2 Chemical Reactions

About the PHOTO

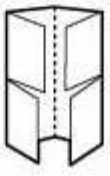
Dazzling fireworks and the Statue of Liberty are great examples of chemical reactions. Chemical reactions cause fireworks to soar, explode, and light up the sky. And the Statue of Liberty has its distinctive green color because of the reaction between the statue's copper and chemicals in the air.

PRE-READING ACTIVITY

FOLDNOTES

Four-Corner Fold

Before you read the chapter, create the FoldNote entitled "Four-Corner Fold" described in the **Study Skills** section of the Appendix. Label the flaps of the four-corner fold with "Chemical formulas," "Chemical equations," "Types of chemical reactions," and "Rates of chemical reactions." Write what you know about each topic under the appropriate flap. As you read the chapter, add other information that you learn.



START-UP ACTIVITY

A Model Formula

Chemicals react in very precise ways. In this activity, you will model a chemical reaction and will predict how chemicals react.

Procedure

1. You will receive **several marshmallow models.** The models are marshmallows attached by **toothpicks.** Each of these models is a Model A.
2. Your teacher will show you an example of Model B and Model C. Take apart one or more Model As to make copies of Model B and Model C.
3. If you have marshmallows left over, use them to make more Model Bs and Model Cs. If you need more parts to complete a Model B or Model C, take apart another Model A.
4. Repeat step 3 until you have no parts left over.

Analysis

1. How many Model As did you use to make copies of Model B and Model C?
2. How many Model Bs did you make? How many Model Cs did you make?
3. Suppose you needed to make six Model Bs. How many Model As would you need? How many Model Cs could you make with the leftover marshmallows?

SECTION 1

Forming New Substances

Each fall, a beautiful change takes place when leaves turn colors. You see bright oranges and yellows that had been hidden by green all summer. What causes this change?

To answer this question, you need to know what causes leaves to be green. Leaves are green because they contain a green substance, or *pigment*. This pigment is called *chlorophyll* (KLAWR uh FIL). During the spring and summer, the leaves have a large amount of chlorophyll in them. But in the fall, when temperatures drop and there are fewer hours of sunlight, chlorophyll breaks down to form new substances that have no color. The green chlorophyll is no longer present to hide the other pigments. You can now see the orange and yellow colors that were present all along.

READING WARM-UP

Objectives

- Describe how chemical reactions produce new substances that have different chemical and physical properties.
- Identify four signs that indicate that a chemical reaction might be taking place.
- Explain what happens to chemical bonds during a chemical reaction.

Terms to Learn

chemical reaction
precipitate

READING STRATEGY

Reading Organizer As you read this section, create an outline of the section. Use the headings from the section in your outline.

Chemical Reactions

A chemical change takes place when chlorophyll breaks down into new substances. This change is an example of a chemical reaction. A **chemical reaction** is a process in which one or more substances change to make one or more new substances. The chemical and physical properties of the new substances differ from those of the original substances. Some results of chemical reactions are shown in **Figure 1.**

chemical reaction the process by which one or more substances change to produce one or more different substances

Figure 1 Results of Chemical Reactions

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

When you mix water with baking powder, substances in the baking powder react to form bubbles of carbon dioxide gas. These bubbles give the muffin its sponge-like texture.

Signs of Chemical Reactions

How can you tell when a chemical reaction is taking place? **Figure 2** shows some signs that tell you that a reaction may be taking place. In some chemical reactions, gas bubbles form. Other reactions form solid precipitates (pree SIP uh TAYTS). A **precipitate** is a solid substance that is formed in a solution. During other chemical reactions, energy is given off. This energy may be in the form of light, thermal energy, or electricity. Reactions often have more than one of these signs. And the more of these signs that you see, the more likely that a chemical reaction is taking place.

