. Each channel allows the diffusion of specific substances that have the right size and charge. For example, only sodium ions can pass through the sodium ion channel shown in **Figure 5.**

Carrier Proteins Carrier proteins transport substances that fit within their binding site, as **Figure 6** shows. A carrier protein binds to a specific substance on one side of the cell membrane. This binding causes the protein to change shape. As the protein's shape changes, the substance is moved across the membrane and is released on the other side.

› **Reading Check** ***Why does oxygen diffuse into the cell?***

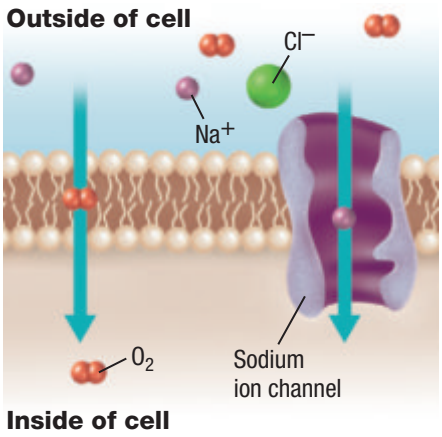


Figure 5 Nonpolar molecules, such as O_2, diffuse through the lipid bilayer. Channel proteins allow certain ions, such as Na^+, to diffuse through the cell membrane. Cl^- ions cannot pass through the sodium ion channel.

equilibrium a state that exists when the concentration of a substance is the same throughout a space

concentration gradient a difference in the concentration of a substance across a distance

diffusion the movement of particles from regions of higher density to regions of lower density

carrier protein a protein that transports substances across a cell membrane

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Facilitated Diffusion

1 A molecule outside the cell binds to a carrier protein on the cell membrane.

2 The carrier protein changes shape, which releases the molecule inside the cell.

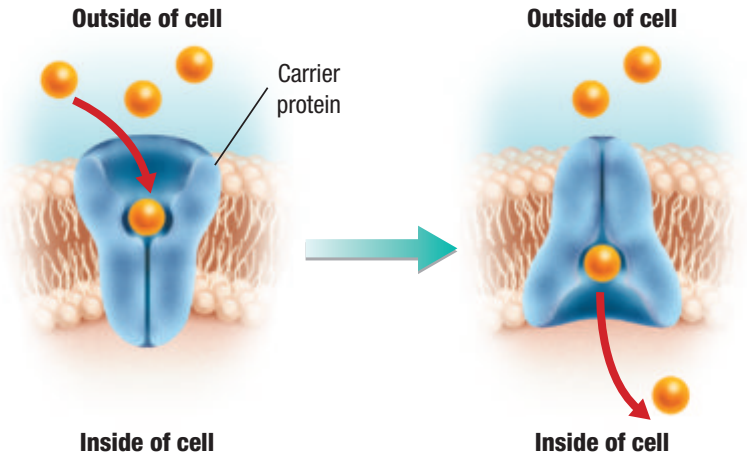
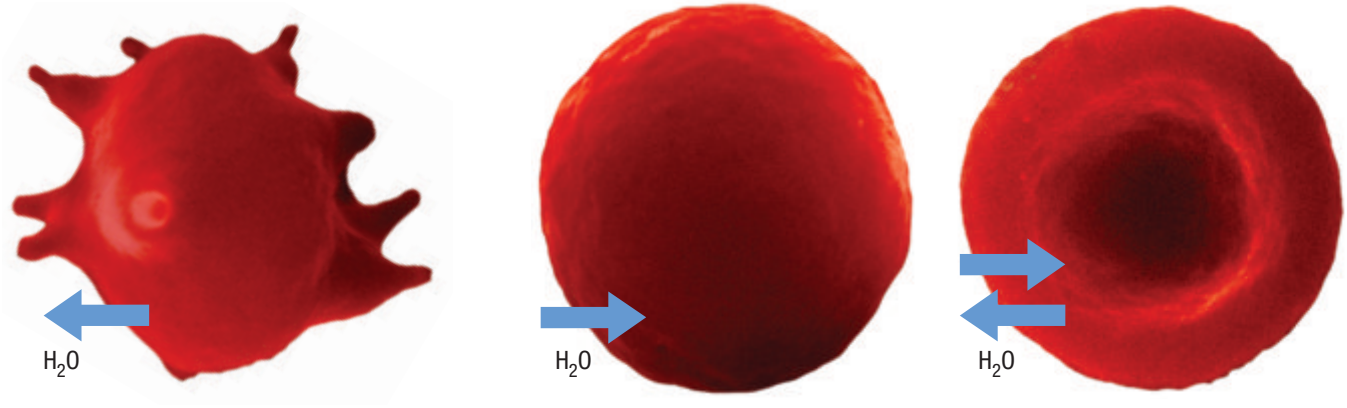


