20.4 Energy and Reaction Rate

Objectives

- **Define** activation energy and explain its role in getting a reaction started.
- **Identify** three factors that affect the rate of a chemical reaction.
- **Describe** how enzymes contribute to body processes.
- **Make** a graph showing how a catalyst lowers the activation energy of a chemical reaction.

ACTIVITY

Hypothesizing

Match Wits

Why do you think a match will do nothing if left alone, but will burst into flame if scratched lightly on a certain surface?

SKILLS WARMUP

You may wish it weren't true, but your homework won't get done if you just put your book, paper, and a pencil together on your desk. Nor will your room get clean unless you put some energy into it. Just like any activity, chemical reactions also need energy to happen. Breaking and forming chemical bonds requires energy.

Getting a Reaction Started

Some reactions, as you have seen, occur at room temperature when the reactants are mixed. For example, if you put a piece of sodium in water, the sodium will leap around the water as it reacts violently. It produces a sizzle of hydrogen bubbles, sodium hydroxide, and heat. Other reactions, however, do not occur unless some condition is changed. Heat must be added or pressure must increase.

You may be tempted to think that exothermic reactions always happen by themselves; they don't need any added energy. This inference is logical, but incorrect.

Many familiar reactions, in fact, are exothermic but need added energy before they will happen. The burning of paper, for example, is exothermic. But paper doesn't burst into flame when exposed to air. To get the reaction started, you need to add the heat energy from a lighted match. More than just the energy change of a reaction is needed to explain whether a reaction will start under a certain set of conditions. The key factor for any chemical reaction is how much energy is needed to drive its first step: the breaking of chemical bonds in the reactants.

Figure 20.14▲
What is needed to start this reaction between paper and oxygen?

Activation Energy

The flame of a match provides the energy needed to get the reactants in paper and air to begin to combine. This start-up energy is called **activation energy**. All chemical reactions need some amount of activation energy.

Look at the graph in Figure 20.15. It is an energy graph, a way of showing the energy changes that occur as a reaction goes from reactants to products. The "hill" in the graph shows the activation energy for the reaction.

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

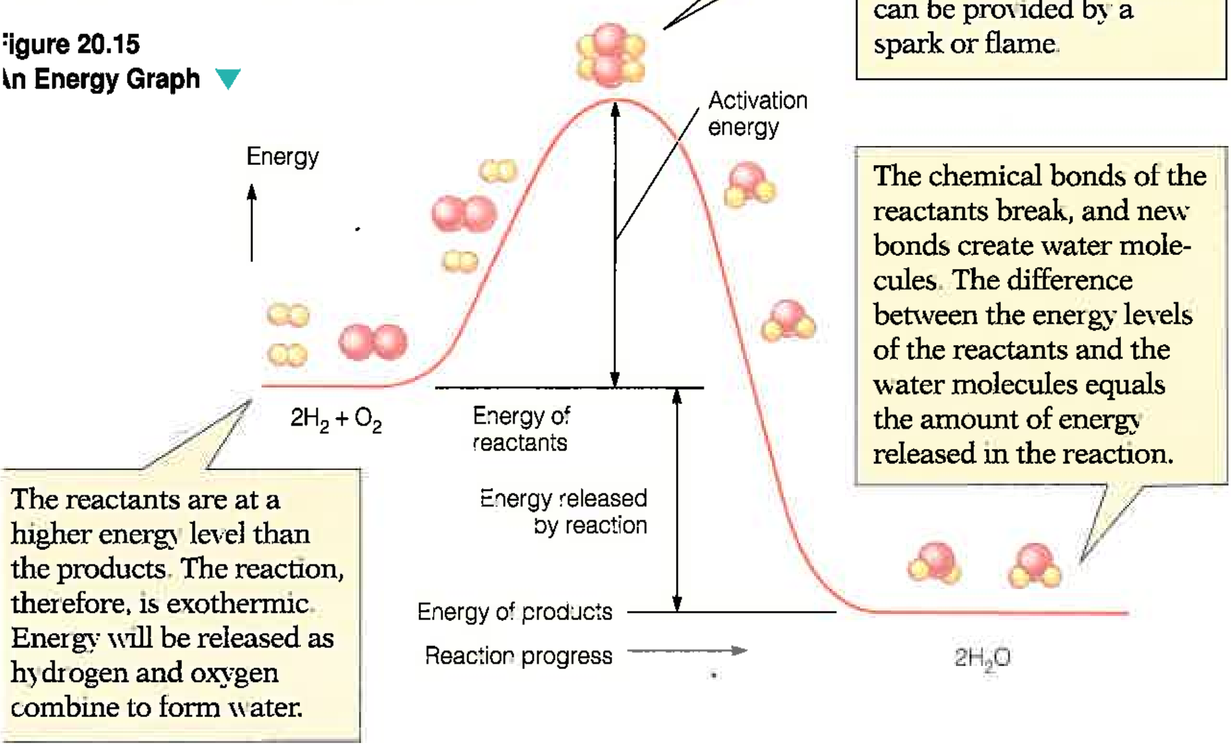
The energy it takes to get the reactants over the activation-energy hill can be compared to the energy it would take to push a boulder up a real hill.