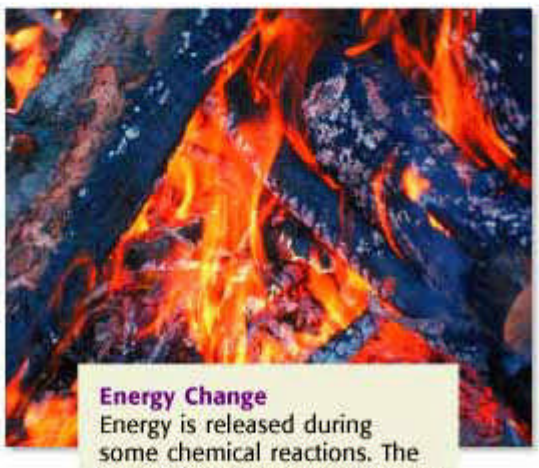
precipitate a solid that is produced as a result of a chemical reaction in solution

Reading Check **What is a precipitate?** *(See the Appendix for answers to Reading Checks.)*

Figure 2 **Some Signs of Chemical Reactions**

Gas Formation
The chemical reaction in the beaker has formed a brown gas, nitrogen dioxide. This gas is formed when a strip of copper is placed into nitric acid.

Solid Formation
Here you see potassium chromate solution being added to a silver nitrate solution. The dark red solid is a precipitate of silver chromate.



Energy Change
Energy is released during some chemical reactions. The fire in this photo gives off light energy and thermal energy. During some other chemical reactions, energy is taken in.

Color Change
Don't spill chlorine bleach on your jeans! The bleach reacts with the blue dye on the fabric and causes the color of the material to change.

Figure 3 *The top photo shows the starting substances: table sugar and sulfuric acid, a clear liquid. The substances formed in this chemical reaction are very different from the starting substances.*

A Change of Properties

Even though the signs we look for to see if a reaction is taking place are good signals of chemical reactions, they do not guarantee that a reaction is happening. For example, gas can be given off when a liquid boils. But this example is a physical change, not a chemical reaction.

So, how can you be sure that a chemical reaction is occurring? The most important sign is the formation of new substances that have different properties. Look at **Figure 3.** The starting materials in this reaction are sugar and sulfuric acid. Several things tell you that a chemical reaction is taking place. Bubbles form, a gas is given off, and the beaker becomes very hot. But most important, new substances form. And the properties of these substances are very different from those of the starting substances.

Bonds: Holding Molecules Together

A *chemical bond* is a force that holds two atoms together in a molecule. For a chemical reaction to take place, the original bonds must break and new bonds must form.

Breaking and Making Bonds

How do new substances form in a chemical reaction? First, chemical bonds in the starting substances must break. Molecules are always moving. If the molecules bump into each other with enough energy, the chemical bonds in the molecules break. The atoms then rearrange, and new bonds form to make the new substances. **Figure 4** shows how bonds break and form in the reaction between hydrogen and chlorine.

Reading Check **What happens to the bonds of substances during a chemical reaction?**

Figure 4 **Reaction of Hydrogen and Chlorine**

hydrogen + chlorine **hydrogen chloride**

Breaking Bonds Hydrogen and chlorine are diatomic. Diatomic molecules are two atoms bonded together. The bonds joining these atoms must first break before the atoms can react with each other.

Making Bonds A new substance, hydrogen chloride, forms as new bonds are made between hydrogen atoms and chlorine atoms.

New Bonds, New Substances

What happens when hydrogen and chlorine are combined? A chlorine gas molecule is a diatomic (DIE uh TAHM ik) molecule. That is, a chlorine molecule is made of two atoms of chlorine. Chlorine gas has a greenish yellow color. Hydrogen gas is also a diatomic molecule. Hydrogen gas is a flammable, colorless gas. When chlorine gas and hydrogen gas react, the bond between the hydrogen atoms breaks. And the bond between the chlorine atoms also breaks. A new bond forms between each hydrogen and chlorine atom. A new substance, hydrogen chloride, is formed. Hydrogen chloride is a nonflammable, colorless gas. Its properties differ from the properties of both of the starting substances.