Figure 6 Carrier proteins allow the diffusion of specific molecules by binding the molecules on one side of the cell membrane and releasing them on the other side.
› **Which side of this membrane has a higher concentration of molecules?**



Hypertonic Solution The fluid outside is more concentrated. As water moves out of the cell, the cell shrinks.

Hypotonic Solution The fluid outside is less concentrated. As water moves into the cell, the cell swells.

Isotonic Solution Water moves into and out of the cell at the same rate. The cell stays the same size.

Figure 7 Red blood cells change shape due to the movement of water. The direction of water movement depends on the difference between the concentration of the solution outside the cell and the concentration of the cytosol.

Osmosis

Water can diffuse across a selectively permeable membrane in a process called **osmosis.** Osmosis is a type of passive transport that is very important to keeping cells functional. **› Osmosis allows cells to maintain water balance as their environment changes.**

When ions and polar substances dissolve in water, they attract and bind some water molecules. The remaining water molecules are free to move around. If a concentration gradient exists across a membrane for solutes, a concentration gradient also exists across the membrane for free water molecules. Osmosis occurs as free water molecules move down their concentration gradient into the solution that has the lower concentration of free water molecules.

Water Channels Polar water molecules do not diffuse directly through the bilayer. But the cell membrane contains channel proteins that only water molecules can pass through. Thus, osmosis in cells is a form of facilitated diffusion. In humans, water channels help in the regulation of body temperature, in digestion, in reproduction, and in water conservation in the kidneys.

Predicting Water Movement The direction of water movement in a cell depends on the concentration of the cell's environment. **Figure 7** shows a red blood cell in solutions of three concentrations.

1. Water moves out. If the solution is *hypertonic,* or has a higher solute concentration than the cytoplasm does, water moves out of the cell. The cell loses water and shrinks.

2. Water moves in. If the solution is *hypotonic,* or has a lower solute concentration than the cytoplasm does, water moves into the cell. The cell gains water and expands in size.

3. No net change in water movement occurs, or equilibrium is reached. If the solution is *isotonic,* or has the same solute concentration that the cytoplasm does, water diffuses into and out of the cell at equal rates. The cell stays the same size.

READING TOOLBOX

Word Parts The prefix *hyper-* means "higher than," and *hypertonic* means "higher concentration." If *hypo-* means "lower than," what does *hypotonic* mean?

osmosis the diffusion of water or another solvent from a more dilute solution (of a solute) to a more concentrated solution (of the solute) through a membrane that is permeable to the solvent

Hands-On

QuickLab

MULTI-DAY 15 min

Osmosis

You will observe the movement of water into or out of a grape under various conditions.

Procedure

1. Make a data table with four columns and three rows.
2. Fill **one jar** with a **sugar solution.** Fill a **second jar** with **grape juice.** Fill a **third jar** with **tap water.** Label each jar with the name of the solution that it contains.
3. Use a **balance** to find the mass of each of **three grapes.** Place one grape in each jar, and put the lids on the jars.
4. Predict whether the mass of each grape will increase or decrease over time. Explain your predictions.
5. After 24 h, remove each grape from its jar, and dry the grape gently with a **paper towel.** Using the balance, find each grape's mass again. Record your results.

Analysis

1. **Identify** the solutions in which osmosis occurred.
2. CRITICAL THINKING **Evaluating Conclusions** How did you determine whether osmosis occurred in each of the three solutions?
3. CRITICAL THINKING **Evaluating Hypotheses** Did the mass of each grape change as you had predicted? Why or why not?

