CHAPTER

15 Chemical Reactions

Imagine . . .

A car slams into a wall at 97 km/h (60 mph). Although both occupants are wearing seat belts, one suffers a crushing blow to the head as he strikes the dashboard. The other occupant suffers only minor bruises thanks to the presence of an air bag. Fortunately, no one was really injured because this was just a crash test using dummies. The results of this test could lead to the design of better air bags.

The key to an air bag's success during a crash is the speed at which it inflates. Inside the bag is a gas generator that contains the compounds sodium azide, potassium nitrate, and silicon dioxide. At the moment of a crash, an electronic sensor in the vehicle detects the sudden decrease in speed. The sensor sends a small electric current to the gas generator, providing the *activation energy,* or the energy needed to start the reaction, to the chemicals in the gas generator.

The rate, or speed, at which the reaction occurs is very fast. In 1/25 of a second—less than the blink of an eye—the gas formed in the reaction inflates the bag. The air bag fills upward and outward. By filling the space between a person and the car's dashboard, the air bag protects him or her from injury.

Designers of air bags must understand a lot about chemical reactions. In this chapter, you will learn about the different types of chemical reactions. You will learn the clues that will help you identify when a chemical reaction is taking place. You will also learn about the factors that affect the rate of a reaction.

The reaction between vinegar and baking soda produces a gas. However, the reaction is too slow for use in an air bag.

Investigate!

What Do You Think?

In your ScienceLog, try to answer the following questions based on what you already know:

1. What clues can help you identify a chemical reaction?
2. What are some types of chemical reactions?
3. How can you change the rate of a chemical reaction?

Reaction Ready

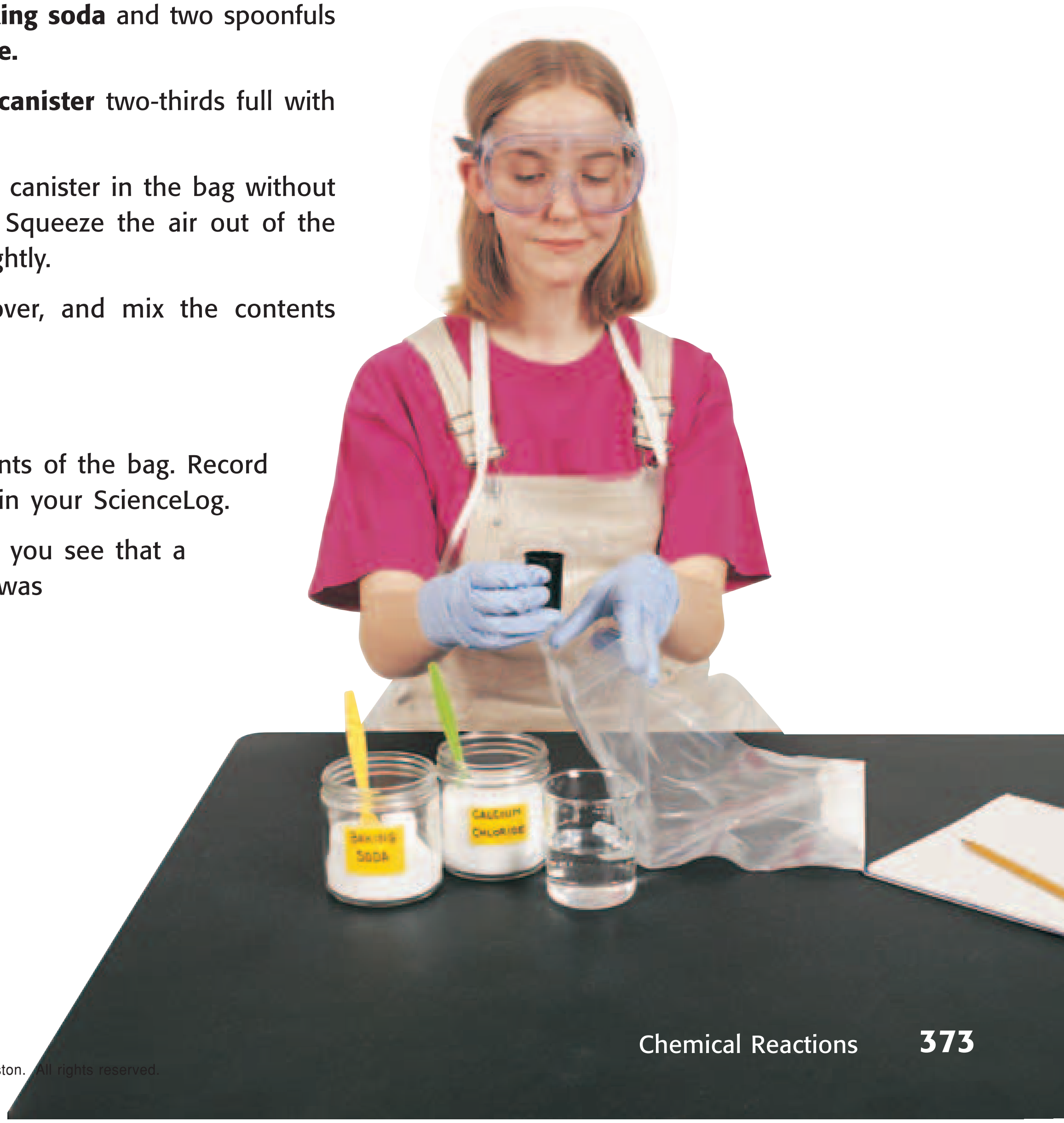
The reactions that occur in an air bag produce the gas that fills the bag. In fact, the production of a gas is often a sign that a chemical reaction is taking place. In this activity, you will observe a reaction and identify signs that indicate that a reaction is taking place.

Procedure

1. In a **large, sealable plastic bag,** place one plastic spoonful of **baking soda** and two spoonfuls of **calcium chloride.**
2. Fill a **plastic film canister** two-thirds full with **water.**
3. Carefully place the canister in the bag without spilling the water. Squeeze the air out of the bag, and seal it tightly.
4. Tip the canister over, and mix the contents of the bag.

Analysis

5. Observe the contents of the bag. Record your observations in your ScienceLog.
6. What evidence did you see that a chemical reaction was taking place?



Section 1

Forming New Substances

NEW TERMS

chemical reaction
chemical formula
subscript
chemical equation
reactants
products
coefficient
law of conservation of mass

OBJECTIVES

- Identify the clues that indicate a chemical reaction might be taking place.
- Interpret and write simple chemical formulas.
- Interpret and write simple balanced chemical equations.
- Explain how a balanced equation illustrates the law of conservation of mass.

Each fall, an amazing transformation takes place. Leaves change color, as shown in **Figure 1.** Vibrant reds, oranges, and yellows that had been hidden by green all year are seen as the temperatures get cooler and the hours of sunlight become fewer. What is happening to cause this change? Leaves have a green color as a result of a compound called chlorophyll (KLOR uh FIL). Each fall, the chlorophyll undergoes a chemical change and forms simpler substances that have no color. The green color of the chlorophyll no longer hides them, so the red, orange, and yellow colors in the leaves can be seen.