Let's look at another example. Sodium is a metal that reacts violently in water. Chlorine gas is poisonous. When chlorine gas and sodium react, the result is a familiar compound—table salt. Sodium chloride, or table salt, is a harmless substance that almost everyone uses. The salt's properties are very different from sodium's or chlorine's. Salt is a new substance.

QUICK LAB

Reaction Ready

1. Place a **piece of chalk** in a **plastic cup.**
2. Add **5 mL of vinegar** to the cup. Record your observations.
3. What evidence of a chemical reaction do you see?
4. What type of new substance was formed?

SECTION Review

Summary

- A chemical reaction is a process by which substances change to produce new substances with new chemical and physical properties.
- Signs that indicate a chemical reaction has taken place are a color change, formation of a gas or a solid, and release of energy.
- During a reaction, bonds are broken, atoms are rearranged, and new bonds are formed.

Using Key Terms

1. Use the following terms in the same sentence: *chemical reaction* and *precipitate*.

Understanding Key Ideas

2. Most chemical reactions
   a. have starting substances that collide with each other.
   b. do not break bonds.
   c. do not rearrange atoms.
   d. cannot be seen.
3. If the chemical properties of a substance have not changed, has a chemical reaction occurred?

Critical Thinking

4. **Analyzing Processes** Steam is escaping from a teapot. Is this a chemical reaction? Explain.
5. **Applying Concepts** Explain why charcoal burning in the grill is a chemical change.

Interpreting Graphics

Use the photo below to answer the questions that follow.

6. What evidence of a chemical reaction is shown in the photo?
7. What is happening to the bonds of the starting substances?

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For a variety of links related to this chapter, go to www.scilinks.org

Topic: Chemical Reactions
SciLinks code: HSM0274

SECTION 2

Chemical Formulas and Equations

How many words can you make using the 26 letters of the alphabet? Many thousands? Now, think of how many sentences you can make with all of those words.

Letters are used to form words. In the same way, chemical symbols are put together to make chemical formulas that describe substances. Chemical formulas can be placed together to describe a chemical reaction, just like words can be put together to make a sentence.

READING WARM-UP

Objectives

- Interpret and write simple chemical formulas.
- Write and balance simple chemical equations.
- Explain how a balanced equation shows the law of conservation of mass.

Terms to Learn

chemical formula
chemical equation
reactant
product
law of conservation of mass

READING STRATEGY

Discussion Read this section silently. Write down questions that you have about this section. Discuss your questions in a small group.

chemical formula a combination of chemical symbols and numbers to represent a substance

Chemical Formulas

All substances are formed from about 100 elements. Each element has its own chemical symbol. A **chemical formula** is a shorthand way to use chemical symbols and numbers to represent a substance. A chemical formula shows how many atoms of each kind are present in a molecule.

As shown in **Figure 1,** the chemical formula for water is H_2O. This formula tells you that one water molecule is made of two atoms of hydrogen and one atom of oxygen. The small 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. Sometimes, a symbol, such as O for oxygen in water's formula, has no subscript. If there is no subscript, only one atom of that element is present. Look at **Figure 1** for more examples of chemical formulas.

Figure 1 Chemical Formulas of Different Substances

Water	Oxygen	Glucose
H_2O	O_2	$C_6H_{12}O_6$
Water molecules are made up of 3 atoms—2 atoms of hydrogen bonded to 1 atom of oxygen.	**Oxygen** is a diatomic molecule. Each molecule has 2 atoms of oxygen bonded together.	**Glucose** molecules have 6 atoms of carbon, 12 atoms of hydrogen, and 6 atoms of oxygen.

Carbon dioxide

CO_2

The ***absence of a prefix*** indicates one carbon atom.

The prefix ***di-*** indicates two oxygen atoms.

Dinitrogen monoxide

N_2O

The prefix ***di-*** indicates two nitrogen atoms.

The prefix ***mono-*** indicates one oxygen atom.

Figure 2 *The formulas of these covalent compounds can be written by using the prefixes in the names of the compounds.*

Writing Formulas for Covalent Compounds

If you know the name of the covalent compound, you can often write the chemical formula for that compound. Covalent compounds are usually composed of two nonmetals. The names of many covalent compounds use prefixes. Each prefix represents a number, as shown in **Table 1.** The prefixes tell you how many atoms of each element are in a formula. **Figure 2** shows you how to write a chemical formula from the name of a covalent compound.