Effects of Osmosis If left unchecked, the swelling caused by a hypotonic solution could cause a cell to burst. The rigid cell walls of plants and fungi prevent the cells of these organisms from expanding too much. In fact, many plants are healthiest in a hypotonic environment, as **Figure 8** shows. Some unicellular eukaryotes have *contractile vacuoles,* which collect excess water inside the cell and force the water out of the cell. Animal cells have neither cell walls nor contractile vacuoles. However, many animal cells can avoid swelling caused by osmosis by actively removing solutes from the cytoplasm. The removal of dissolved solutes from a cell increases the concentration of free water molecules inside the cell.

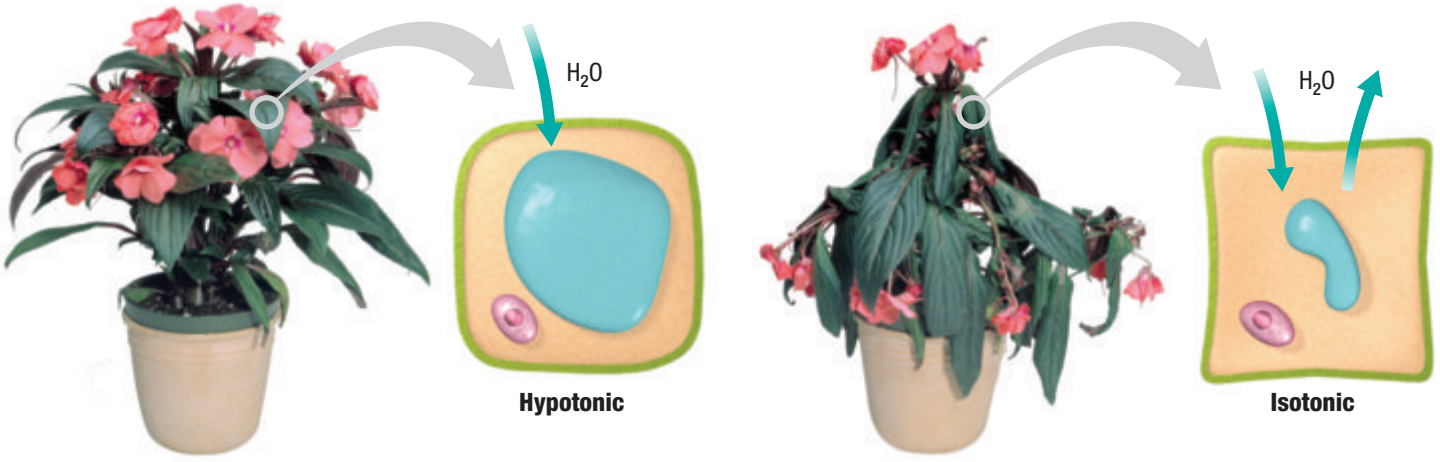


Figure 8 Plant cells are healthiest in a hypotonic environment. When its cells swell, the plant stands rigid. In an isotonic environment, a plant wilts. **What would happen if you added water to the plant on the right?**

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Topic: Active Transport
Code: HX80018

sodium-potassium pump a carrier protein that uses ATP to actively transport sodium ions out of a cell and potassium ions into the cell

Active Transport

Sometimes, cells must transport substances against their concentration gradients. This movement is called *active transport* because the cell must use energy to move these substances. ❯ **Active transport requires energy to move substances against their concentration gradients.** Most often, the energy needed for active transport is supplied directly or indirectly by ATP.

Pumps Many active transport processes use carrier proteins to move substances. In facilitated diffusion, the carrier proteins do not require energy. In active transport, the carrier proteins do require energy to "pump" substances against their concentration gradient.

One of the most important carrier proteins in animal cells is the **sodium-potassium pump,** shown in **Figure 9.** Sodium ions inside the cell bind to the carrier protein. A phosphate group from ATP transfers energy to the protein. The protein changes shape and releases the sodium ions outside the cell membrane. Outside the cell, potassium ions bind to the pump. As a result, the phosphate group is released from the pump. The pump returns to its original shape and releases the potassium ions inside the cell membrane. For every three sodium ions taken out, two potassium ions are brought inside.

This pump prevents sodium ions from building up in the cell. Osmosis results when sodium ion levels are high. The cell could swell or even burst if too much water enters. The concentration gradients of sodium ions and potassium ions also help transport other substances, such as glucose, across the cell membrane.