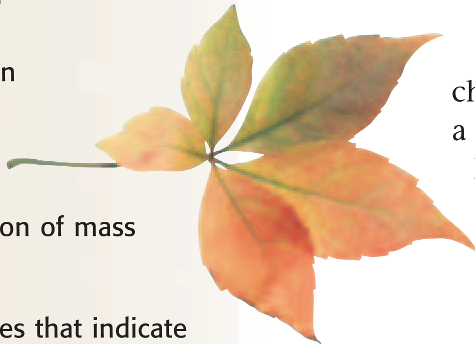


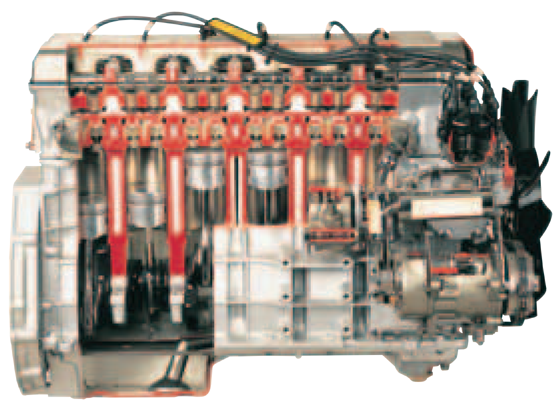
Figure 1 *The change of color in the fall is a result of chemical changes in the leaves.*

Chemical Reactions

The chemical change that occurs as chlorophyll breaks down into simpler substances is one example of a chemical reaction. A **chemical reaction** is the process by which one or more substances undergo change to produce one or more different substances. These new substances have different chemical and physical properties from the original substances. Many of the changes you are familiar with are chemical reactions, including the ones shown in **Figure 2.**

Figure 2 Examples of Chemical Reactions

The substances that make up baking powder undergo a chemical reaction when mixed with water. One new substance that forms is carbon dioxide gas, which causes the bubbles in this muffin.



Once ignited, gasoline reacts with oxygen gas in the air. The new substances that form, carbon dioxide and water, push against the pistons in the engine to keep the car moving.

Clues to Chemical Reactions How can you tell when a chemical reaction is taking place? There are several clues that indicate when a reaction might be occurring. The more of these clues you observe, the more likely it is that the change is a chemical reaction. Several of these clues are described below.

Some Clues to Chemical Reactions

Gas Formation

The formation of gas bubbles is a clue that a chemical reaction might be taking place. For example, bubbles of carbon dioxide are produced when hydrochloric acid is placed on a piece of limestone. Hydrogen gas is produced when a metal reacts with an acid.

Solid Formation

Sometimes a solid forms when two solutions react. A solid formed in a solution as a result of a chemical reaction is called a *precipitate* (pruh SIP uh TAYT). Here you see potassium chromate solution being added to a silver nitrate solution. The dark red solid is a precipitate of silver chromate.

Color Change

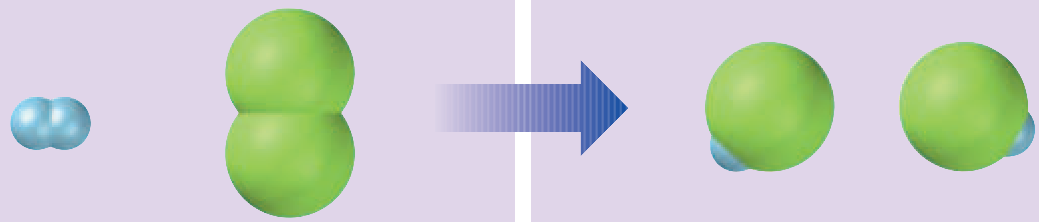
Chlorine bleach is great for removing the color from stains on white clothes. But don't spill it on your jeans. The bleach reacts with the blue dye on the fabric, causing the color of the material to change.

Energy Change

Energy is released during some chemical reactions. A fire heats a room and provides light. Electrical energy is released when chemicals in a battery react. During some other chemical reactions, energy is absorbed. Chemicals on photographic film react when they absorb energy from light shining on the film.

Breaking and Making Bonds New substances are formed in a chemical reaction because chemical bonds in the starting substances break, atoms rearrange, and new bonds form to make the new substances. Look at the model in **Figure 3** to understand how this process occurs.

Figure 3
Reaction of Hydrogen and Chlorine



Breaking Bonds The elements hydrogen and chlorine are diatomic, meaning they are composed of molecules that consist of two atoms bonded together. For these molecules to react, the bonds joining the atoms must break.

Making Bonds Molecules of the new substance, hydrogen chloride, are formed as new bonds are made between hydrogen atoms and chlorine atoms.

Chemical Formulas

Remember that a chemical symbol is a shorthand method of identifying an element. A **chemical formula** is a shorthand notation for a compound or a diatomic element using chemical symbols and numbers. A chemical formula indicates the chemical makeup by showing how many of each kind of atom is present in a molecule.

The chemical formula for water, H_2O, tells you that a water molecule is composed of two atoms of hydrogen and one atom of oxygen. The small number *2* in the formula is a subscript. A **subscript** is a number written below and to the right of a chemical symbol in a formula. When no subscript is written after a symbol, as with the oxygen in water's formula, only one atom of that element is present. **Figure 4** shows two more chemical formulas and what they mean.

Figure 4 *A chemical formula shows the number of atoms of each element present.*

$$O_2$$

Oxygen is a diatomic element. Each molecule of oxygen gas is composed of two atoms of oxygen bonded together.

$$C_6H_{12}O_6$$

Every molecule of glucose (the sugar formed by plants during photosynthesis) is composed of six atoms of carbon, twelve atoms of hydrogen, and six atoms of oxygen.

MATH BREAK

Counting Atoms

Some chemical formulas contain two or more chemical symbols enclosed by parentheses. When counting atoms in these formulas, multiply everything inside the parentheses by the subscript as though they were part of a mathematical equation. For example, $Ca(NO_3)_2$ contains:

1 calcium atom
2 nitrogen atoms (2 × 1)
6 oxygen atoms (2 × 3)

Now It's Your Turn

Determine the number of atoms of each element in the formulas $Mg(OH)_2$ and $Al_2(SO_4)_3$.

Writing Formulas for Covalent Compounds You can often write a chemical formula if you know the name of the substance. Remember that covalent compounds are usually composed of two nonmetals. The names of covalent compounds use prefixes to tell you how many atoms of each element are in the formula. A *prefix* is a syllable or syllables joined to the beginning of a word. Each prefix used in a chemical name represents a number, as shown in the table at right. **Figure 5** demonstrates how to write a chemical formula from the name of a covalent compound.

Figure 5 *The formulas of these covalent compounds can be written using the prefixes in their names.*

Carbon dioxide

The lack of a prefix indicates 1 carbon atom.

The prefix *di-* indicates 2 oxygen atoms.

CO_2

Dinitrogen monoxide

The prefix *di-* indicates 2 nitrogen atoms.

The prefix *mono-* indicates 1 oxygen atom.

N_2O

Writing Formulas for Ionic Compounds If the name of a compound contains the name of a metal and a nonmetal, the compound is probably ionic. To write the formula for an ionic compound, you must make sure the compound's overall charge is zero. In other words, the formula must have subscripts that cause the charges of the ions to cancel out. (Remember that the charge of many ions can be determined by looking at the periodic table.) **Figure 6** demonstrates how to write a chemical formula from the name of an ionic compound.

Figure 6 *The formula of an ionic compound is written by using enough of each ion to make the overall charge zero.*

Sodium chloride

A sodium ion has a 1+ charge.

A chloride ion has a 1− charge.

$NaCl$

One sodium ion and one chloride ion have an overall charge of $(1+) + (1-) = 0$

Magnesium chloride

A magnesium ion has a 2+ charge.

A chloride ion has a 1− charge.

$MgCl_2$

One magnesium ion and two chloride ions have an overall charge of $(2+) + 2(1-) = 0$

Prefixes Used in Chemical Names			
mono-	1	hexa-	6
di-	2	hepta-	7
tri-	3	octa-	8
tetra-	4	nona-	9
penta-	5	deca-	10

Self-Check

How many atoms of each element make up Na_2SO_4? *(See page 596 to check your answer.)*

Explore

Determine whether each of the following compounds is covalent or ionic, and write the chemical formula for each: sulfur trioxide, calcium fluoride, phosphorus pentachloride, dinitrogen trioxide, and lithium oxide.

Figure 7 *The symbols on this music are understood around the world—just like chemical symbols!*

Chemical Equations

A composer writing a piece of music, like the one in **Figure 7,** must communicate to the musician what notes to play, how long to play each note, and in what style each note should be played. The composer does not use words to describe what must happen. Instead, he or she uses musical symbols to communicate in a way that can be easily understood by anyone in the world who can read music.