The height of the "energy hill" determines the amount of energy needed to get a reaction started. Reactions that happen by themselves at room temperature have a low activation energy. The energy needed to start the reaction is contained in the energy of the reactants themselves, as measured by their temperature.

Once a reaction has started, the energy level of its products compared to its reactants determines whether it needs a continuous supply of added energy to keep going. An endothermic reaction needs a constant supply of added energy, even if it has a low activation energy.

An exothermic reaction, in contrast, will keep going on its own. The burning of paper is a good example. The energy released as some molecules react provides the activation energy other molecules need to start reacting.

Figure 20.15
An Energy Graph ▼



Reaction Rate

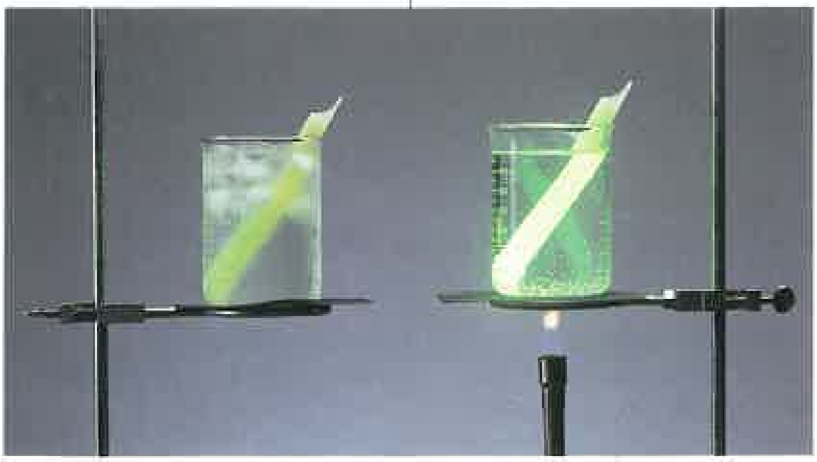
A chemical reaction occurs when reactant particles collide with enough energy to break and form chemical bonds. The more reactant particles there are, the more collisions there will be. With more reactant particles, the speed, or rate, of a reaction increases. The reaction rate also increases when the force of the collisions between reacting particles increases. You can control the rate of a reaction, therefore, by changing factors that affect the collisions between reacting particles.

Surface Area

◀ Have you ever made a fire in a fireplace? Several small pieces of wood ignite faster than one big piece. Why? The total surface area of several small objects is much greater than that of one object with the same volume. Greater surface area means more reactant particles come in contact with each other, causing an increase in the rate of reaction. Solids, for example, react much faster as powders because powders have a very large surface area.

