2–4 Chemical Reactions and Enzymes

Living things, as you have seen, are made up of chemical compounds—some simple and some complex. But chemistry isn't just what life is made of—chemistry is also what life does. Everything that happens in an organism—its growth, its interaction with the environment, its reproduction, and even its movement—is based on chemical reactions.

Chemical Reactions

A **chemical reaction** is a process that changes, or transforms, one set of chemicals into another. An important scientific principle is that mass and energy are conserved during chemical transformations. This is also true for chemical reactions that occur in living organisms. Some chemical reactions occur slowly, such as the combination of iron and oxygen to form an iron oxide called rust, shown in **Figure 2–18.** Other reactions occur quickly. The elements or compounds that enter into a chemical reaction are known as **reactants.** The elements or compounds produced by a chemical reaction are known as **products.** **Chemical reactions always involve changes in the chemical bonds that join atoms in compounds.**

One example of an important chemical reaction that occurs in your body involves carbon dioxide. Your cells constantly produce carbon dioxide as a normal part of their activity. This carbon dioxide is carried to your lungs through the bloodstream, and then is eliminated as you exhale. However, carbon dioxide is not very soluble in water. The bloodstream could not possibly dissolve enough carbon dioxide to carry it away from your tissues were it not for a chemical reaction. As it enters the blood, carbon dioxide reacts with water to produce a highly soluble compound called carbonic acid, H_2CO_3.

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

The reaction shown above enables the bloodstream to carry carbon dioxide to the lungs. In the lungs, the reaction is reversed.

$$H_2CO_3 \longrightarrow CO_2 + H_2O$$

This reverse reaction produces carbon dioxide gas, which is released as you exhale.

Guide for Reading

Key Concepts
- What happens to chemical bonds during chemical reactions?
- How do energy changes affect whether a chemical reaction will occur?
- Why are enzymes important to living things?

Vocabulary
chemical reaction
reactant
product
activation energy
catalyst
enzyme
substrate

Reading Strategy: Building Vocabulary
After you read, write a phrase or sentence in your own words to define or describe each highlighted, boldface term.

Figure 2–18 **Chemical reactions always involve changes in chemical bonds.** The iron in these chain links gradually combined with oxygen to produce a compound known as rust.

SECTION RESOURCES

Print:
- ***Teaching Resources,*** Lesson Plan 2–4, Adapted Section Summary 2–4, Adapted Worksheets 2–4, Section Summary 2–4, Worksheets 2–4, Section Review 2–4
- ***Reading and Study Workbook A,*** Section 2–4
- ***Adapted Reading and Study Workbook B,*** Section 2–4
- ***Probeware Lab Manual,*** Investigating the Effect of Temperature on Enzyme Activity
- ***Lab Worksheets,*** Chapter 2 Design an Experiment

Technology:
- ***iText,*** Section 2–4
- ***Animated Biological Concepts DVD,*** 4 Enzymatic Reactions
- ***Transparencies Plus,*** Section 2–4
- ***Virtual Labs CD-ROM,*** Catalase Action in Living Tissue

Section 2–4

1 FOCUS

Objectives

2.4.1 ***Explain*** how chemical reactions affect chemical bonds in compounds.
2.4.2 ***Describe*** how energy changes affect how easily a chemical reaction will occur.
2.4.3 ***Explain*** why enzymes are important to living things.

Guide for Reading

Vocabulary Preview

Before students read the section, call on volunteers to pronounce each word in the Vocabulary list. Correct any mispronunciations.

Reading Strategy

Students should focus their attention on the section's Vocabulary terms, not the words in the boldface Key Concepts. Before writing a definition using their own words, students might use the glossary at the back of their books. Explain that often words are defined in context within a section. The glossary sometimes provides a more general definition.

2 INSTRUCT

Chemical Reactions

Demonstration

To show students what a chemical reaction looks like, use baking soda and vinegar. In separate beakers, mix 5 mL of baking soda with 120 mL of water and 5 mL of vinegar with 120 mL of water. Have students observe that nothing extraordinary happens when these substances are mixed. Then, in a third beaker, mix 5 mL of baking soda with 5 mL of vinegar. Students should observe that this third mixture produces foaming and fizzling, indicating that a gas is produced in a chemical reaction. L1 L2

2–4 (continued)

Energy in Reactions

Use Visuals

Figure 2–19 Have students compare the graphs representing the two types of chemical reactions. Then, ask: **How would you compare the energy of the products and reactants in the two types of reactions?** *(In an energy-absorbing reaction, the products have more energy than the reactants. In an energy-releasing reaction, the products have less energy than the reactants.)* **Which type of reaction is more likely to be spontaneous?** *(An energy-releasing reaction)* L2

Go Online active art
For: Enzyme Action activity
Visit: PHSchool.com
Web Code: cbe-1024
Students can interact with the art online.