Similarly, people who work with chemical reactions need to communicate information about reactions clearly to other people throughout the world. Describing reactions using long descriptive sentences would require translations into other languages. Chemists have developed a method of describing reactions that is short and easily understood by anyone in the world who understands chemical formulas. A **chemical equation** is a shorthand description of a chemical reaction using chemical formulas and symbols. Because each element's chemical symbol is understood around the world, a chemical equation needs no translation.

Reactants Yield Products Consider the example of carbon reacting with oxygen to yield carbon dioxide, as shown in **Figure 8.** The starting materials in a chemical reaction are **reactants** (ree AKT UHNTS). The substances formed from a reaction are **products.** In this example, carbon and oxygen are reactants, and carbon dioxide is the product formed. The parts of the chemical equation for this reaction are described in **Figure 9.**

Figure 8 *Charcoal is used to cook food on a barbecue. When carbon in charcoal reacts with oxygen in the air, the primary product is carbon dioxide, as shown in the chemical equation in Figure 9.*

Figure 9 The Parts of a Chemical Equation

The formulas of the reactants are written before the arrow.

The formulas of the products are written after the arrow.

$$C + O_2 \rightarrow CO_2$$

A plus sign separates the formulas of two or more reactants or products from one another.

The arrow, also called the yields sign, separates the formulas of the reactants from the formulas of the products.

The symbol or formula for each substance in the reaction must be written correctly. For a compound, determine if it is a covalent compound or an ionic compound, and write the appropriate formula. For an element, use the proper chemical symbol, and be sure to use a subscript of 2 for the diatomic elements. (The seven diatomic elements are hydrogen, nitrogen, oxygen, fluorine, chlorine, bromine, and iodine.) An equation with an incorrect chemical symbol or formula will not accurately describe the reaction. In fact, even a simple mistake in a symbol or formula can make a huge difference, as shown in **Figure 10.**

BRAIN FOOD

Hydrogen gas, H_2, is an important fuel that may help reduce air pollution. Because water is the only product formed as hydrogen burns, there is little air pollution from vehicles that use hydrogen as fuel.

Figure 10 *The symbols and formulas shown here are similar, but confusing them while writing an equation would cause you to indicate the wrong substance.*

The chemical formula for the compound carbon dioxide is CO_2. Carbon dioxide is a colorless, odorless gas that you exhale.

The chemical formula for the compound carbon monoxide is CO. Carbon monoxide is a colorless, odorless, poisonous gas.

The chemical symbol for the element cobalt is Co. Cobalt is a hard, bluish gray metal.

Self-Check

When calcium bromide reacts with chlorine, bromine and calcium chloride are produced. Write an equation to describe this reaction. Identify each substance as either a reactant or a product. *(See page 596 to check your answers.)*

An Equation Must Be Balanced In a chemical reaction, every atom in the reactants becomes part of the products. Atoms are never lost or gained in a chemical reaction. When writing a chemical equation, you must show that the number of atoms of each element in the reactants equals the number of atoms of those elements in the products by writing a balanced equation.

MATH BREAK

Balancing Act

When balancing a chemical equation, you must place coefficients in front of an entire chemical formula, never in the middle of a formula. Notice where the coefficients are in the balanced equation below:

$F_2 + 2KCl \rightarrow 2KF + Cl_2$

Now It's Your Turn

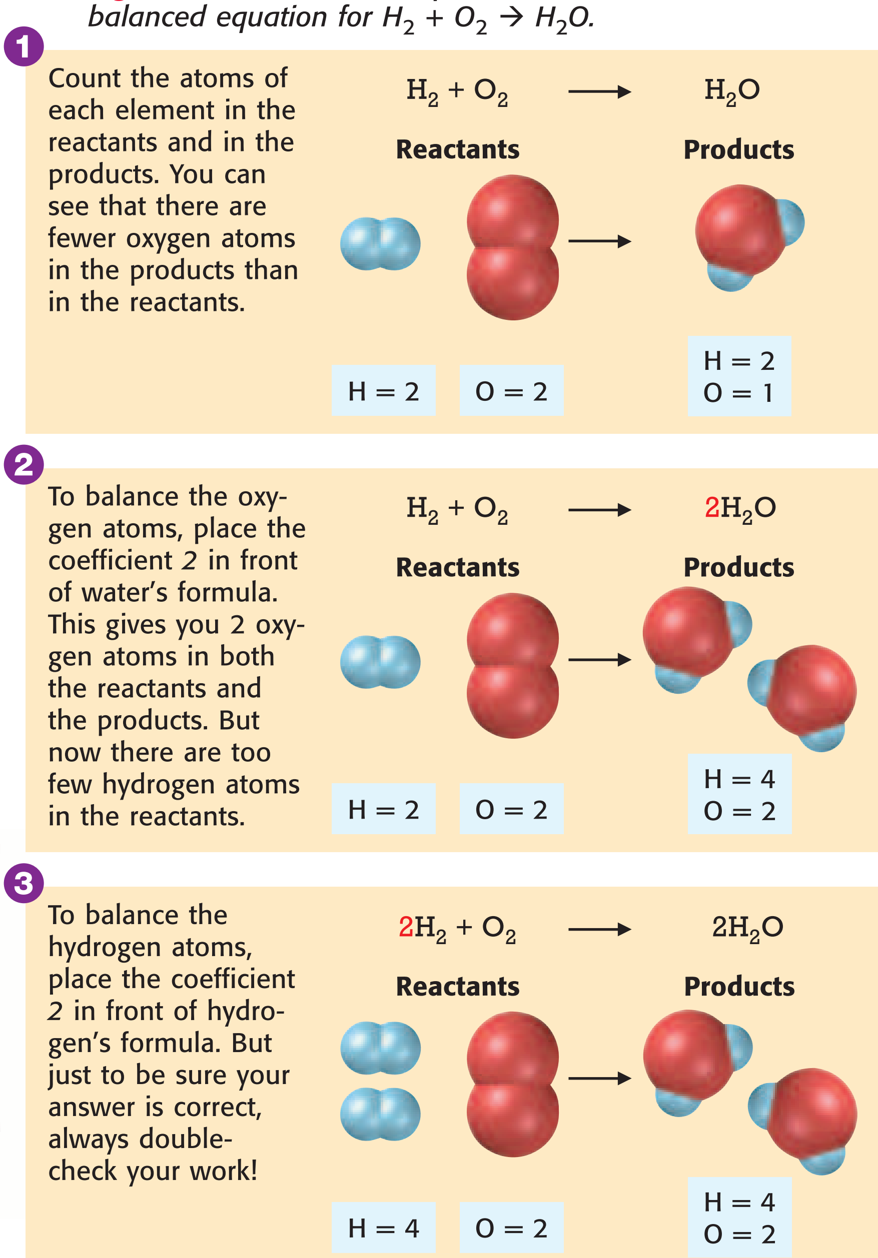
Write balanced equations for the following:

$HCl + Na_2S \rightarrow H_2S + NaCl$

$Al + Cl_2 \rightarrow AlCl_3$

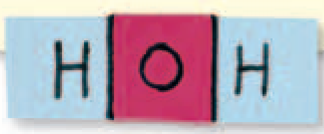
Writing a balanced equation requires the use of coefficients (KOH uh FISH uhnts). A **coefficient** is a number placed in front of a chemical symbol or formula. When counting atoms, you multiply a coefficient by the subscript of each of the elements in the formula that follows it. Thus, $2CO_2$ represents 2 carbon dioxide molecules containing a total of 2 carbon atoms and 4 oxygen atoms. Coefficients are used when balancing equations because the subscripts in the formulas cannot be changed. Changing a subscript changes the formula so that it no longer represents the correct substance. **Figure 11** shows how to use coefficients to balance an equation. After you learn how to use coefficients, you can practice balancing chemical equations by doing the MathBreak at left.