Figure 9 The sodium-potassium pump actively transports both Na^+ and K^+ ions across the cell membrane. ❯ **In this figure, is the concentration of sodium ions higher inside the cell or outside the cell?**

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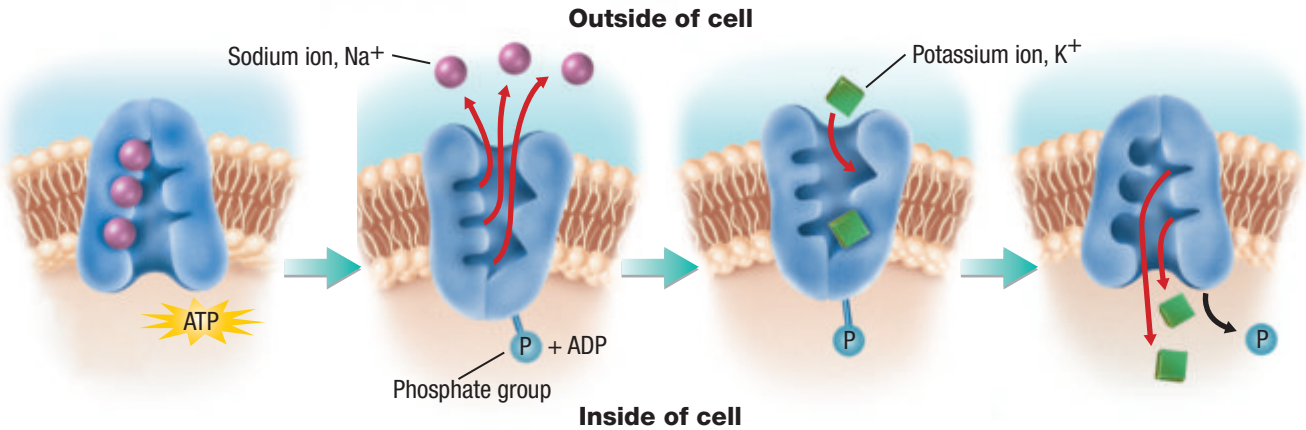
Sodium-Potassium Pump

1. Three sodium ions bind to the pump. A phosphate from ATP also binds, which transfers energy.
2. The pump changes shape, releasing the three sodium ions on the other side of the membrane.
3. Two potassium ions bind to the pump and are tranported across the cell membrane.
4. The phosphate group is released. The pump returns to its original shape, releasing the two potassium ions.



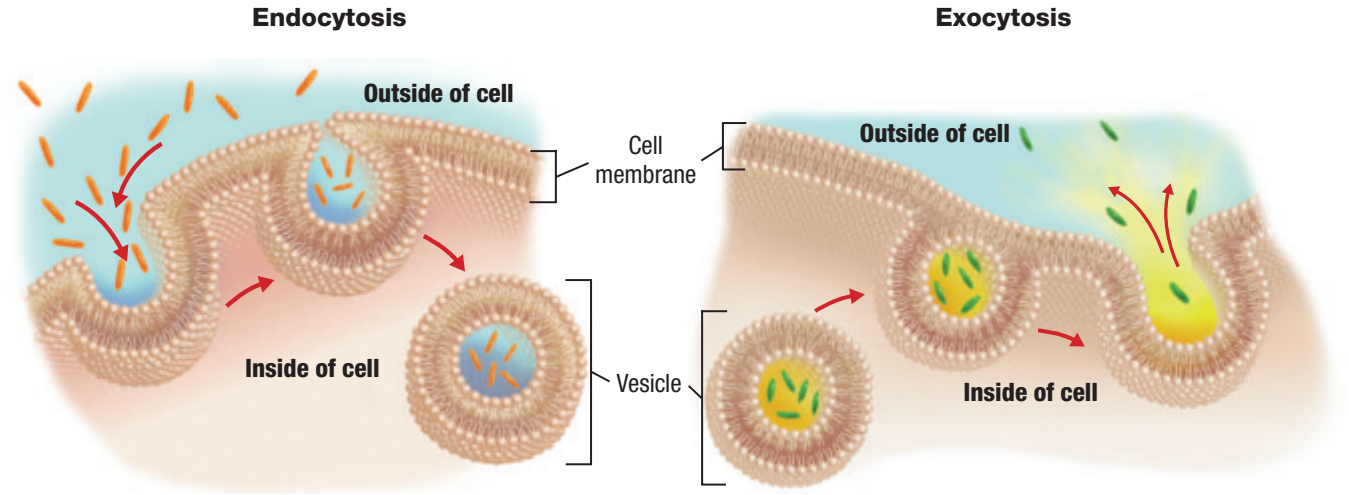


Figure 10 A cell moves large substances or large amounts of materials in vesicles. Vesicles can fuse with the cell membrane to take in and release substances.