Temperature

An increase in temperature makes particles absorb energy and move faster. They collide more often and with more energy. As a result, more particles react. You can see that the reaction causing a light stick to glow happens faster at a higher temperature. ▼



Concentration ▲

A candle burns much faster in pure oxygen than it does in air. The difference is in the number of oxygen molecules available to react with the candle wax. When more particles are packed into a certain space, the number of collisions increases. Therefore, an increase in the concentration of one or more reactants increases the reaction rate.

Catalysts

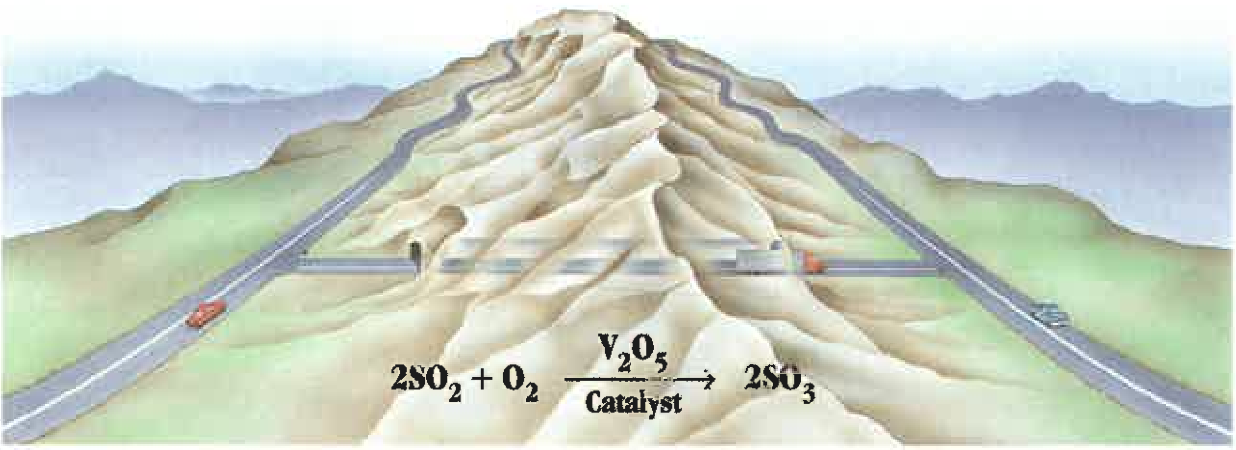
Many chemical reactions can be made to go much more rapidly without raising the temperature, and without increasing the surface area or concentration of the reactants. All that's necessary is to add a small amount of a substance that speeds up a reaction without being used up in the process, a **catalyst** (CAT uh lihst).

The effect of a catalyst is often very dramatic. If you pour a solution of the common disinfectant, hydrogen peroxide, into a beaker, it will take months for a small amount to decompose quietly into water and oxygen. Add a pinch of the catalyst manganese dioxide (MnO_2), however, and the hydrogen peroxide will decompose so rapidly that oxygen gas fizzes out. How does a catalyst produce such results?

Recall that for a chemical reaction to proceed, it needs a certain amount of activation energy. A catalyst lowers the amount of activation energy needed for a reaction to take place. A catalyst does this by providing the necessary energy.

Look at Figure 20.16. It compares a chemical reaction to driving over a hill. Both actions require energy.

igure 20.16
ffect of a Catalyst ▼



Colliding oxygen and ulfur dioxide molecules ıust overcome a large ctivation energy to react nd form sulfur trioxide. It ; as if they must climb a teep mountain.

The addition of the catalyst V_2O_5 lowers the activation energy of the reaction. It's like using a tunnel through a mountain. Colliding reactants don't need as much energy to react.

With the catalyst, the reaction proceeds rapidly. Large amounts of the product, sulfur trioxide, can be produced because more reactants have the energy needed to react.

Once energy has been used to get up the hill, going downhill is easy. A catalyst is compared to a shortcut through the mountain tunnel. It reduces the energy required and allows the reaction to take place.

A catalyst is neither a reactant nor a product in a chemical reaction. When the reaction is over, all the added catalyst can be recovered. When you write an equation for a reaction that uses a catalyst, the catalyst is written above the yield sign. Look at Figure 20.16 to see how this is done.