Table 1 **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

Writing Formulas for Ionic Compounds

If the name of a compound contains the name of a metal and the name of a nonmetal, the compound is ionic. To write the formula for an ionic compound, make sure the compound's charge is 0. In other words, the formula must have subscripts that cause the charges of the ions to cancel out. **Figure 3** shows you how to write a chemical formula from the name of an ionic compound.

Reading Check **What kinds of elements make up an ionic compound?** *(See the Appendix for answers to Reading Checks.)*

Sodium chloride

$NaCl$

A sodium ion has a **1+ charge.**

A chloride ion has a **1− charge.**

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

Magnesium chloride

$MgCl_2$

A magnesium ion has a **2+ charge.**

A chloride ion has a **1− charge.**

One magnesium ion and two chloride ions have an overall **charge of (2+) + 2(1−) = 0.**

Figure 3 *The formula of an ionic compound is written by using enough of each ion so that the overall charge is 0.*

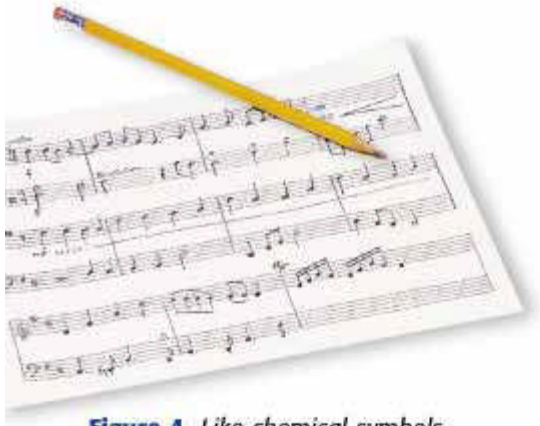


Figure 4 *Like chemical symbols, the symbols on this musical score are understood around the world!*

Chemical Equations

Think about a piece of music, such as the one in **Figure 4.** Someone writing music must tell the musician what notes to play, how long to play each note, and how each note should be played. Words aren't used to describe the musical piece. Instead, musical symbols are used. The symbols can be understood by anyone who can read music.

Describing Reactions by Using Equations

In the same way that composers use musical symbols, chemists around the world use chemical symbols and chemical formulas. Instead of changing words and sentences into other languages to describe reactions, chemists use chemical equations. A **chemical equation** uses chemical symbols and formulas as a shortcut to describe a chemical reaction. A chemical equation is short and is understood by anyone who understands chemical formulas.

chemical equation a representation of a chemical reaction that uses symbols to show the relationship between the reactants and the products

reactant a substance or molecule that participates in a chemical reaction

product the substance that forms in a chemical reaction

From Reactants to Products

When carbon burns, it reacts with oxygen to form carbon dioxide. **Figure 5** shows how a chemist would use an equation to describe this reaction. The starting materials in a chemical reaction are **reactants** (ree AK tuhnts). The substances formed from a reaction are **products.** In this example, carbon and oxygen are reactants. Carbon dioxide is the product.

Reading Check **What is the difference between reactants and products in a chemical reaction?**

Figure 5 **The Parts of a Chemical Equation**

Charcoal is used to cook food on a barbecue grill. When carbon in charcoal reacts with oxygen in the air, the primary product is carbon dioxide, as shown by the 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.

Figure 6 Examples of Similar Symbols and Formulas

CO_2

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

CO

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

Co

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

The Importance of Accuracy

The symbol or formula for each substance in the equation must be written correctly. For a compound, use the correct chemical formula. For an element, use the proper chemical symbol. An equation that has the wrong chemical symbol or formula will not correctly describe the reaction. In fact, even a simple mistake can make a huge difference. **Figure 6** shows how formulas and symbols can be mistaken.

