KEY CONCEPT

12.3 Chemical reactions involve energy changes.

BEFORE, you learned

- Bonds are broken and made during chemical reactions
- Mass is conserved in all chemical reactions
- Chemical reactions are represented by balanced chemical equations

NOW, you will learn

- About the energy in chemical bonds between atoms
- Why some chemical reactions release energy
- Why some chemical reactions absorb energy

VOCABULARY

bond energy p. 410
exothermic reaction p. 411
endothermic reaction p. 411
photosynthesis p. 414

EXPLORE Energy Changes

How can you identify a transfer of energy?

PROCEDURE

1. Pour 50 mL of hot tap water into the cup and place the thermometer in the cup.
2. Wait 30 seconds, then record the temperature of the water.
3. Measure 5 tsp of Epsom salts. Add the Epsom salts to the cup and immediately record the temperature while stirring the contents of the cup.
4. Continue to record the temperature every 30 seconds for 2 minutes.

WHAT DO YOU THINK?

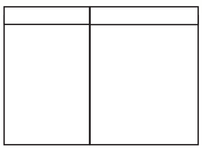
- What happened to the temperature after you added the Epsom salts?
- What do you think caused this change to occur?

MATERIALS

- graduated cylinder
- hot tap water
- plastic cup
- thermometer
- stopwatch
- plastic spoon
- Epsom salts

Chemical reactions release or absorb energy.

COMBINATION NOTES
Use combination notes to organize information on how chemical reactions absorb or release energy.



Chemical reactions involve breaking bonds in reactants and forming new bonds in products. Breaking bonds requires energy, and forming bonds releases energy. The energy associated with bonds is called **bond energy.** What happens to this energy during a chemical reaction?

Chemists have determined the bond energy for bonds between atoms. Breaking a bond between carbon and hydrogen requires a certain amount of energy. This amount of energy is different from the amount of energy needed to break a bond between carbon and oxygen, or between hydrogen and oxygen.

Energy is needed to break bonds in reactant molecules. Energy is released when bonds are formed in product molecules. By adding up the bond energies in the reactants and products, you can determine whether energy will be released or absorbed.

If more energy is released when the products form than is needed to break the bonds in the reactants, then energy is released during the reaction. A reaction in which energy is released is called an **exothermic reaction.**

If more energy is required to break the bonds in the reactants than is released when the products form, then energy must be added to the reaction. That is, the reaction absorbs energy. A reaction in which energy is absorbed is called an **endothermic reaction.**

These types of energy changes can also be observed in different physical changes such as dissolving or changing state. The state change from a liquid to a solid, or freezing, releases energy—this is an exothermic process. The state change from a solid to a liquid, or melting, absorbs energy—this is an endothermic process.

CHECK YOUR READING How are exothermic and endothermic reactions different?

The white clouds of water vapor are formed by the exothermic reaction between hydrogen and oxygen.

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

Exothermic reactions release energy.

Exothermic chemical reactions often produce an increase in temperature. In exothermic reactions, the bond energies of the reactants are less than the bond energies of the products. As a result, less energy is needed to break the bonds in the reactants than is released during the formation of the products. This energy difference between reactants and products is often released as heat. The release of heat causes a change in the temperature of the reaction mixture.

Even though energy is released by exothermic reactions, some energy must first be added to break bonds in the reactants. In exothermic reactions, the formation of bonds in the products releases more energy. Overall, more energy is released than is added.

Some reactions are highly exothermic. These reactions produce a great deal of heat and significantly raise the temperature of their surroundings. One example is the reaction of powdered aluminum metal with a type of iron oxide, a reaction known as the thermite reaction. The equation for this reaction is

$$2Al + Fe_2O_3 \longrightarrow Al_2O_3 + 2Fe$$

This reaction releases enough heat to melt the iron that is produced. In fact, this reaction is used to weld iron rails together.

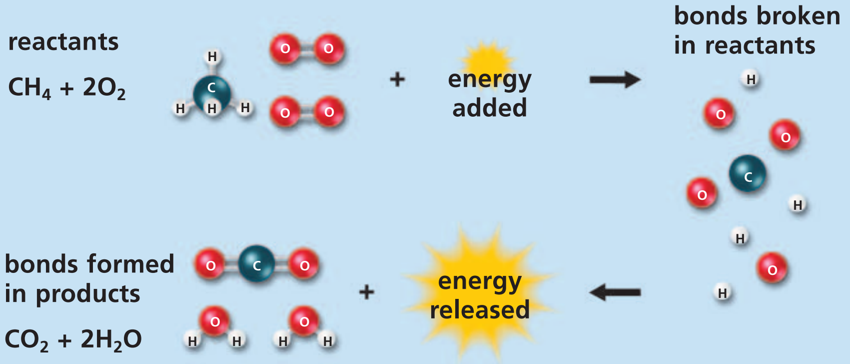
CHECK YOUR READING What is evidence for an exothermic chemical reaction?