Figure 11 *Follow these steps to write a balanced equation for $H_2 + O_2 \rightarrow H_2O$.*



LabBook

Become a better balancer of chemical equations on page 576 of the LabBook.



Mass Is Conserved—It's a Law! The practice of balancing equations is a result of the work of a French chemist, Antoine Lavoisier (luh vwa ZYAY). In the 1700s, Lavoisier performed experiments in which he carefully measured and compared the masses of the substances involved in chemical reactions. He determined that the total mass of the reactants equaled the total mass of the products. Lavoisier's work led to the **law of conservation of mass,** which states that mass is neither created nor destroyed in ordinary chemical and physical changes. Thus, a chemical equation must show the same number and kind of atom on both sides of the arrow. The law of conservation of mass is demonstrated in **Figure 12.** You can explore this law for yourself in the QuickLab at right.

Figure 12 *In this demonstration, magnesium in the flashbulb of a camera reacts with oxygen. Notice that the mass is the same before and after the reaction takes place.*

REVIEW

1. List four clues that a chemical reaction is occurring.
2. How many atoms of each element make up $2Na_3PO_4$?
3. Write the chemical formulas for carbon tetrachloride and calcium bromide.
4. Explain how a balanced chemical equation illustrates that mass is never lost or gained in a chemical reaction.
5. **Applying Concepts** Write the balanced chemical equation for methane, CH_4, reacting with oxygen gas to produce water and carbon dioxide.

QuickLab

Mass Conservation

1. Place about 5 g (1 tsp) of **baking soda** into a **sealable plastic bag.**
2. Place about 5 mL (1 tsp) of **vinegar** into a **plastic film canister,** and close the lid.
3. Use a **balance** to determine the masses of the bag with baking soda and the canister with vinegar, and record both values in your ScienceLog.
4. Place the canister into the plastic bag. Squeeze the air out of the bag, and tightly seal the bag.
5. Carefully open the lid of the canister while it is in the bag. Pour the vinegar onto the baking soda, and mix them.
6. When the reaction has stopped, use the same balance used in step 3 to determine the total mass of the bag and its contents.
7. Compare the mass of the materials before and after the reaction.

Section 2

Types of Chemical Reactions

NEW TERMS

synthesis reaction
decomposition reaction
single-replacement reaction
double-replacement reaction

OBJECTIVES

- Describe four types of chemical reactions.
- Classify a chemical equation as one of the four types of chemical reactions described here.

Imagine having to learn 50 chemical reactions. Sound tough? Well, there are thousands of known chemical reactions. It would be impossible to remember them all. But there is help! Remember that the elements are divided into categories based on their properties. In a similar way, reactions can be classified according to their similarities.

Many reactions can be grouped into one of four categories: synthesis (SIN thuh sis), decomposition, single replacement, and double replacement. By dividing reactions into these categories, you can better understand the patterns of how reactants become products. As you learn about each type of reaction, study the models provided to help you recognize each type of reaction.

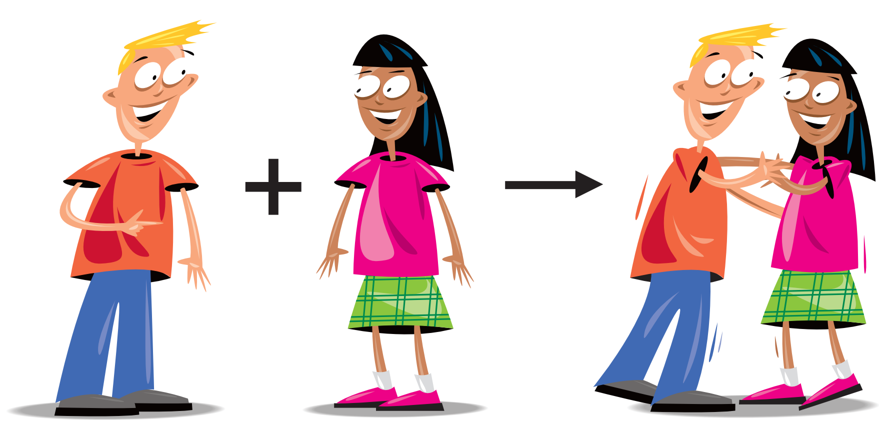
Synthesis Reactions

A **synthesis reaction** is a reaction in which two or more substances combine to form a single compound. For example, the synthesis reaction in which the compound magnesium oxide is produced is seen in **Figure 13.** (This is the same reaction that occurs in the flashbulb in Figure 12.) One way to remember what happens in each type of reaction is to imagine people at a dance. A synthesis reaction would be modeled by two people joining to form a dancing couple, as shown in **Figure 14.**

Figure 13 *The synthesis reaction that occurs when magnesium reacts with oxygen in the air forms the compound magnesium oxide.*

Figure 14 *A model for the synthesis reaction of sodium reacting with chlorine to form sodium chloride is shown below.*

$$2Na + Cl_2 \longrightarrow 2NaCl$$



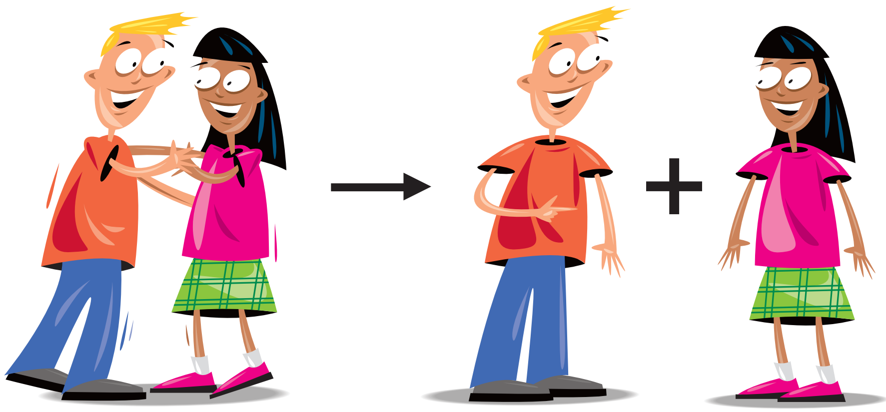
Decomposition Reactions

A **decomposition reaction** is a reaction in which a single compound breaks down to form two or more simpler substances. The decomposition of water is shown in **Figure 15.** Decomposition is the reverse of synthesis. The dance model would represent a decomposition reaction as a dancing couple splitting up, as shown in **Figure 16.**

Figure 15 *Water can be decomposed into the elements hydrogen and oxygen through electrolysis.*

Figure 16 *A model for the decomposition reaction of carbonic acid to form water and carbon dioxide is shown below.*

$$H_2CO_3 \longrightarrow H_2O + CO_2$$

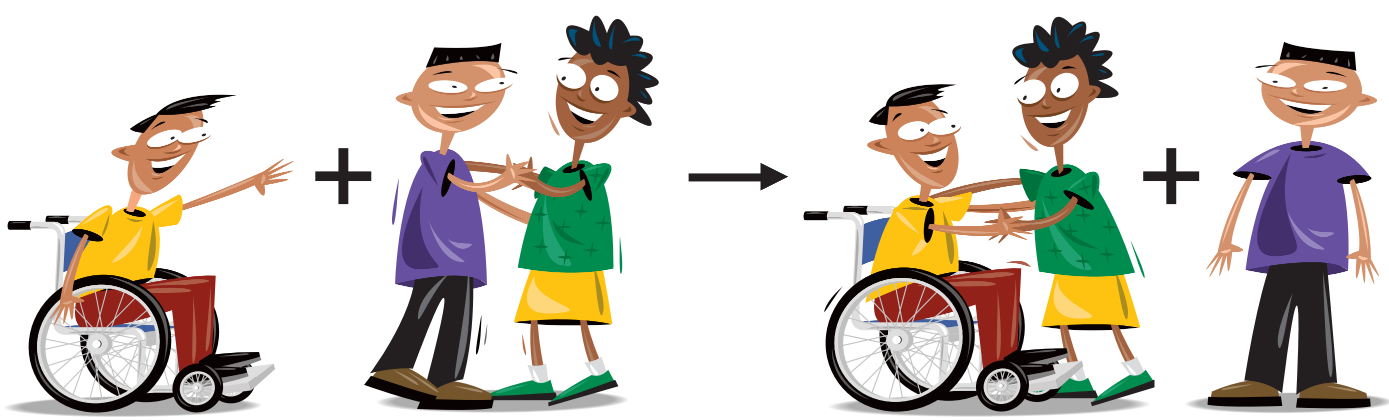


Single-Replacement Reactions

A **single-replacement reaction** is a reaction in which an element takes the place of another element that is part of a compound. The products of single-replacement reactions are a new compound and a different element. The dance model for single-replacement reactions is a person who cuts in on a couple dancing. A new couple is formed and a different person is left alone, as shown in **Figure 17.**