The Reason Equations Must Be Balanced

Atoms are never lost or gained in a chemical reaction. They are just rearranged. Every atom in the reactants becomes part of the products. When writing a chemical equation, make sure the number of atoms of each element in the reactants equals the number of atoms of those elements in the products. This is called balancing the equation.

Balancing equations comes from the work of a French chemist, Antoine Lavoisier (lah vwah ZYAY). In the 1700s, Lavoisier found that the total mass of the reactants was always the same as the total mass of the products. Lavoisier's work led to the **law of conservation of mass.** This law states that mass is neither created nor destroyed in ordinary chemical and physical changes. This law means that a chemical equation must show the same numbers and kinds of atoms on both sides of the arrow.

MATH PRACTICE

Counting Atoms

Some chemical formulas contain parentheses. When counting atoms, multiply everything inside the parentheses by the subscript. For example, $Ca(NO_3)_2$ has one calcium atom, two (2×1) nitrogen atoms, and six (2×3) oxygen atoms. Find the number of atoms of each element in the formulas $Mg(OH)_2$ and $Al_2(SO_4)_3$.

law of conservation of mass
the law that states that mass cannot be created or destroyed in ordinary chemical and physical changes

How to Balance an Equation

To balance an equation, you must use coefficients (KOH uh FISH uhnts). A *coefficient* is a number that is placed in front of a chemical symbol or formula. For example, 2CO represents two carbon monoxide molecules. The number *2* is the coefficient.

For an equation to be balanced, all atoms must be counted. So, you must multiply the subscript of each element in a formula by the formula's coefficient. For example, $2H_2O$ contains a total of four hydrogen atoms and two oxygen atoms. Only coefficients—not subscripts—are changed when balancing equations. Changing the subscripts in the formula of a compound would change the compound. **Figure 7** shows you how to use coefficients to balance an equation.

Reading Check **If you see $4O_2$ in an equation, what is the coefficient?**

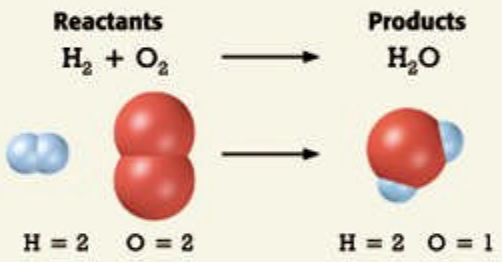
CONNECTION TO Language Arts

WRITING SKILL **Diatomic Molecules** Seven of the chemical elements exist as diatomic molecules. Do research to find out which seven elements these are. Write a short report that describes each diatomic molecule. Be sure to include the formula for each molecule.

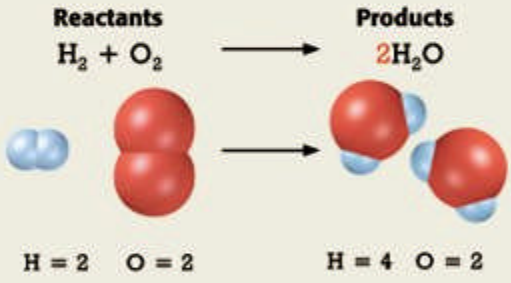
Figure 7 **Balancing a Chemical Equation**

Follow these steps to write a balanced equation for $H_2 + O_2 \longrightarrow H_2O$.

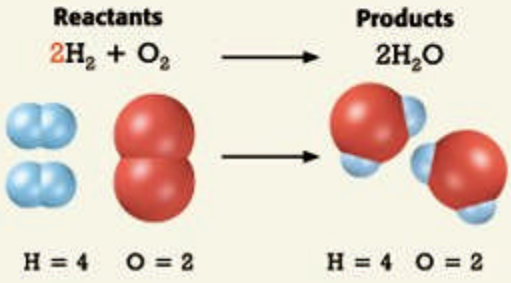
1 **Count the atoms** of each element in the reactants and in the products. You can see that there are fewer oxygen atoms in the product than in the reactants.



