2.4 Chemical Reactions

VOCABULARY

chemical reaction
reactant
product
bond energy
equilibrium
activation energy
exothermic
endothermic

KEY CONCEPT **Life depends on chemical reactions.**

MAIN IDEAS

- Bonds break and form during chemical reactions.
- Chemical reactions release or absorb energy.

Connect to Your World

When you hear the term *chemical reaction,* what comes to mind? Maybe you think of liquids bubbling in beakers. You probably do not think of the air in your breath, but most of the carbon dioxide and water vapor that you breathe out are made by chemical reactions in your cells.

MAIN IDEA

Bonds break and form during chemical reactions.

Plant cells make cellulose by linking simple sugars together. Plant and animal cells break down sugars to get usable energy. And all cells build protein molecules by bonding amino acids together. These are just a few of the chemical reactions in living things. **Chemical reactions** change substances into different substances by breaking and forming chemical bonds.

Reactants, Products, and Bond Energy

Your cells need the oxygen molecules that you breathe in. Oxygen (O_2) plays a part in a series of chemical reactions that provides usable energy for your cells. These reactions, which are described in detail in the chapter Cells and Energy, break down the simple sugar glucose ($C_6H_{12}O_6$). The process uses oxygen and glucose and results in carbon dioxide (CO_2), water (H_2O), and usable energy. Oxygen and glucose are the reactants. **Reactants** are the substances changed during a chemical reaction. Carbon dioxide and water are the products. **Products** are the substances made by a chemical reaction. Chemical equations are used to show what happens during a reaction. The overall equation for the process that changes oxygen and glucose into carbon dioxide and water is

$$6O_2 + C_6H_{12}O_6 \longrightarrow 6CO_2 + 6H_2O$$

Reactants   Direction   Products

The reactants are on the left side of the equation, and the products are on the right side. The arrow shows the direction of the reaction. This process, which is called cellular respiration, makes the carbon dioxide and water vapor that you breathe out. But for carbon dioxide and water to be made, bonds must be broken in the reactants, and bonds must form in the products. What causes bonds in oxygen and glucose molecules to break? And what happens when new bonds form in carbon dioxide and water?

FIGURE 4.1 The breakdown of glucose provides chemical energy for all activities, including speed skating.

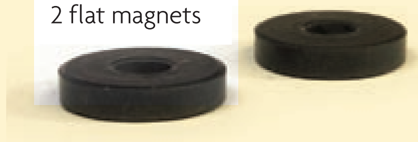
QUICK LAB **MODELING**

Chemical Bonding

You use energy to put things together, but chemical bonding is different. Energy is added to break bonds, and energy is released when bonds form.

MATERIALS

2 flat magnets



PROBLEM How is chemical bonding similar to the interaction between two magnets?

PROCEDURE

1. Bring the magnets close to each other until they snap together.
2. Pull the magnets away from each other.

ANALYZE AND CONCLUDE

1. **Infer** How is bond formation represented by the snapping sound?
2. **Apply** How is bond energy related to your separation of the magnets?

First, energy is added to break bonds in molecules of oxygen and glucose. **Bond energy** is the amount of energy that will break a bond between two atoms. Bonds between different types of atoms have different bond energies. A certain amount of energy is needed to break bonds in an oxygen molecule. A different amount of energy is needed to break bonds in a glucose molecule.

Energy is released when bonds form, such as when molecules of water and carbon dioxide are made. When a bond forms, the amount of energy released is equal to the amount of energy that breaks the same bond. For example, energy is released when hydrogen and oxygen atoms bond to form a water molecule. The same amount of energy is needed to break apart a water molecule.

Chemical Equilibrium

Some reactions go from reactants to products until the reactants are used up. However, many reactions in living things are reversible. They move in both directions at the same time. These reactions tend to go in one direction or the other depending on the concentrations of the reactants and products. One such reaction lets blood, shown in **FIGURE 4.2**, carry carbon dioxide. Carbon dioxide reacts with water in blood to form a compound called carbonic acid (H_2CO_3). Your body needs this reaction to get rid of carbon dioxide waste from your cells.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

The arrows in the equation above show that the reaction goes in both directions. When the carbon dioxide concentration is high, as it is around your cells, the reaction moves toward the right and carbonic acid forms. In your lungs, the carbon dioxide concentration is low. The reaction goes in the other direction, and carbonic acid breaks down.