Figure 17 *A model for a single-replacement reaction of zinc reacting with hydrochloric acid to form zinc chloride and hydrogen is shown below.*

$$Zn + 2HCl \longrightarrow ZnCl_2 + H_2$$



Remember that some elements are more reactive than others. In a single-replacement reaction, a more-reactive element can replace a less-reactive one from a compound. However, the opposite reaction does not occur, as shown in **Figure 18.**

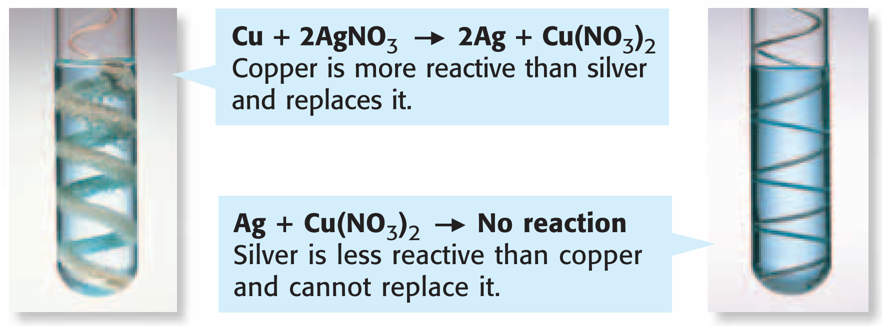


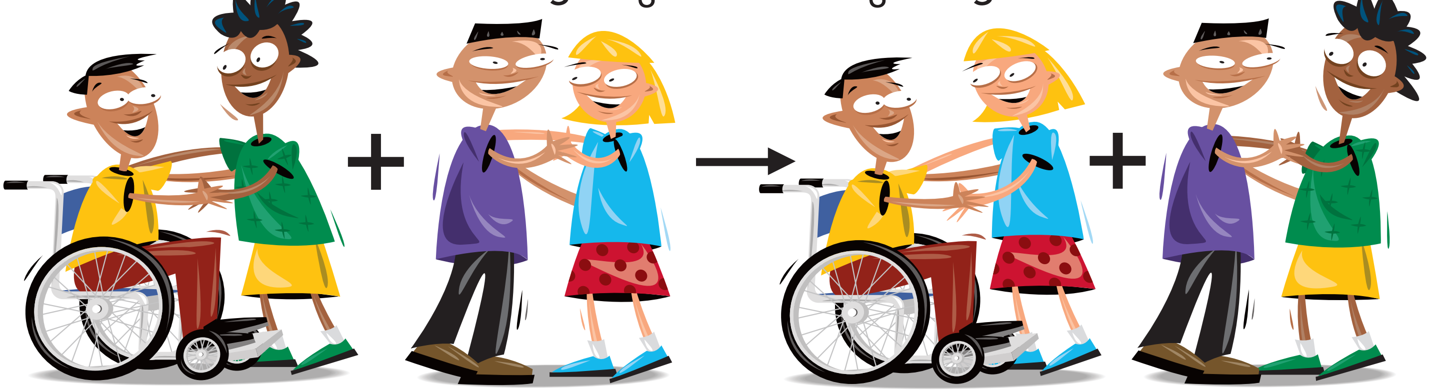
Figure 18 *More-reactive elements replace less-reactive elements in single-replacement reactions.*

Double-Replacement Reactions

A **double-replacement reaction** is a reaction in which ions in two compounds switch places. One of the products of this reaction is often a gas or a precipitate. A double-replacement reaction in the dance model would be two couples dancing and switching partners, as shown in **Figure 19.**

Figure 19 *A model for the double-replacement reaction of sodium chloride reacting with silver nitrate to form sodium nitrate and the precipitate silver chloride is shown below.*

$$NaCl + AgNO_3 \longrightarrow NaNO_3 + AgCl$$



REVIEW

1. What type of reaction does each of the following equations represent?
   a. $FeS + 2HCl \longrightarrow FeCl_2 + H_2S$
   b. $NH_4OH \longrightarrow NH_3 + H_2O$
2. Which type of reaction always has an element and a compound as reactants?
3. **Comparing Concepts** Compare synthesis and decomposition reactions.

Section 3

Energy and Rates of Chemical Reactions

NEW TERMS

exothermic
endothermic
law of conservation of energy
activation energy
catalyst
inhibitor

OBJECTIVES

- Compare exothermic and endothermic reactions.
- Explain activation energy.
- Interpret an energy diagram.
- Describe the factors that affect the rate of a reaction.

You just learned one method of classifying chemical reactions. In this section, you will learn how to classify reactions in terms of the energy associated with the reaction and learn how to change the rate at which the reaction occurs.

Every Reaction Involves Energy

All chemical reactions involve chemical energy. Remember that during a reaction, chemical bonds in the reactants break as they absorb energy. As new bonds form in the products, energy is released. Energy is released or absorbed in the overall reaction depending on how the chemical energy of the reactants compares with the chemical energy of the products.

Energy Is Released in Exothermic Reactions If the chemical energy of the reactants is greater than the chemical energy of the products, the difference in energy is released during the reaction. A chemical reaction in which energy is released or removed is called **exothermic.** *Exo* means "go out" or "exit," and *thermic* means "heat" or "energy." The energy can be released in several different forms, as shown in **Figure 20.** The energy released in an exothermic reaction is often written as a product in a chemical equation, as in this equation:

$$2Na + Cl_2 \longrightarrow 2NaCl + energy$$

Figure 20 Types of Energy Released in Reactions

Energy in the form of light is released in the exothermic reaction taking place in these necklaces and light sticks.

Electrical energy is released in the exothermic reaction taking place in the dry cells in this flashlight.

Energy that keeps you warm and lights your way is released in the exothermic reaction taking place in a campfire.

life science CONNECTION

Photosynthesis is an endothermic process in which light energy from the sun is used to produce glucose, a simple sugar. The equation that describes photosynthesis is as follows:

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

The cells in your body use glucose to get the energy they need through cellular respiration, an exothermic process described by the reverse of the above reaction:

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

Energy Is Absorbed in Endothermic Reactions If the chemical energy of the reactants is less than the chemical energy of the products, the difference in energy is absorbed during the reaction. A chemical reaction in which energy is absorbed is called **endothermic.** *Endo* means "go in," and *thermic* means "heat" or "energy." The energy absorbed in an endothermic reaction is often written as a reactant in a chemical equation, as in this equation:

$$2H_2O + \text{energy} \longrightarrow 2H_2 + O_2$$

Energy Is Conserved—It's a Law! You learned that mass is never created or destroyed in chemical reactions. The same holds true for energy. The **law of conservation of energy** states that energy can be neither created nor destroyed. The energy released in exothermic reactions was originally stored in the reactants. And the energy absorbed in endothermic reactions does not just vanish. It is stored in the products that form. If you could carefully measure all the energy in a reaction, you would find that the total amount of energy (of all types) is the same before and after the reaction.