2 **To balance the oxygen atoms,** place the coefficient 2 in front of H_2O. Doing so gives you two oxygen atoms in both the reactants and the products. But now there are too few hydrogen atoms in the reactants.



3 **To balance the hydrogen atoms,** place the coefficient 2 in front of H_2. But to be sure that your answer is correct, always double-check your work!



QUICK LAB

Conservation of Mass

1. Place **5 g of baking soda** into a **sealable plastic bag.**
2. Place **5 mL of vinegar** into a **plastic film canister.** Put the lid on the canister.
3. Place the canister into the bag. Squeeze the air out of the bag. Seal the bag tightly.
4. Use a **balance** to measure the mass of the bag and its contents. Record the mass.
5. Keeping the bag closed, open the canister in the bag. Mix the vinegar with the baking soda. Record your observations.
6. When the reaction has stopped, measure the mass of the bag and its contents. Record the mass.
7. Compare the mass of the materials before the reaction and the mass of the materials after the reaction. Explain your observations.

SECTION Review

Summary

- A chemical formula uses symbols and subscripts to describe the makeup of a compound.
- Chemical formulas can often be written from the names of covalent and ionic compounds.
- A chemical equation uses chemical formulas, chemical symbols, and coefficients to describe a reaction.
- Balancing an equation requires that the same numbers and kinds of atoms be on each side of the equation.
- A balanced equation illustrates the law of conservation of mass: mass is neither created nor destroyed during ordinary physical and chemical changes.

Using Key Terms

The statements below are false. For each statement, replace the underlined word to make a true statement.

1. A chemical <u>formula</u> describes a chemical reaction.
2. The substances formed from a chemical reaction are <u>reactants</u>.

Understanding Key Ideas

3. The correct chemical formula for carbon tetrachloride is
   - **a.** CCl_3.
   - **b.** C_3Cl.
   - **c.** CCl.
   - **d.** CCl_4.
4. Calcium oxide is used to make soil less acidic. Its formula is
   - **a.** Ca_2O_2.
   - **b.** CaO.
   - **c.** CaO_2.
   - **d.** Ca_2O.
5. Balance the following equations by adding the correct coefficients.
   - **a.** $Na + Cl_2 \longrightarrow NaCl$
   - **b.** $Mg + N_2 \longrightarrow Mg_3N_2$
6. How does a balanced chemical equation illustrate that mass is never lost or gained in a chemical reaction?
7. What is the difference between a subscript and a coefficient?

Math Skills

8. Calculate the number of atoms of each element represented in each of the following: $2Na_3PO_4$, $4Al_2(SO_4)_3$, and $6PCl_5$.

Critical Thinking

9. **Analyzing Methods** Describe how to write a formula for a covalent compound. Give an example of a covalent compound.
10. **Applying Concepts** Explain why the subscript in a formula of a chemical compound cannot be changed when balancing an equation.

SCILINKS. NSTA

For a variety of links related to this chapter, go to www.scilinks.org

Topic: Chemical Formulas; Chemical Equations

SciLinks code: HSM0271; HSM0269

SECTION 3

Types of Chemical Reactions

There are thousands of known chemical reactions. Can you imagine having to memorize even 50 of them?

Remembering all of them would be impossible! But fortunately, there is help. In the same way that the elements are divided into groups based on their properties, reactions can be classified based on what occurs during the reaction.

Most reactions can be placed into one of four categories: synthesis (SIN thuh sis), decomposition, single-displacement, and double-displacement. Each type of reaction has a pattern that shows how reactants become products. One way to remember what happens in each type of reaction is to imagine people at a dance. As you learn about each type of reaction, study the models of students at a dance. The models will help you recognize each type of reaction.

READING WARM-UP

Objectives

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

Terms to Learn

synthesis reaction
decomposition reaction
single-displacement reaction
double-displacement reaction

READING STRATEGY

Mnemonics As you read this section, create a mnemonic device to help you remember the four types of chemical reactions.