Vesicles Many substances, such as proteins and polysaccharides, are too large to be transported by carrier proteins. Instead, they cross the cell membrane in vesicles. Recall that vesicles are membrane-bound sacs. The vesicle membrane is a lipid bilayer, like the cell membrane. Therefore, vesicles can bud off from the membrane, fuse with it, or fuse with other vesicles.

The movement of a large substance into a cell by means of a vesicle is called *endocytosis.* During endocytosis, shown in **Figure 10,** the cell membrane forms a pouch around the substance. The pouch then closes up and pinches off from the membrane to form a vesicle inside the cell. Vesicles that form by endocytosis may fuse with lysosomes or other organelles.

The movement of material out of a cell by means of a vesicle is called *exocytosis.* During exocytosis, shown in **Figure 10,** vesicles inside the cell fuse with the cell membrane. From the cell membrane, the contents of the vesicle are released to the outside of the cell. Cells use exocytosis to export proteins modified by the Golgi apparatus. Some protists release their waste products through this process. Some cells also use exocytosis to remove bacteria or other microbes.

ACADEMIC VOCABULARY

release to set free

› **Reading Check** *What is the structure of the vesicle membrane?*

Section 2 Review

› KEY IDEAS

1. **Compare** the functions of channel proteins and carrier proteins in facilitated diffusion.
2. **Explain** why the presence of dissolved particles on one side of a membrane results in diffusion of water across the membrane.
3. **List** two ways that a cell can move a substance against its concentration gradient.

CRITICAL THINKING

4. **Applying Logic** Based on have learned about homeostasis and osmosis, why should humans avoid drinking sea water?
5. **Predicting Outcomes** If a cell were unable to make ATP, how would the cell membrane's transport processes be affected?

METHODS OF SCIENCE

6. **Designing an Experiment** What data would a biologist need to collect to determine whether a specific molecule is transported into cells by diffusion, by facilitated diffusion, or by active transport?

Section 3

Cell Communication

Key Ideas	Key Terms	Why It Matters
❯ How do cells use signal molecules? ❯ How do cells receive signals? ❯ How do cells respond to signaling?	signal receptor protein second messenger	Cells developed sophisticated methods of communication long before humans developed the Internet, cell phones, or even regular conversation.

We communicate in many ways to share information. In **Figure 11,** one person is surfing the Internet, another is talking on her cell phone, and two are having a face-to-face conversation. All of these are forms of communication. To coordinate activities, information must be shared. Cells in multicellular organisms depend on the activities of other cells to survive. Even unicellular organisms need to communicate—for example, to find a mate.

Sending Signals

You use different methods to communicate in different ways. You may whisper a secret to a trusted friend, or you may shout a warning to several people nearby. You may phone a friend who is far away, or you may put an ad in the newspaper for everyone to see.

Cells also use various methods of communication. These methods vary depending on whether the target is specific or general. They also depend on whether the target is nearby or far away. ❯ **Cells communicate and coordinate activity by sending chemical signals that carry information to other cells.** A *signaling cell* produces a **signal,** often a molecule, that is detected by the *target cell.* Typically, target cells have specific proteins that recognize and respond to the signal.

Targets Neighboring cells can communicate through direct contact between their membranes. Short-distance signals may act locally, a few cells away from the originating cell. Long-distance signals are carried by hormones and nerve cells. Hormones are signal molecules that are made in one part of the body. Hormones are distributed widely in the bloodstream throughout the body, but they affect only specific cells. Nerve cells also signal information to distant locations in the body, but their signals are not widely distributed.

Environmental Signals While most signal molecules originate within the body, some signals come from outside. For example, light has a great effect on the action of hormones in plants. The length of the day determines when some plants flower.