The thermite reaction releases enough heat to weld pieces of iron together.

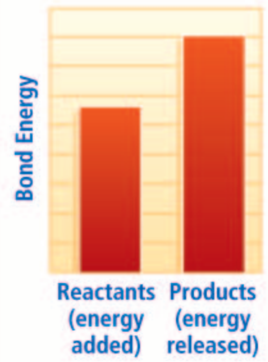
Exothermic Reactions

The products have greater bond energies than the reactants.

Methane Combustion



Difference in Energy



More energy is released than added.

READING VISUALS What information in the diagram shows that methane combustion is exothermic?

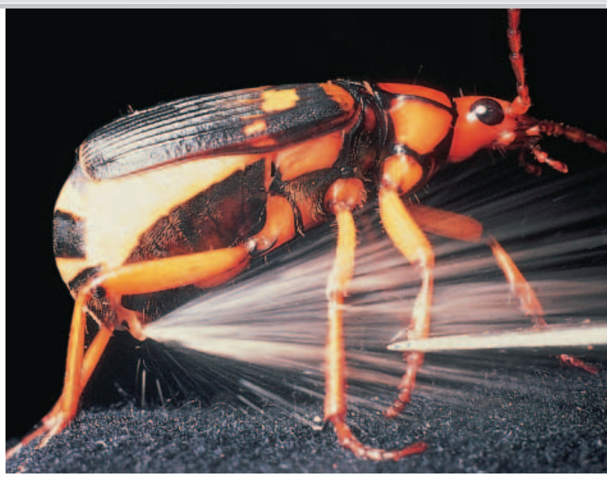
All common combustion reactions, such as the combustion of methane, are exothermic. To determine how energy changes in this reaction, the bond energies in the reactants—oxygen and methane—and in the products—carbon dioxide and water—can be added and compared. This process is illustrated by the diagram shown above. The difference in energy is released to the surrounding air as heat.

Some chemical reactions release excess energy as light instead of heat. For example, glow sticks work by a chemical reaction that releases energy as light. One of the reactants, a solution of hydrogen peroxide, is contained in a thin glass tube within the plastic stick. The rest of the stick is filled with a second chemical and a brightly colored dye. When you bend the stick, the glass tube inside it breaks and the two solutions mix. The result is a bright glow of light.

These cup coral polyps glow because of exothermic chemical reactions.

Exothermic chemical reactions also occur in living things. Some of these reactions release energy as heat, and others release energy as light. Fireflies light up due to a reaction that takes place between oxygen and a chemical called luciferin. This type of exothermic reaction is not unique to fireflies. In fact, similar reactions are found in several different species of fish, squid, jellyfish, and shrimp.

CHECK YOUR READING In which ways might an exothermic reaction release energy?



The bombardier beetle, shown in the photograph on the right, uses natural exothermic reactions to defend itself. Although several chemical reactions are involved, the end result is the production of a hot, toxic spray. The most important reaction in the process is the decomposition of hydrogen peroxide into water and oxygen.

$$2H_2O_2 \longrightarrow 2H_2O + O_2$$

When the hydrogen peroxide rapidly breaks down, the hot, toxic mixture made by the series of reactions is pressurized by the oxygen gas from the reaction in the equation above. After enough pressure builds up, the beetle can spray the mixture.

Endothermic reactions absorb energy.

Endothermic reactions often produce a decrease in temperature. In endothermic reactions, the bond energies of the reactants are greater than the bond energies of the products. As a result, more energy is needed to break the bonds in the reactants than is released during the formation of the products. The difference in energy is usually absorbed from the surroundings as heat. This often causes a decrease in the temperature of the reaction mixture.

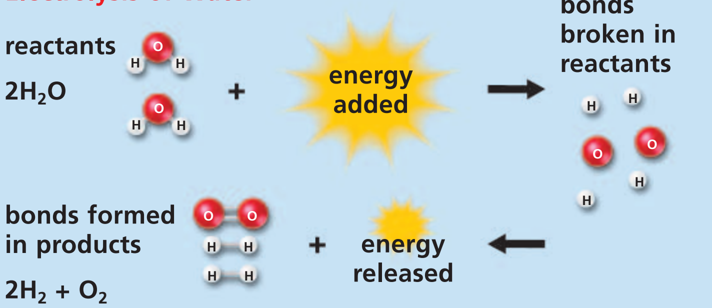
READING TIP The prefix *endo-* means "inside."