Demonstration

Help students understand that enzymes lower the activation energy needed to get a reaction going by using the analogy of a book on the edge of a table. Show students that the book will not fall off the table without a push, which is the activation energy in this case. Then, place some kind of wedge under one side of the book, in such a way that the book is slanted off the edge of the table. Now, the push, or activation energy, needed to make the book fall is much less. Likewise, an enzyme lowers the activation energy needed to begin a chemical reaction. L1 L2

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Visit: PHSchool.com
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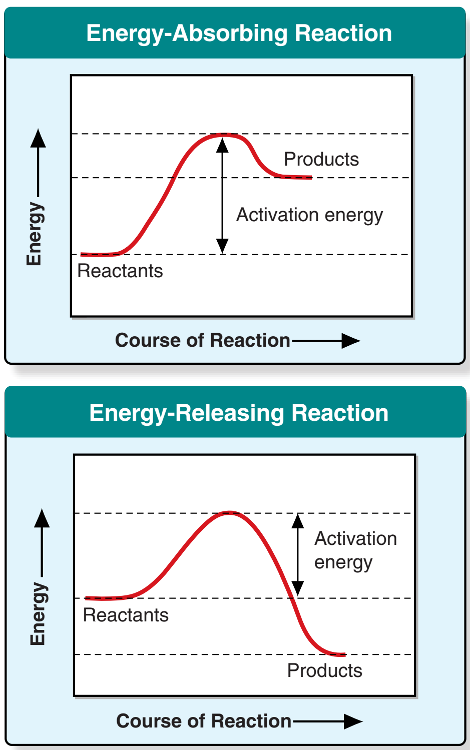
▼ **Figure 2–19 Chemical reactions that release energy often occur spontaneously. Chemical reactions that absorb energy will occur only with a source of energy.** The peak of each graph represents the energy needed for the reaction to go forward. The difference between this required energy and the energy of the reactants is the activation energy.



Energy in Reactions

Energy is released or absorbed whenever chemical bonds form or are broken. Because chemical reactions involve breaking and forming bonds, they involve changes in energy.

Energy Changes Some chemical reactions release energy, and other reactions absorb energy. Energy changes are one of the most important factors in determining whether a chemical reaction will occur. **Chemical reactions that release energy often occur spontaneously. Chemical reactions that absorb energy will not occur without a source of energy.** An example of an energy-releasing reaction is hydrogen gas burning, or reacting, with oxygen to produce water vapor.

$$2H_2 + O_2 \longrightarrow 2H_2O$$

The energy is released in the form of heat, and sometimes—when hydrogen gas explodes—light and sound.

The reverse reaction, in which water is changed into hydrogen and oxygen gas, absorbs so much energy that it generally doesn't occur by itself. In fact, the only practical way to reverse the reaction is to pass an electrical current through water to decompose water into hydrogen gas and oxygen gas. Thus, in one direction the reaction produces energy, and in the other direction the reaction requires energy.

In order to stay alive, organisms need to carry out reactions that require energy. Because matter and energy are conserved in chemical reactions, every organism must have a source of energy to carry out chemical reactions. Plants get that energy by trapping and storing the energy from sunlight in energy-rich compounds. Animals get their energy when they consume plants or other animals. Humans release the energy needed to grow tall, to breathe, to think, and even to dream through the chemical reactions that occur when humans metabolize, or break down, digested food.

Activation Energy Even chemical reactions that release energy do not always occur spontaneously. That's a good thing because if they did, the pages of this book might burst into flames. The cellulose in paper burns in the presence of oxygen and releases heat and light. However, the cellulose will burn only if you light it with a match, which supplies enough energy to get the reaction started. Chemists call the energy that is needed to get a reaction started the **activation energy.** As **Figure 2–19** shows, activation energy is a factor in whether the overall chemical reaction releases energy or absorbs energy.