❯ **Reading Check** ***Compare the targets of signaling hormones and nerve cells.***

Figure 11 This young man dials a phone number, which sends a signal to a target. ❯ **Is this target general or specific?**

Hands-On

QuickLab

10 min

Sensitive Plants

The sensitive plant *(Mimosa pudica)* reacts to touch. This reaction results from rapid cell-to-cell communication.

Procedure

1. Observe and sketch the extended leaves on the ***Mimosa* plant branch.**
2. Touch the tip of the end leaf on this branch. Observe the plant's reaction.
3. Make a sketch showing the branch's new appearance.

Analysis

1. **Identify** what stimulus produced the plant's response.
2. **Describe** the plant's response.
3. **Explain** whether the reaction behavior was communicated beyond the leaf that was touched.
4. CRITICAL THINKING **Making Inferences** Plants can respond to touch, although they lack a nervous system. Propose a mechanism for the response you observed.

Receiving Signals

A target cell is bombarded by hundreds of signals. But it recognizes and responds only to the few signals that are important for its function. This response to some signals, but not to others, is made possible by **receptor proteins,** such as the ones in the cell's membrane.

signal anything that serves to direct, guide, or warn

receptor protein a protein that binds specific signal molecules, which causes the cell to respond

Binding Specificity A receptor protein binds specific substances, such as signal molecules. The outer part of the protein is folded into a unique shape, called the *binding site.* **A receptor protein binds only to signals that match the specific shape of its binding site.** As **Figure 12** shows, only signal molecules that have the "right" shape can fit into the receptor protein. Signal molecules that have the "wrong" shape have no effect on that particular receptor protein. A cell may also have receptor proteins that bind to molecules in its environment. Some cells may have receptor proteins that can detect and respond to light. Receptor proteins enable a cell to detect its environment.

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Topic: Receptor Proteins
Code: HX81274

Effect Once it binds the signal molecule, the receptor protein changes its shape in the membrane. This change in shape relays information into the cytoplasm of the target cell.

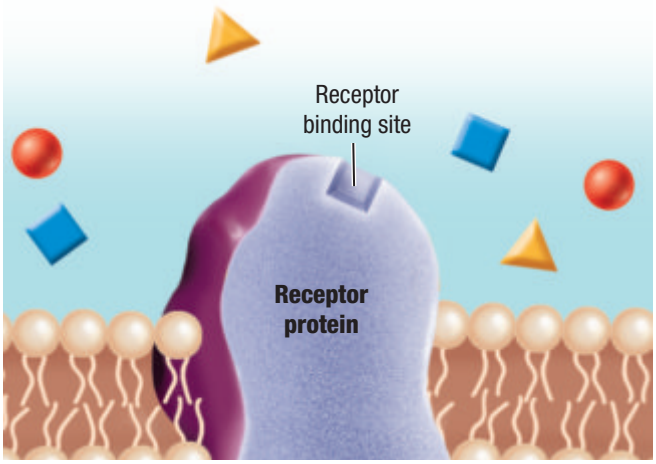

Figure 12 The binding site of this receptor protein has a specific shape to which only one type of signal molecule can bind. **Which of these molecules would bind with the receptor?**