Synthesis Reactions

A **synthesis reaction** is a reaction in which two or more substances combine to form one new compound. For example, a synthesis reaction takes place when sodium reacts with chlorine. This synthesis reaction produces sodium chloride, which you know as table salt. A synthesis reaction would be modeled by two people pairing up to form a dancing couple, as shown in **Figure 1.**

synthesis reaction a reaction in which two or more substances combine to form a new compound

Reading Check **What is a synthesis reaction?** *(See the Appendix for answers to Reading Checks.)*

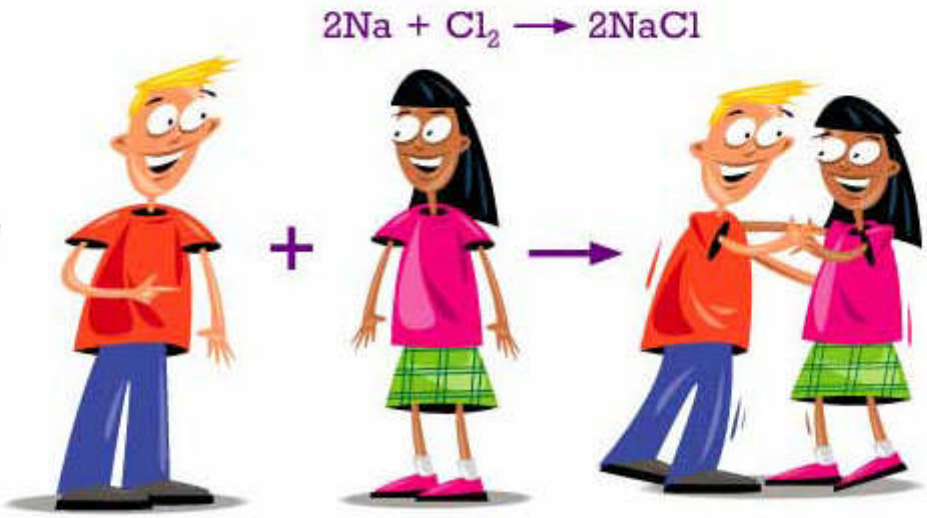


Figure 1 *Sodium reacts with chlorine to form sodium chloride in this synthesis reaction.*

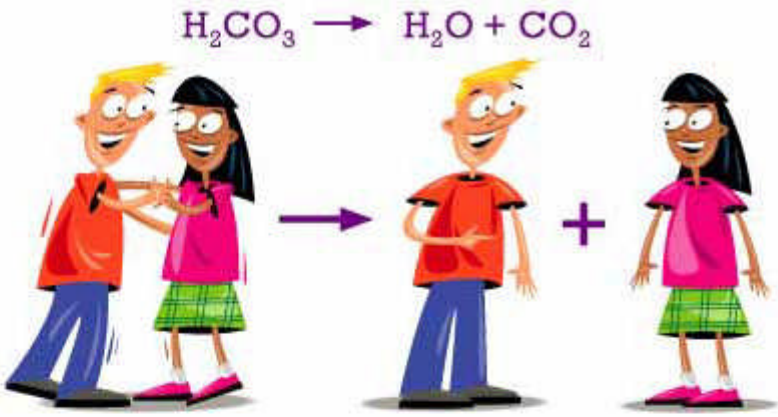


Figure 2 *In this decomposition reaction, carbonic acid, H_2CO_3, decomposes to form water and carbon dioxide.*

Decomposition Reactions

A **decomposition reaction** is a reaction in which a single compound breaks down to form two or more simpler substances. Decomposition is the reverse of synthesis. The dance model for a decomposition reaction would be a couple that finishes a dance and separates, as shown in **Figure 2.**

Reading Check How is a decomposition reaction different from a synthesis reaction?

decomposition reaction a reaction in which a single compound breaks down to form two or more simpler substances

single-displacement reaction a reaction in which one element or radical takes the place of another element or radical in a compound

Single-Displacement Reactions

Sometimes, an element replaces another element that is a part of a compound. This type of reaction is called a **single-displacement reaction.** The products of single-displacement reactions are a new compound and a different element. The dance model for a single-displacement reaction would show a person cutting in on a couple who is dancing. A new couple is formed. And a different person is left alone, as shown in **Figure 3.**