CHECKPOINT *What is activation energy?*

UNIVERSAL ACCESS

Less Proficient Readers
Direct students' attention to the cycle diagram in Figure 2–21 on page 52. Go step-by-step around the diagram, calling on volunteers to explain what is being depicted in each step. As students mention Vocabulary terms, such as *enzyme* and *substrate*, have other students read the definitions in the text. After this oral lesson, ask students to make their own cycle diagrams of enzyme action, using their own words to describe what is illustrated in the figure. L1 L2

Advanced Learners
Students will learn about the enzyme amylase in Chapter 38 when they study the digestive system. Ask students who need an extra challenge to anticipate this study by researching the enzyme in saliva at this time and then presenting information about the action of this chemical to the class. Encourage students to use visual aids in their presentation. Students might want to prepare a demonstration of saliva's effect on a soda cracker. L3

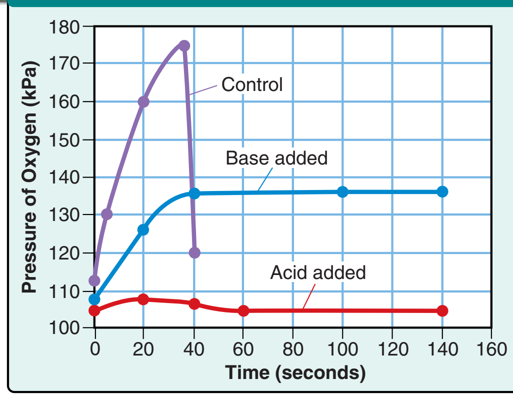
Analyzing Data

How Does pH Affect an Enzyme?

Catalase is an enzyme that helps decompose the toxic hydrogen peroxide that is produced during normal cell activities. The products of this reaction are water and oxygen gas. The pressure of the oxygen gas in a closed container increases as oxygen is produced. Any increase in the rate of the reaction will cause an increase in the pressure of the oxygen.

The purple line on the graph represents the normal rate of the reaction in a water solution of hydrogen peroxide and catalase. The red line represents the rate of reaction when an acid is added to the solution. The blue line represents the rate of reaction when a base is added to the solution.

Effect of pH on Catalase Activity



1. **Applying Concepts** What variable is plotted on the *x*-axis? What variable is plotted on the *y*-axis?
2. **Interpreting Graphics** How did the rate of reaction change over time in the control reaction?
3. **Inferring** Suggest an explanation for the change in the control reaction at about 40 seconds.
4. **Drawing Conclusions** What effect do acids and bases have on the enzyme catalase?
5. **Drawing Conclusions** Would it be valid to conclude that if a base were added, the rate of the reaction would slow down? Explain.
6. **Going Further** Predict what would happen if vinegar were added to a water solution of hydrogen peroxide and catalase.

Enzymes

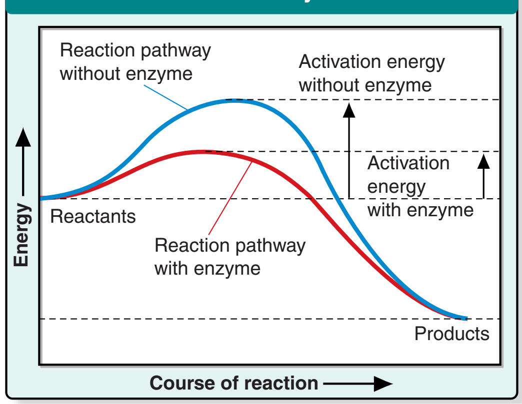
Some chemical reactions that make life possible are too slow or have activation energies that are too high to make them practical for living tissue. These chemical reactions are made possible by a process that would make any chemist proud—cells make catalysts. A **catalyst** is a substance that speeds up the rate of a chemical reaction. Catalysts work by lowering a reaction's activation energy.

Enzymes are proteins that act as biological catalysts. **Enzymes speed up chemical reactions that take place in cells.** Like other catalysts, enzymes act by lowering the activation energies, as illustrated by the graph in **Figure 2–20.** Lowering the activation energy has a dramatic effect on how quickly the reaction is completed. How big an effect does it have? Consider the reaction in which carbon dioxide combines with water to produce carbonic acid.

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

▼ **Figure 2–20** **Enzymes speed up chemical reactions that take place in cells.** Notice how the addition of an enzyme lowers the activation energy in this reaction. This action speeds up the reaction.

Effect of Enzymes



TEACHER TO TEACHER

To help students understand the action of enzymes, I have them do a lab in which they investigate bromelin, an enzyme in pineapple that breaks down certain proteins. Students mix liquid gelatin and fresh pineapple in one test tube, liquid gelatin and canned pineapple in a second, liquid gelatin and meat tenderizer in a third, and plain liquid gelatin in a fourth. After refrigerating the mixtures overnight, they let all four test tubes sit out at room temperature for 20 minutes and then assess each for how much the liquids have jelled.