When a reaction takes place at an equal rate in both directions, the reactant and product concentrations stay the same. This state is called equilibrium. **Equilibrium** (EE-kwuh-LIHB-ree-uhm) is reached when both the reactants and products are made at the same rate.

Apply **Explain why concentration is important in a chemical reaction.**

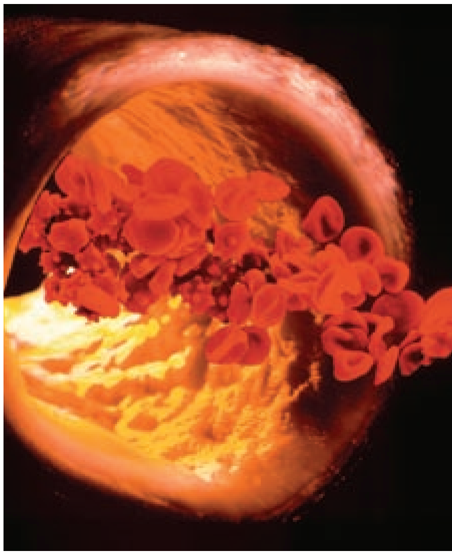


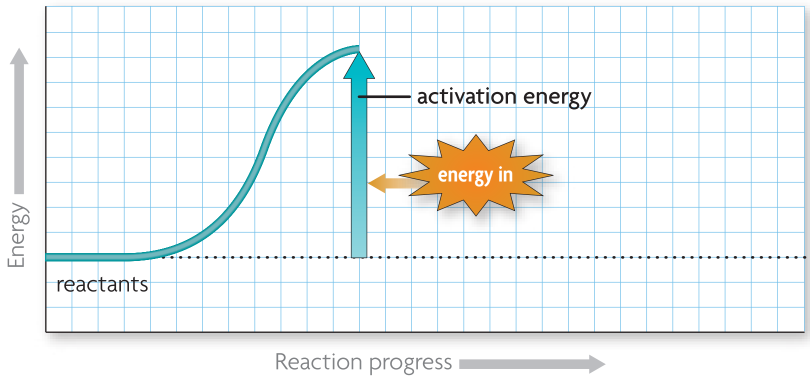
FIGURE 4.2 Blood cells and plasma transport materials throughout the body. Carbonic acid dissolves in the blood so that carbon dioxide can be transported to the lungs. (composite colored SEM; magnification 1000×)

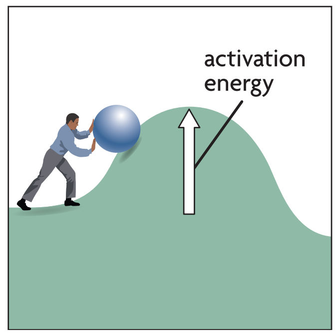
FIGURE 4.3 Energy and Chemical Reactions

Energy is required to break bonds in reactants, and energy is released when bonds form in products. Overall, a chemical reaction either absorbs or releases energy.

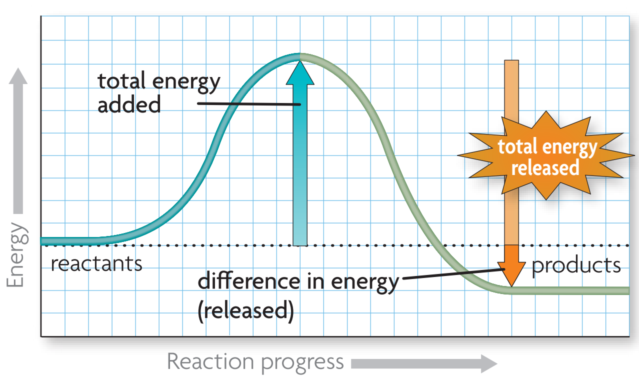
ACTIVATION ENERGY

When enough activation energy is added to the reactants, bonds in the reactants break and the reaction begins.