Activation Energy Gets a Reaction Started A match can be used to light a campfire—but only if the match is lit! A strike-anywhere match, like the one shown in **Figure 21,** has all the reactants it needs to be able to burn. And though the chemicals on a match are intended to react and burn, they will not ignite by themselves. Energy is needed to start the reaction. The minimum amount of energy needed for substances to react is called **activation energy.**

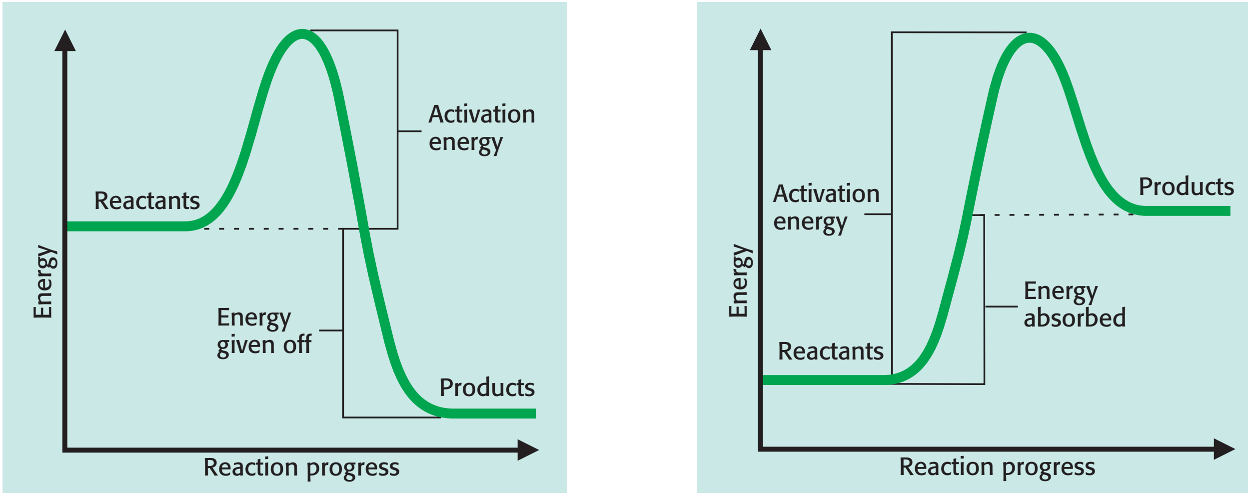
Figure 21 *Rubbing the tip of this strike-anywhere match on a rough surface provides the energy needed to get the chemicals to react.*

The friction of striking a match heats the substances on the match, breaking bonds in the reactants and allowing the new bonds in the products to form. Chemical reactions require some energy to get started. An electric spark in a car's engine provides activation energy to begin the burning of gasoline. Light can also provide the activation energy for a reaction. You can better understand activation energy and the differences between exothermic reactions and endothermic reactions by studying the diagrams in **Figure 22.**

BRAIN FOOD

Matches rubbing together in a box could provide the activation energy to light a strike-anywhere match. Safety matches, which must be struck on a strike plate on the box, were developed to prevent such accidents.

Figure 22 **Energy Diagrams**



Exothermic Reaction Once begun, an exothermic reaction can continue to occur, as in a fire. The energy released as the product forms continues to supply the activation energy needed for the substances to react.

Endothermic Reaction An endothermic reaction requires a continuous supply of energy. Energy must be absorbed to provide the activation energy needed for the substances to react.

APPLY

Hydrogen peroxide is used as a disinfectant for minor scrapes and cuts because it decomposes to produce oxygen gas and water, which help cleanse the wound. The decomposition of hydrogen peroxide is an exothermic reaction. Explain why hydrogen peroxide must be stored in a dark bottle to maintain its freshness. (HINT: What type of energy would be blocked by this type of container?)

Factors Affecting Rates of Reactions

You can think of a reaction as occurring only if the particles of reactants collide when they have enough energy to break the appropriate bonds. The rate of a reaction is a measure of how rapidly the reaction takes place. Four factors that affect the rate of a reaction are temperature, concentration, surface area, and the presence of a catalyst or inhibitor.

Fighting fires with slime? Read more about it on page 394.

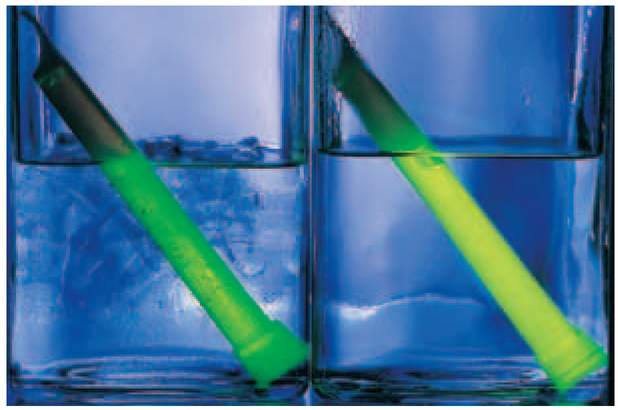
QuickLab

Which Is Quicker?

1. Fill a **clear plastic cup** half-full with **warm water.** Fill a **second clear plastic cup** half-full with **cold water.**
2. Place one-quarter of an **effervescent tablet** in each of the two cups of water at the same time.
3. Observe the reaction, and record your observations in your ScienceLog.
4. In which cup did the reaction occur at a greater rate? What evidence supports your answer?

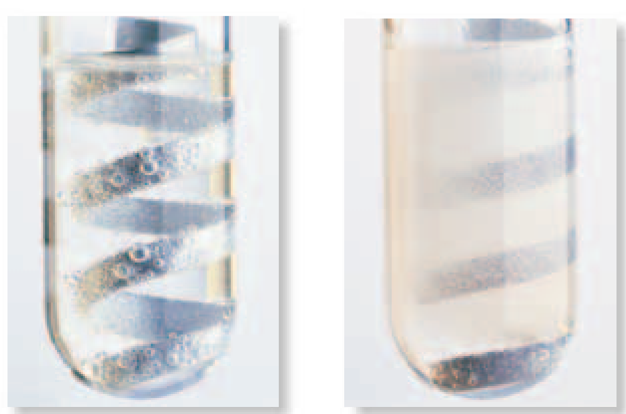
Temperature An increase in temperature increases the rate of a reaction. At higher temperatures, particles of reactants move faster, so they collide with each other more frequently and with more energy. More particles therefore have the activation energy needed to react and can change into products faster. Thus, more particles react in a shorter time. You can see this effect in **Figure 23** and by doing the QuickLab at left.

Figure 23 *The light stick on the right glows brighter than the one on the left because the higher temperature causes the rate of the reaction to increase.*



Concentration Generally, increasing the concentration of reactants increases the rate of a reaction, as shown in **Figure 24.** *Concentration* is a measure of the amount of one substance dissolved in another. Increasing the concentration increases the number of reactant particles present and decreases the distance between them. The reactant particles collide more often, so more particles react each second. Increasing the concentration is similar to having more people in a room. The more people that are in the room, the more frequently they will collide and interact.

Figure 24 *The reaction on the right produces bubbles of hydrogen gas at a faster rate because the concentration of hydrochloric acid used is higher.*



LabBook

Do you feel as though you are not up to speed on controlling the rate of a reaction? Then hurry over to page 580 of the LabBook.

Surface Area Increasing the surface area, or the amount of exposed surface, of solid reactants increases the rate of a reaction. Grinding a solid into a powder exposes more particles of the reactant to other reactant particles. The number of collisions between reactant particles increases, increasing the rate of the reaction. You can see the effect of increasing the surface area in the QuickLab at right.