—LouEllen Parker Brademan
Science Teacher
Potomac Senior High School
Dumfries, VA

Analyzing Data

Write the equation for the reaction on the chalkboard:

$2H_2O_2 \rightarrow O_2 + 2H_2O$

Explain that the pressure of oxygen gas is a measure of the amount of oxygen produced. The slope of the graphs is an indication of the rates of the reactions. L2 L3

Answers

1. Time is plotted on the *x*-axis and pressure of oxygen on the *y*-axis.
2. The rate was very rapid at first and then dropped off dramatically after about 40 seconds.
3. Students may suggest that the hydrogen peroxide was used up or that the reaction is reversible.
4. A base inhibits the enzyme so that it is less effective. An acid may deactivate the enzyme so that the reaction cannot take place.
5. It would be valid to draw that conclusion, because the blue line shows that the pressure of oxygen evened out when the base was added. That effect suggests that the rate of reaction slowed down, because any increase in the rate would cause an increase in the pressure of the oxygen.
6. Because vinegar is an acid, it would inhibit and possibly destroy the catalyst.

Enzymes

Use Visuals

Figure 2–20 Have students study the graph and explain its subject as well as what its axes represent. Then, ask: **What does the graph show would be the effect if enzymes were not available within a cell?** *(Without enzymes, reactions would need more activation energy to get started.)* **Would a reaction take a longer or shorter time with an enzyme?** *(A shorter time)* Explain that an enzyme may accelerate a reaction by a factor of 10^{10}, making it 10 billion times faster. L2

Answer to . . .

CHECKPOINT *Activation energy is the energy that is needed to get a reaction started.*

Go Online NSTA SCiLINKS

Download a worksheet on enzymes for students to complete, and find additional teacher support from NSTA SciLinks.

Build Science Skills

Using Models Have students model the action of enzymes by carrying out the "chemical reaction" of breaking toothpicks in half. Divide the class into groups, each with an increasing number of students. Group 1 should have two students, group 2 should have three students, and so on. Give each group 200 toothpicks, and ask one member to be a timer. The other student or students in each group represent enzyme molecules, and the toothpicks represent substrate molecules in a chemical reaction. Then, at your signal, all groups should begin breaking their toothpicks in half. The timer for each group should record the time it takes for the group to break all the toothpicks. Compare the times of each group. Students will find that the more "enzyme molecules" available, the faster the reaction is completed. L1 L2

Enzyme Action

Use Visuals

Figure 2–21 Ask students: **What are the substrates in this reaction?** *(Glucose and ATP)* **What are the products?** *(ADP and glucose-6-phosphate)* **How does the presence of an enzyme affect this reaction?** *(The enzyme speeds up the reaction.)* **What do the three arrows at the top left indicate?** *(Two arrows indicate that both products are released. The third arrow indicates that the enzyme is free to find new substrate molecules and start a new reaction cycle.)* L1