Catalysts are vital in the manufacturing of many products. Using a catalyst saves energy and reduces costs. A small amount of catalyst can be used over and over. Catalysts are especially useful when changing the factors of temperature, surface area, or concentration is impractical or expensive. Some of the common products that require the aid of catalysts are ammonia, polyester, margarine, and gasoline.

Life Science LINK

There are many catalysts that speed up reactions in the human body. One of these is salivary amylase, which is produced in the mouth. Salivary amylase breaks down starches into sugars called glucose and maltose.

Obtain some saltine crackers. Put one in your mouth and chew it until it tastes sweet.

Write a word equation for the breakdown of starch in your mouth.

ACTIVITY

Career Corner *Quality-Control Chemist*

Who Checks the Quality of Products?

When you wash your hair, how do you know the shampoo won't damage it? Most chemical products used by people are tested for harmful side effects before they are put on the market. Thus, you can be fairly confident that the products won't hurt you.

What if something goes wrong, however, in the manufacturing process? Could a bad batch of a product harm you? Not if the quality-control chemists do their jobs.

Quality-control chemists work in laboratories where they test samples of the different products that people buy. These chemists make sure that the products contain just the right kinds and amounts of chemicals they are supposed to contain.

If you want to be a quality-control chemist, you need to be good at math. You should also like to work with electronic instruments. A quality-control chemist needs to pay careful attention to a great number of details. A single wrong calculation or missed reading of a number on a computer screen could endanger the health of many consumers.

To get a job as a quality-control chemist, you need a bachelor's degree in chemistry. In high school, you should take classes in biology, chemistry, physics, algebra, and geometry. English composition and computer classes are also good preparation for this career.

ACTIVITY

Hypothesizing

Catalysts

Using the particle model of matter, form a hypothesis that explains how a catalyst can take part in a chemical reaction but not be changed in the process.

SKILLS WORKOUT

Enzymes: Biological Catalysts

If you chew a potato for a few minutes, you will begin to taste something sweet. Since there is no sugar in the potato, where does the sweet taste come from? The salivary glands in your mouth produce a catalyst that helps split starch molecules in the potato into sugar molecules.

Organisms produce many such catalysts. These biological catalysts are called **enzymes**. Enzymes are protein molecules that control the rate of chemical reactions that occur in living things. Each enzyme affects a specific reaction. These reactions occur thousands or even millions of times faster with enzymes than they would without them.

Some enzymes, such as the one that converts starch to sugar, play a role in the digestion of foods. Other enzymes help in the conduction of nerve impulses, the clotting of blood, the contraction of muscle tissue, and the everyday functioning of cells, tissues, and organs.

Of the more than 2,000 enzymes known to be produced by various living things, about 150 have commercial uses. Cheese, for example, is made with the aid of an enzyme called rennin. Candy makers use an enzyme called invertase to create liquid-centered candies, such as chocolate-covered cherries.

'igure 20.17
, cheesemaker checks the consistency of milk that has been urdled by rennin.

Science and Technology
Catalytic Converters and Smog Reduction

Explosive chemical reactions inside a car's engine are what make the crankshaft turn and the wheels go around. Gasoline reacts with oxygen in the air to form water, carbon dioxide, and energy. In the high temperatures that exist in an engine cylinder, other reactions also occur. Nitrogen in the air reacts with the gasoline to form various oxides of nitrogen. Some of the gasoline doesn't burn completely, producing carbon monoxide (CO) and other substances that are known to be harmful to people.

Over the past 20 years, efforts have been made to reduce the amount of harmful gases in automobile exhaust. One of the most important anti-smog devices is the catalytic converter introduced in 1975. A catalytic converter is a mufflerlike reaction chamber installed in a vehicle's exhaust system. It contains several catalysts, usually finely divided metals, such as platinum, palladium, and rhodium.