Catalysts and Inhibitors Some reactions would be too slow to be useful without a catalyst (KAT uh LIST). A **catalyst** is a substance that speeds up a reaction without being permanently changed. A catalyst lowers the activation energy of a reaction. The lower energy needed to start the reaction allows the reaction to occur more rapidly. Most reactions in your body are sped up using catalysts called enzymes. Catalysts are even found in cars, as seen in **Figure 25.**

An **inhibitor** is a substance that slows down or stops a chemical reaction. Preservatives added to foods are inhibitors that slow down reactions in the bacteria or fungus that can spoil food. Many poisons are also inhibitors.

Figure 25 *This catalytic converter contains platinum and palladium—two catalysts used to treat automobile exhaust. They increase the rate of reactions that make the car's exhaust less polluting.*

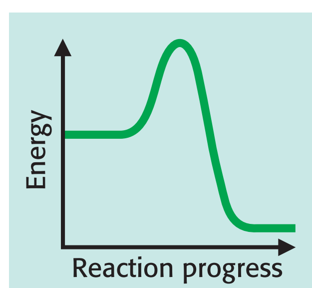
QuickLab

I'm Crushed!

1. Fill **two clear plastic cups** half-full with **room-temperature water.**
2. Fold a **sheet of paper** around one-quarter of an **effervescent tablet.** Carefully crush the tablet.
3. Get another one-quarter of an effervescent tablet. Carefully pour the crushed tablet into one cup, and place the uncrushed tablet in the second cup.
4. Observe the reaction, and record your observations in your ScienceLog.
5. In which cup did the reaction occur at a greater rate? What evidence supports your answer?
6. Explain why the water in each cup must have the same temperature.

REVIEW

1. How does the rate of a reaction change when the temperature is decreased?
2. What is activation energy?
3. List four ways to increase the rate of a reaction.
4. **Comparing Concepts** Compare exothermic and endothermic reactions.
5. **Interpreting Graphics** Does the energy diagram at right show an exothermic or an endothermic reaction? How can you tell?



Chapter Highlights

SECTION 1

Vocabulary

chemical reaction *(p. 374)*
chemical formula *(p. 376)*
subscript *(p. 376)*
chemical equation *(p. 378)*
reactants *(p. 378)*
products *(p. 378)*
coefficient *(p. 380)*
law of conservation of mass *(p. 381)*

Section Notes

- Chemical reactions form new substances with different properties than the starting substances.
- Clues that a chemical reaction is taking place include formation of a gas or solid, a color change, and an energy change.
- A chemical formula tells the composition of a compound using chemical symbols and subscripts. Subscripts are small numbers written below and to the right of a symbol in a formula.
- Chemical formulas can sometimes be written from the names of covalent compounds and ionic compounds.
- A chemical equation describes a reaction using formulas, symbols, and coefficients.
- A balanced equation uses coefficients to illustrate the law of conservation of mass, that mass is neither created nor destroyed during a chemical reaction.

Labs

Finding a Balance *(p. 576)*

SECTION 2

Vocabulary

synthesis reaction *(p. 382)*
decomposition reaction *(p. 383)*
single-replacement reaction *(p. 383)*
double-replacement reaction *(p. 384)*

Section Notes

- Many chemical reactions can be classified as one of four types by comparing reactants with products.
- In synthesis reactions, the reactants form a single product.
- In decomposition reactions, a single reactant breaks apart into two or more simpler products.

Skills Check

Math Concepts

SUBSCRIPTS AND COEFFICIENTS A subscript is a number written below and to the right of a chemical symbol when writing the chemical formula of a compound. A coefficient is a number written in front of a chemical formula in a chemical equation. When you balance a chemical equation, you cannot change the subscripts in a formula; you can only add coefficients, as seen in the equation $2H_2 + O_2 \longrightarrow 2H_2O$.

Visual Understanding

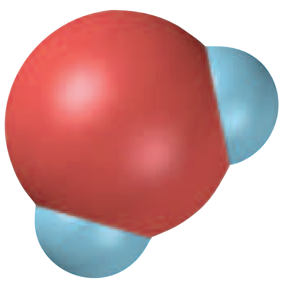
REACTION TYPES It can be challenging to identify which type of reaction a particular chemical equation represents. Review four reaction types by studying Figures 14, 16, 17, and 19.

SECTION 2

- In single-replacement reactions, a more-reactive element takes the place of a less-reactive element in a compound. No reaction will occur if a less-reactive element is placed with a compound containing a more-reactive element.
- In double-replacement reactions, ions in two compounds switch places. A gas or precipitate is often formed.

Labs

Putting Elements Together *(p. 578)*



SECTION 3

Vocabulary

exothermic *(p. 385)*

endothermic *(p. 386)*

law of conservation of energy *(p. 386)*

activation energy *(p. 386)*

catalyst *(p. 389)*

inhibitor *(p. 389)*

Section Notes

- Energy is released in exothermic reactions. The energy released can be written as a product in a chemical equation.
- Energy is absorbed in endothermic reactions. The energy absorbed can be written as a reactant in a chemical equation.
- The law of conservation of energy states that energy is neither created nor destroyed.
- Activation energy is the energy needed to start a chemical reaction.
- Energy diagrams indicate whether a reaction is exothermic or endothermic by showing whether energy is given off or absorbed during the reaction.
- The rate of a chemical reaction is affected by temperature, concentration, surface area, and the presence of a catalyst or inhibitor.
- Raising the temperature, increasing the concentration, increasing the surface area, and adding a catalyst can increase the rate of a reaction.

Labs

Cata-what? Catalyst! *(p. 577)*

Speed Control *(p. 580)*

internetconnect

GO TO: go.hrw.com

Visit the **HRW** Web site for a variety of learning tools related to this chapter. Just type in the keyword:

KEYWORD: HSTREA

GO TO: www.scilinks.org

Visit the **National Science Teachers Association** on-line Web site for Internet resources related to this chapter. Just type in the ***sci*LINKS** number for more information about the topic:

TOPIC: Chemical Reactions	***sci*LINKS NUMBER:** HSTP330
TOPIC: Chemical Formulas	***sci*LINKS NUMBER:** HSTP335
TOPIC: Chemical Equations	***sci*LINKS NUMBER:** HSTP340
TOPIC: Exothermic and Endothermic Reactions	***sci*LINKS NUMBER:** HSTP345

Chapter Review

USING VOCABULARY

To complete the following sentences, choose the correct term from each pair of terms listed below.

1. Adding a(n) ____ will slow down a chemical reaction. (*catalyst* or *inhibitor*)

2. A chemical reaction that gives off light is called ____. (*exothermic* or *endothermic*)

3. A chemical reaction that forms one compound from two or more substances is called a ____. (*synthesis reaction* or *decomposition reaction*)

4. The *2* in the formula Ag_2S is a ____. (*subscript* or *coefficient*)

5. The starting materials in a chemical reaction are ____. (*reactants* or *products*)

UNDERSTANDING CONCEPTS

Multiple Choice

6. Balancing a chemical equation so that the same number of atoms of each element is found in both the reactants and the products is an illustration of
   a. activation energy.
   b. the law of conservation of energy.
   c. the law of conservation of mass.
   d. a double-replacement reaction.

7. What is the correct chemical formula for calcium chloride?
   a. $CaCl$
   b. $CaCl_2$
   c. Ca_2Cl
   d. Ca_2Cl_2

8. In which type of reaction do ions in two compounds switch places?
   a. synthesis
   b. decomposition
   c. single-replacement
   d. double-replacement

9. Which is an example of the use of activation energy?
   a. plugging in an iron
   b. playing basketball
   c. holding a lit match to paper
   d. eating

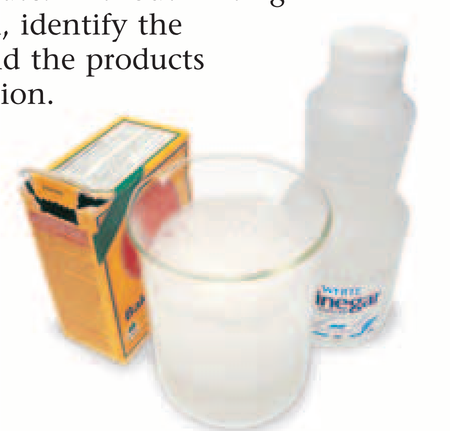
10. Enzymes in your body act as catalysts. Thus, the role of enzymes is to
    a. increase the rate of chemical reactions.
    b. decrease the rate of chemical reactions.
    c. help you breathe.
    d. inhibit chemical reactions.