Go Online NSTA SCiLINKS

For: Links on enzymes
Visit: www.SciLinks.org
Web Code: cbn-1024

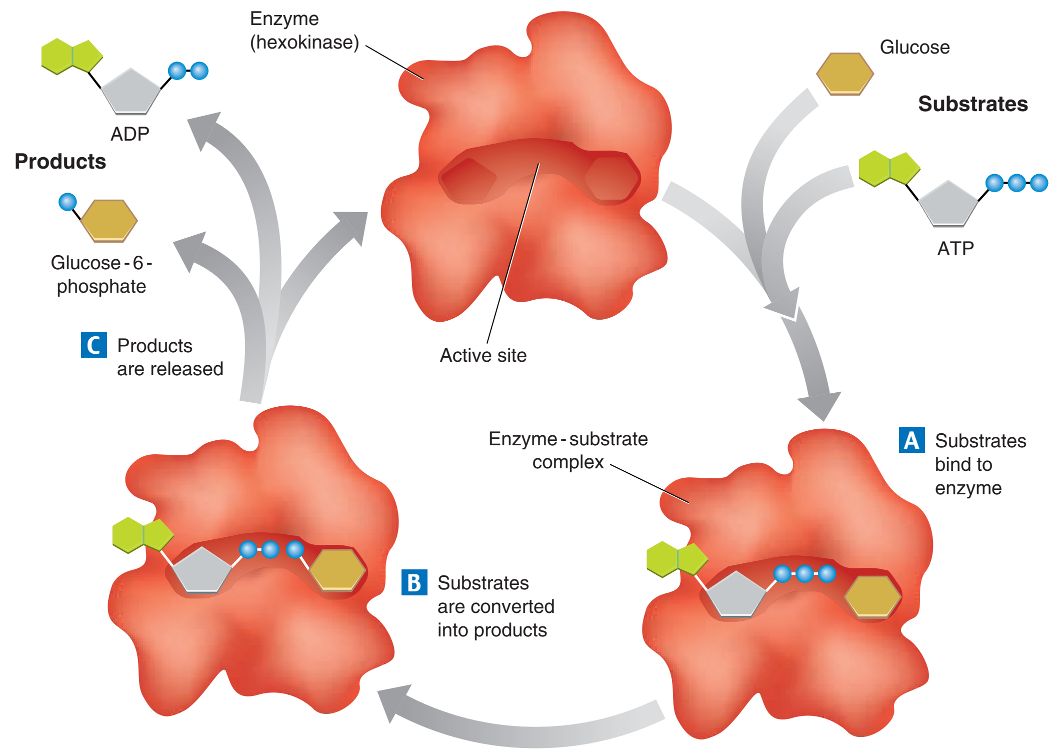
Left to itself, this reaction is so slow that carbon dioxide might build up in the body faster than the bloodstream could remove it. Your bloodstream contains an enzyme called carbonic anhydrase that speeds up the reaction by a factor of 10 million. With carbonic anhydrase on the job, the reaction takes place immediately and carbon dioxide is removed from the blood quickly.

Enzymes are very specific, generally catalyzing only one chemical reaction. For this reason, part of an enzyme's name is usually derived from the reaction it catalyzes. Carbonic anhydrase gets its name because it catalyzes the reaction that removes water from carbonic acid.

Enzyme Action

How do enzymes do their jobs? For a chemical reaction to take place, the reactants must collide with enough energy so that existing bonds will be broken and new bonds will be formed. If the reactants do not have enough energy, they will be unchanged after the collision.

The Enzyme-Substrate Complex Enzymes provide a site where reactants can be brought together to react. Such a site reduces the energy needed for reaction. The reactants of enzyme-catalyzed reactions are known as **substrates.**



▼ **Figure 2–21** The enzyme hexokinase converts the substrates glucose and ATP into glucose-6-phosphate and ADP. **Predicting** *What happens to the hexokinase after the products are released?*

BIO INSIGHTS — FACTS AND FIGURES

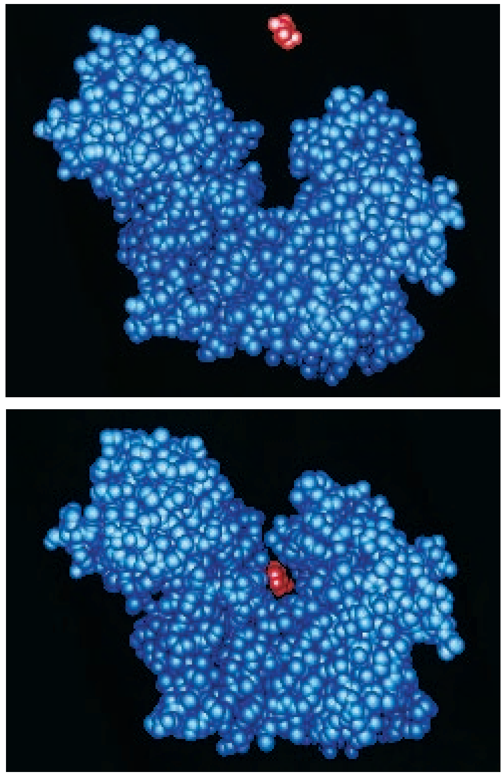
Just the right temperature
Each enzyme works best—that is, its reaction rate is fastest—at an optimal temperature. Enzymes in the human body generally function best near body temperature, or 35–40°C. Below an enzyme's optimal temperature, the reaction is slower. But, if the temperature rises above the optimal temperature, the reaction speed drops sharply because the high temperature disrupts the chemical bonds in the enzyme, which changes its shape; that is, the enzyme undergoes denaturation and is no longer functional. This is what occurs when the body has a high fever. Because denaturation is not reversible, a temperature higher than 44°C usually causes death. Enzymes in other organisms have different optimal temperatures. The bacteria in the hot springs of Yellowstone National Park, for instance, contain enzymes with optimal temperatures as high as 100°C.