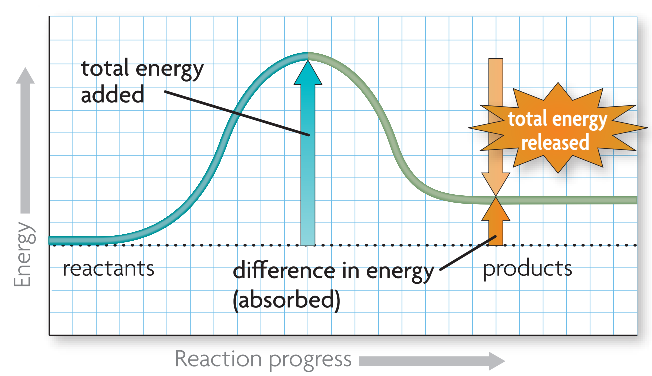


EXOTHERMIC REACTION Energy Released



The products in an exothermic reaction have a lower bond energy than the reactants, and the difference in bond energy is released to the surroundings.

ENDOTHERMIC REACTION Energy Absorbed



The products in an endothermic reaction have a higher bond energy than the reactants, and the difference in bond energy is absorbed from the surroundings.

CRITICAL VIEWING **Is the amount of activation energy related to whether a reaction is exothermic or endothermic? Why or why not?**

MAIN IDEA

Chemical reactions release or absorb energy.

All chemical reactions involve changes in energy. Energy that is added to the reactants breaks their chemical bonds. When new bonds form in the products, energy is released. This means that energy is both absorbed and released during a chemical reaction. Some chemical reactions release more energy than they absorb. Other chemical reactions absorb more energy than they release. Whether a reaction releases or absorbs energy depends on bond energy.

Some energy must be absorbed by the reactants in any chemical reaction. **Activation energy** is the amount of energy that needs to be absorbed for a chemical reaction to start. Activation energy is like the energy you would need to push a rock up a hill. Once the rock is at the top of the hill, it rolls down the other side by itself. A graph of the activation energy that is added to start a chemical reaction is shown at the top of **FIGURE 4.3.**

An **exothermic** chemical reaction releases more energy than it absorbs. If the products have a lower bond energy than the reactants, the reaction is exothermic. The excess energy—the difference in bond energy between the reactants and products—is often given off as heat or light. Some animals, such as squids and fireflies, give off light that comes from exothermic reactions, as shown in **FIGURE 4.4.** Cellular respiration, the process that uses glucose and oxygen to provide usable energy for cells, is also exothermic. Cellular respiration releases not only usable energy for your cells but also heat that keeps your body warm.

An **endothermic** chemical reaction absorbs more energy than it releases. If products have a higher bond energy than reactants, the reaction is endothermic. Energy must be absorbed to make up the difference. One of the most important processes for life on Earth, photosynthesis, is endothermic. During photosynthesis, plants absorb energy from sunlight and use that energy to make simple sugars and complex carbohydrates.

Analyze **How is activation energy related to bond energy?**

READING TOOLBOX

VOCABULARY

The prefix *exo-* means “out,” and the prefix *endo-* means “in.” Energy “moves out of” an exothermic reaction, and energy “moves into” an endothermic reaction.

FIGURE 4.4 The glow of the bugeye squid comes from an exothermic reaction that releases light.

2.4 Formative Assessment

REVIEWING MAIN IDEAS

1. Hydrogen peroxide (H_2O_2) breaks down into water (H_2O) and oxygen (O_2). Explain why this is a **chemical reaction**. What are the **reactants** and the **products** in the reaction?
2. How do endothermic and exothermic reactions differ?

CRITICAL THINKING

3. **Infer** The process below is exothermic. What must be true about the **bond energies** of the reactants and the products? Explain.

$$6O_2 + C_6H_{12}O_6 \longrightarrow 6CO_2 + 6H_2O$$

4. **Evaluate** Why might it not always be possible to determine the reactants and the products in a reaction? Explain your answer in terms of chemical **equilibrium.**

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CONNECT TO BIOCHEMISTRY

5. A chemical reaction can start when enough **activation energy** is added to the reactants. Do you think the activation energy for chemical reactions in living things is high or low? Explain your answer.