All endothermic reactions absorb energy. However, they do not all absorb energy as heat. One example of an endothermic reaction of this type is the decomposition of water by electrolysis. In this case, the energy that is absorbed is in the form of electrical energy. When the electric current is turned off, the reaction stops. The change in energy that occurs in this reaction is shown below.

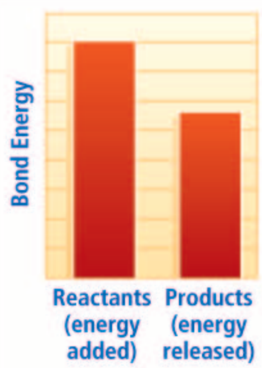
Endothermic Reactions

The products have lower bond energies than the reactants.

Electrolysis of Water



Difference in Energy



More energy is added than released.

READING VISUALS What information in the diagram shows that the decomposition of water is endothermic?

Probably the most important series of endothermic reactions on Earth is photosynthesis. Many steps occur in the process, but the overall chemical reaction is

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

Unlike many other endothermic reactions, photosynthesis does not absorb energy as heat. Instead, during **photosynthesis,** plants absorb energy from sunlight to turn carbon dioxide and water into oxygen and glucose, which is a type of sugar molecule. The energy is stored in the glucose molecules, ready to be used when needed.

CHECK YOUR READING How can you determine if a reaction is endothermic?

Exothermic and endothermic reactions work together to supply energy.

When thinking about exothermic and endothermic reactions, it is often useful to consider energy as part of the reaction. An exothermic reaction releases energy, so energy is on the product side of the chemical equation. An endothermic reaction absorbs energy, so energy is on the reactant side of the chemical equation.

Exothermic Reaction

Reactants $\longrightarrow$ Products + Energy

Endothermic Reaction

Reactants + Energy $\longrightarrow$ Products

As you can see in the general reactions above, exothermic and endothermic reactions have opposite energy changes. This means that if an exothermic chemical reaction proceeds in the opposite direction, it becomes an endothermic reaction that absorbs energy. Similarly, if an endothermic reaction proceeds in the opposite direction, it becomes an exothermic reaction that releases energy.

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View examples of endothermic and exothermic reactions.

CHECK YOUR READING What happens when an exothermic reaction is reversed?

A large amount of the energy we use on Earth comes from the Sun. This energy includes energy in fossil fuels such as coal and petroleum, as well as energy obtained from food. In all of these cases, the energy in sunlight is stored by endothermic reactions. When the energy is needed, it is released by exothermic reactions.

This combination of reactions forms a cycle of energy storage and use. For example, examine the photosynthesis equation at the top of the page. If you look at this equation in reverse—that is, if the direction of the arrow is reversed—it is a combustion reaction, with oxygen and glucose as the reactants, and it is exothermic.

Plants such as trees store energy through photosynthesis. Cars and trucks release this energy through combustion.

Plants store energy through the endothermic reactions of photosynthesis. Living things can release this energy through a series of exothermic reactions that will be described in the next section.

The energy stored in plants through photosynthesis can also be released in other ways. Consider energy from fossil fuels. Fossil fuels include petroleum, natural gas, and coal. These substances formed from fossilized materials, mainly plants, that had been under high pressures and temperatures for millions of years. When these plants were alive, they used photosynthesis to produce glucose and other molecules from carbon dioxide and water.

The energy stored in the bonds of these molecules remains, even though the molecules have changed over time. The burning of gasoline in a car releases this energy, enabling the car's engine to work. Similarly, the burning of coal in a power plant, or the burning of natural gas in a stove, releases the energy originally stored by the endothermic series of photosynthesis reactions.

CHECK YOUR READING How can endothermic and exothermic reactions work together?

12.3 Review

KEY CONCEPTS

1. What are the differences between exothermic and endothermic reactions?
2. Is the combustion of methane an exothermic or endothermic reaction? Explain.
3. Is photosynthesis an exothermic or endothermic reaction? Explain.

CRITICAL THINKING

4. **Synthesize** Describe the connections between the processes of photosynthesis and combustion.
5. **Communicate** Explain how most energy used on Earth can be traced back to the Sun.

CHALLENGE

6. **Synthesize** Electrolysis of water is endothermic. What does this indicate about the bond energy in the reactants and products? What happens when this reaction is reversed?