Figure 2–21 provides an example of an enzyme-catalyzed reaction. The enzyme is hexokinase. The substrates are glucose and ATP. During the reaction, a phosphate group is transferred from ATP to the glucose molecule. Recall that each protein has a specific, complex shape. The substrates bind to a site on the enzyme called the active site. The active site and the substrates have complementary shapes. The fit is so precise that the active site and substrates are often compared to a lock and key.

Figure 2–22 shows a substrate fitting into an active site on an enzyme. The enzyme and substrate are bound together by intermolecular forces and form an enzyme-substrate complex. They remain bound together until the reaction is done. Once the reaction is over, the products of the reaction are released and the enzyme is free to start the process again.

Regulation of Enzyme Activity Because they are catalysts for reactions, enzymes can be affected by any variable that influences a chemical reaction. Enzymes, including those that help digest food, work best at certain pH values. Many enzymes are affected by changes in temperature. Not surprisingly, those enzymes produced by human cells generally work best at temperatures close to 37°C, the normal temperature of the human body.

Cells can regulate the activities of enzymes in a variety of ways. Most cells contain proteins that help to turn key enzymes "on" or "off" at critical stages in the life of the cell. Enzymes play essential roles in regulating chemical pathways, making materials that cells need, releasing energy, and transferring information.



▲ **Figure 2–22** This space-filling model shows how a substrate binds to an active site on an enzyme. **Interpreting Graphics** ***What happens after the substrate binds to the enzyme?***

2–4 Section Assessment

1. **Key Concept** What happens to chemical bonds during chemical reactions?
2. **Key Concept** Describe the role of energy in chemical reactions.
3. **Key Concept** What are enzymes, and how are they important to living things?
4. Describe how enzymes work, including the role of the enzyme-substrate complex.
5. **Critical Thinking Applying Concepts** A change in pH can change the shape of a protein. How might a change in pH affect the function of an enzyme such as hexokinase? (*Hint:* Think about the analogy of the lock and key.)

Sharpen Your Skills

Modeling

Make a model that demonstrates how an active site and a substrate are like a lock and a key. Give a brief talk in which you refer to your model as you explain how enzymes work.

2–4 Section Assessment

1. Bonds are broken in reactants and new bonds are formed in products.
2. Some chemical reactions release energy, and other chemical reactions absorb energy. Energy changes determine how easily a chemical reaction will occur.
3. Enzymes are biological catalysts. Living cells use enzymes to speed up virtually every important chemical reaction that takes place in cells.
4. Substrates, the reactants of an enzyme-catalyzed reaction, attach to the enzyme at an active site and form an enzyme-substrate complex. Once the complex is formed, the enzyme helps convert substrate into product.
5. A change in pH could change the shape of hexokinase. This change would diminish or possibly eliminate the ability of glucose and ATP to bind to the active site on the enzyme.

Build Science Skills

Using Analogies As students watch, open a large padlock with its key. Ask: **In a chemical reaction, which of these is like the enzyme and which is like the substrate?** *(The padlock is like the enzyme and the key is like the substrate.)* **Which place on this padlock is like an active site?** *(The keyhole)* Direct students' attention to Figure 2–22. Ask: **How is inserting a key into a lock different from the formation of an enzyme-substrate complex?** *(The enzyme changes its shape when it binds to the substrate.)* L1 L2

3 ASSESS

Evaluate Understanding

Direct students' attention to Figure 2–21, and ask them to write as full a description as possible of the chemical reaction that is illustrated. They should mention the substrates and the products, the enzyme involved, how the enzyme lowers the activation energy, and the formation of the enzyme-substrate complex.

Reteach

Call on student volunteers to explain what a chemical reaction is, the energy changes involved in reactions, and how enzymes affect the rate of biochemical reactions.

Sharpen Your Skills

Provide students with a variety of materials, including modeling compound, fabric, sponges, construction paper, and papier-mâché. Labels on the model should include *enzyme, active site,* and *substrate.* Paragraphs should explain how the model demonstrates the enzyme function.

Interactive Textbook

If your class subscribes to the iText, use it to review the Key Concepts in Section 2–4.

Answers to . . .

Figure 2–21 *It is free to form a new enzyme-substrate complex.*

Figure 2–22 *The substrate reacts and forms one or more products.*