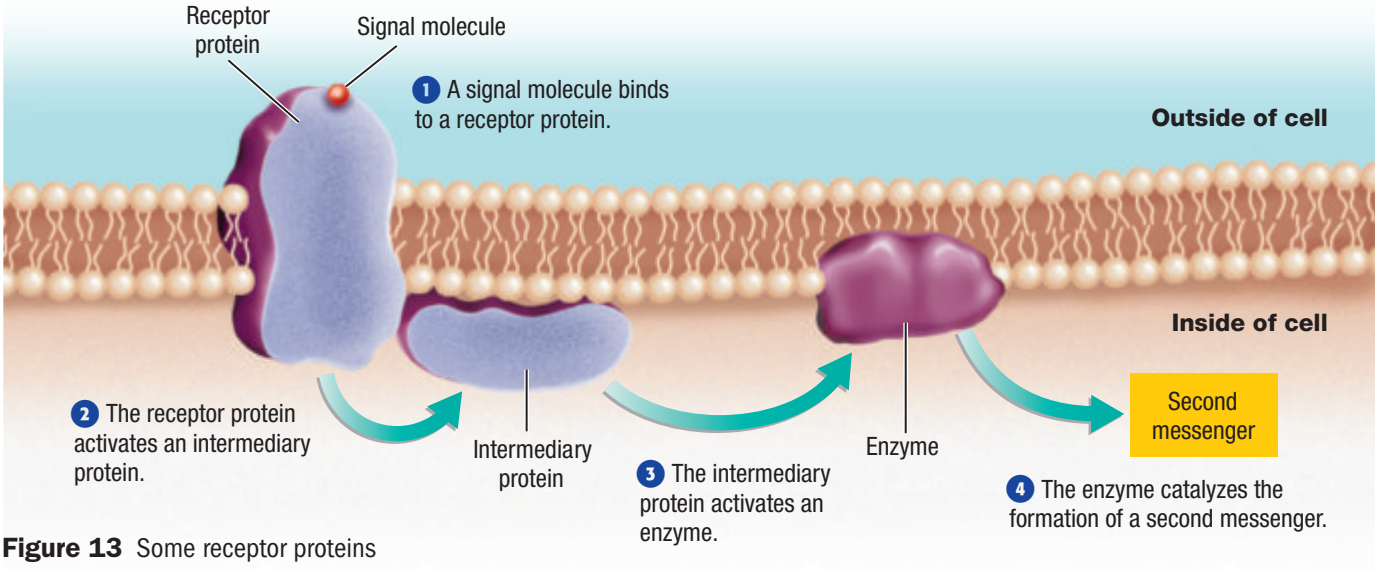

Figure 13 Some receptor proteins trigger the production of second messengers.

Responding to Signals

When a signal molecule binds to a receptor protein, the protein changes shape, which triggers changes in the cell membrane. **› The cell may respond to a signal by changing its membrane permeability, by activating enzymes, or by forming a second messenger.**

- **Permeability Change** Transport proteins may open or close in response to a signal. For example, a nerve impulse may result when ion channels in nerve cells open after receiving a signal.
- **Enzyme Activation** Some receptor proteins activate enzymes in the cell membrane. Some receptors are enzymes themselves and are activated by the binding of a signal molecule. Enzymes trigger chemical reactions in the cell.
- **Second Messenger** Binding of a signal molecule outside the cell may cause a second messenger to form, as **Figure 13** shows. The **second messenger** acts as a signal molecule within the cell and causes changes in the cytoplasm and nucleus.

› Reading Check ***How does membrane permeability change?***

READING TOOLBOX

Finding Examples Search the text on this page to find an example of the function of a transport protein.

second messenger a molecule that is generated when a specific substance attaches to a receptor on the outside of a cell membrane, which produces a change in cellular function

Section 3 Review

› KEY IDEAS

1. **Identify** one function of signal molecules in a multicellular organism.
2. **Describe** the relationship between receptor proteins and signal molecules.
3. **List** three ways that a receptor protein may respond when a signal molecule binds to it.

CRITICAL THINKING

4. **Applying Logic** Why do you think that there are many forms of communication between body cells?
5. **Applying Logic** Why is specificity between a receptor protein and a signal molecule important?

WRITING FOR SCIENCE

6. **Finding Information** Use library or Internet resources to research a human disease that results from problems in the transport of molecules across the cell membrane. Describe the disease's symptoms and treatments. Summarize your findings in a written report.

Chapter 8 Summary

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SUPER SUMMARY
Keyword: HX8CENS

Key Ideas	Key Terms

1 Cell Membrane

- One way that a cell maintains homeostasis is by controlling the movement of substances across the cell membrane.
- The lipid bilayer is selectively permeable to small, nonpolar substances.
- Proteins in the cell membrane include cell-surface markers, receptor proteins, enzymes, and transport proteins.

phospholipid (176)
lipid bilayer (176)

2 Cell Transport

- In passive transport, substances cross the cell membrane down their concentration gradient.
- Osmosis allows cells to maintain water balance as their environment changes.
- Active transport requires energy to move substances against their concentration gradients.

equilibrium (178)
concentration gradient (178)
diffusion (178)
carrier protein (178)
osmosis (180)
sodium-potassium pump (182)

3 Cell Communication

- Cells communicate and coordinate activity by sending chemical signals that carry information to other cells.
- A receptor protein binds only to the signals that match the specific shape of its binding site.
- The cell may respond to a signal by changing its membrane permeability, by activating enzymes, or by forming a second messenger.

signal (184)
receptor protein (185)
second messenger (186)