Look at the diagram of a catalytic converter in Figure 20.18. When a mixture of exhaust gases from the engine and outside air passes over the catalysts, several chemical reactions occur. These reactions change harmful gases into compounds that are safe for both people and the environment.

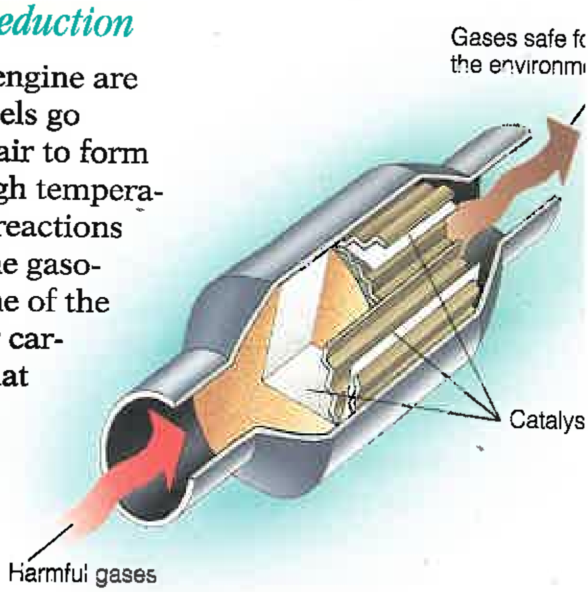


Figure 20.18 ▲
What is the purpose of an automobile's catalytic converter?

Check and Explain

1. What is activation energy? Draw an energy graph and identify the activation energy.
2. Name three ways to increase the rate of a reaction. Explain how each works.
3. **Reason and Conclude** Use an everyday example to explain why the surface area, temperature, and concentration of reactants affect the rate of a reaction.
4. **Make a Graph** A catalyst lowers the activation energy of a certain exothermic reaction by 50 percent. Draw an energy graph showing both the catalyzed and uncatalyzed reactions. Label all of the parts of your graph.

ctivity 20 *How do some everyday substances react chemically?*

ills Observe; Infer; Interpret Data

sk 1 Prelab Prep

ıllect the following items: iron nail, beaker or ıss jar, test tube, copper sulfate solution, gar, test-tube holder, Bunsen burner.

sk 2 Data Record

ı a separate sheet of paper, copy the data ɔle shown. Use the table to record your obser-tions of the chemical reactions.

ısk 3 Procedure

Put the iron nail in the beaker or jar.
Add enough copper sulfate solution to the beaker to cover the nail. Set the beaker aside while you do the next two steps.
Place about 1 cm of sugar into the test tube.
Light the Bunsen burner. Using the test-tube holder, hold the test tube over the tip of the Bunsen burner flame. Move the test tube around in the flame in order to heat the sugar evenly. **CAUTION! Wear your goggles. Be careful around the open flame. When heating a test tube, hold the open end away from you.**
Record in your data table what happens as the sugar is heated.
Observe the nail in the copper sulfate solution. Has any change occurred? If not, wait 5 minutes or more.
Record in your data table the changes you observe in the nail and the copper sulfate solution.

Task 4 Analysis

1. What changes occurred when you heated the sugar?
2. The formula for sugar is $C_{12}H_{22}O_{11}$. Based on this information and your observations, how many new substances do you think were formed when the sugar was heated? Give reasons for your answer.
3. What type of chemical reaction do you think took place in the sugar?
4. What changes did you observe in the nail or copper sulfate?
5. The formula for copper sulfate is $CuSO_4$. Iron (Fe) replaces the copper in copper sulfate. Knowing this, what do you think makes up the coating you observed on the nail?
6. What type of chemical reaction occurred between the nail and the copper sulfate? How do you know?

Task 5 Conclusion

Describe the two chemical reactions. Explain how they differ.

Everyday Application

What happens when food is heated too hot or for too long? What chemical change occurs? How do you prevent this from happening when you cook your food?

Extension

Write balanced equations for both reactions in this activity.

Reactants	Evidence of Chemical Reaction
Heated sugar	
Copper sulfate and iron	