Short Answer

11. Classify each of the following reactions:
    a. $Fe + O_2 \longrightarrow Fe_2O_3$
    b. $Al + CuSO_4 \longrightarrow Al_2(SO_4)_3 + Cu$
    c. $Ba(CN)_2 + H_2SO_4 \longrightarrow BaSO_4 + HCN$

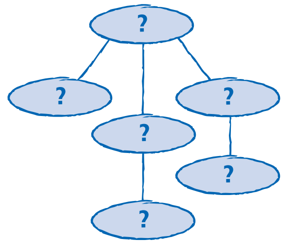
12. Name two ways that you could increase the rate of a chemical reaction.

13. Acetic acid, a compound found in vinegar, reacts with baking soda to produce carbon dioxide, water, and sodium acetate. Without writing an equation, identify the reactants and the products of this reaction.



Concept Mapping

14. Use the following terms to create a concept map: chemical reaction, chemical equation, chemical formulas, reactants, products, coefficients, subscripts.



CRITICAL THINKING AND PROBLEM SOLVING

15. Your friend is very worried by rumors he has heard about a substance called dihydrogen monoxide. What could you say to your friend to calm his fears? (Be sure to write the formula of the substance.)

16. As long as proper safety precautions have been taken, why can explosives be transported long distances without exploding?

MATH IN SCIENCE

17. Calculate the number of atoms of each element shown in each of the following:
    - **a.** $CaSO_4$
    - **b.** $4NaOCl$
    - **c.** $Fe(NO_3)_2$
    - **d.** $2Al_2(CO_3)_3$

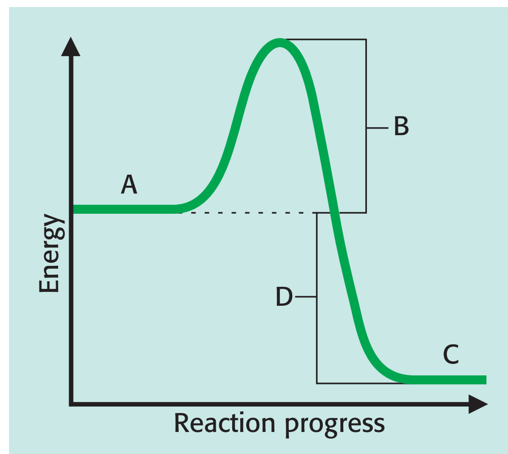
18. Write balanced equations for the following:
    - **a.** $Fe + O_2 \longrightarrow Fe_2O_3$
    - **b.** $Al + CuSO_4 \longrightarrow Al_2(SO_4)_3 + Cu$
    - **c.** $Ba(CN)_2 + H_2SO_4 \longrightarrow BaSO_4 + HCN$

19. Write and balance chemical equations from each of the following descriptions:
    - **a.** Bromine reacts with sodium iodide to form iodine and sodium bromide.
    - **b.** Phosphorus reacts with oxygen gas to form diphosphorus pentoxide.
    - **c.** Lithium oxide decomposes to form lithium and oxygen.

INTERPRETING GRAPHICS

20. What evidence in the photo supports the claim that a chemical reaction is taking place?

21. Use the energy diagram below to answer the questions that follow.



- **a.** Which letter represents the energy of the products?
- **b.** Which letter represents the activation energy of the reaction?
- **c.** Is energy given off or absorbed by this reaction?

NOW What Do You Think?

Take a minute to review your answers to the ScienceLog questions on page 373. Have your answers changed? If necessary, revise your answers based on what you have learned since you began this chapter.

EYE ON THE ENVIRONMENT

Slime That Fire!

Once a fire starts in the hard-to-reach mountains of the western United States, it is difficult to stop. Trees, grasses, and brush can provide an overwhelming supply of fuel. In order to stop a fire, firefighters make a fire line. This is an area where all the burnable materials are removed from the ground. How would you slow down a fire to give a ground crew more time to build a fire line? Would you suggest dropping water from a plane? That is not a bad idea, but what if you had something even better than water—like some slimy red goop?

▲ *This plane is dropping fire retardant on a forest fire.*

Red Goop Goes the Distance

The slimy red goop is actually a powerful fire retardant. The goop is a mixture of a powder and water that is loaded directly onto an old military plane. Carrying between 4,500 and 11,000 L of the slime, the plane drops it all in front of the raging flames when the pilot presses the button.

The amount of water added to the powder depends on the location of the fire. If a fire is burning over shrubs and grasses, more water is needed. In this form the goop actually rains down to the ground through the treetops. But if a fire is burning in tall trees, less water is used so the slime will glob onto the branches and ooze down very slowly.

Failed Flames

The burning of trees, grass, and brush is an exothermic reaction. A fire retardant slows or stops this self-feeding reaction. A fire retardant increases the activation energy for the materials it is applied to. Although a lot depends on how hot the fire is when it hits the area treated with the retardant and how much of the retardant is applied, firefighters on the ground can gain valuable time when a fire is slowed with a fire retardant. This extra time allows them to create a fire line that will ultimately stop the fire.

Neon Isn't Necessary

Once a fire is put out, the slimy red streaks left on the blackened ground can be an eyesore. To solve the problem, scientists have created special dyes for the retardant. These dyes make the goop neon colors when it is first applied, but after a few days in the sun, the goop turns a natural brown shade!

What Do They Study?

▶ Do some research to learn about a firefighter's training. What classes and exams are firefighters required to pass? How do they maintain their certifications once they become firefighters?

CAREERS

ARSON INVESTIGATOR

Once a fire dies down, you might see arson investigator **Lt. Larry McKee** on the scene. “After the fire is out, I can investigate the fire scene to determine where the fire started and how it started. If it was intentionally set and I'm successful at putting the arson case together, I can get a conviction. That's very satisfying,” says Lt. McKee.

During a fire, fuel and oxygen combine in a chemical reaction called combustion. On the scene, Lt. Larry McKee questions witnesses and firefighters about what they saw. He knows, for example, that the color of the smoke can indicate certain chemicals.

McKee explains that fires usually burn “up and out, in a V shape.” To find where the V begins, he says, “We work from the area with the least amount of damage to the one with the most damage. This normally leads us to the point of origin.” Once the origin has been determined, it's time to call in the dogs!

An Accelerant-Sniffing Canine

“We have what we call an accelerant-sniffing canine. Our canine, Nikki, has been trained to detect approximately 11 different chemicals.” When Nikki arrives on the scene, she sniffs for traces of chemicals, called accelerants, that may have been used to start the fire. When she finds one, she immediately starts to dig at it. At that point, McKee takes a sample from the area and sends it to the lab for analysis.

At the Lab

Once at the laboratory, the sample is treated so that any accelerants in it are dissolved in a liquid. A small amount of the liquid is then injected into an instrument called a *gas chromatograph.* The instrument heats the liquid, forming a mixture of gases. The gases then are passed through a flame. As each gas passes through the flame, it “causes a fluctuation in an electronic signal, which creates our graphs.”

Solving the Case

If the laboratory report indicates that a suspicious accelerant has been found, McKee begins to search for arson suspects. By combining detective work with scientific evidence, fire investigators can successfully catch and convict arsonists.

Fascinating Fire Facts

▶ The temperature of a house fire can reach 980°C! At that temperature, aluminum window frames melt, and furniture goes up in flames. Do some research to discover three more facts about fires. Create a display with two or more classmates to illustrate some of your facts.

▲ *Nikki searches for traces of gasoline, kerosene, and other accelerants.*