Figure 3 *Zinc replaces the hydrogen in hydrochloric acid to form zinc chloride and hydrogen gas in this single-displacement reaction.*

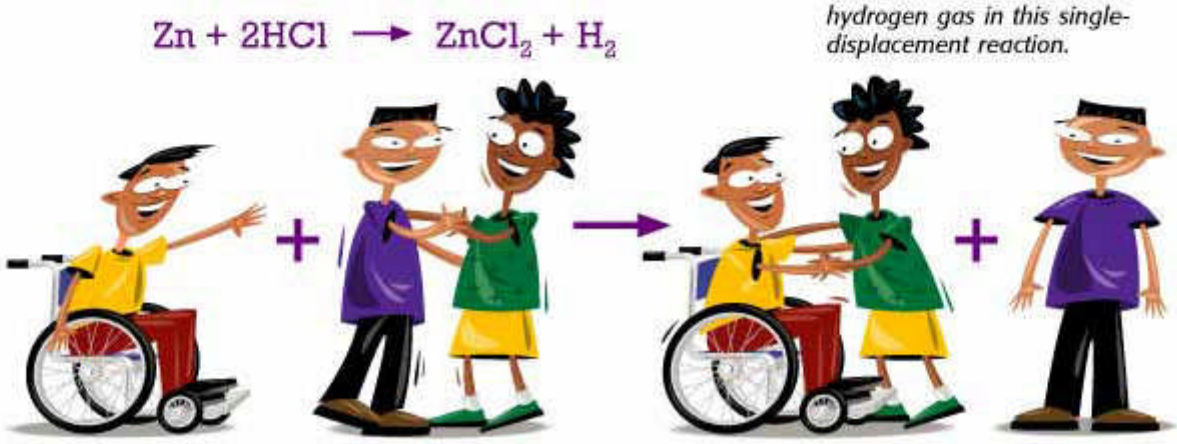
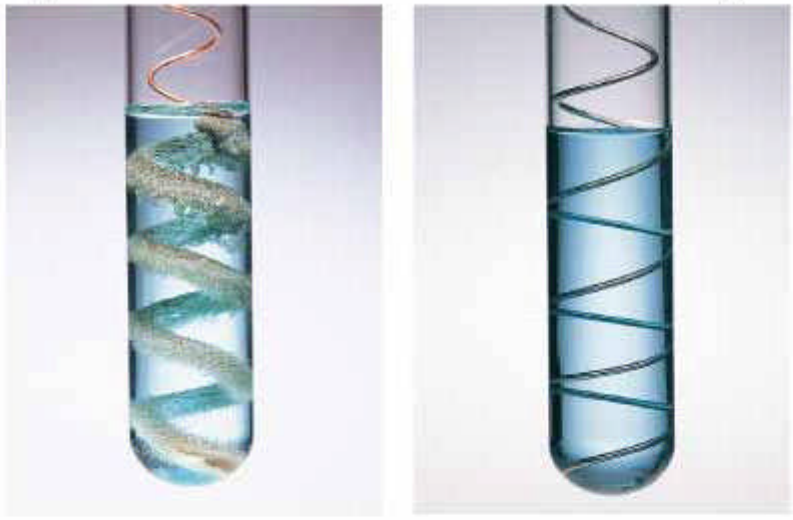


Figure 4 **Reactivity of Elements**

$Cu + 2AgNO_3 \rightarrow 2Ag + Cu(NO_3)_2$
Copper is more reactive than silver.

$Ag + Cu(NO_3)_2 \rightarrow$ no reaction
Silver is less reactive than copper.



Reactivity of Elements

In a single-displacement reaction, a more reactive element can displace a less reactive element in a compound. For example, **Figure 4** shows that copper is more reactive than silver. Copper (Cu) can replace the silver (Ag) ion in the compound silver nitrate. But the opposite reaction does not occur, because silver is less reactive than copper.

The elements in Group 1 of the periodic table are the most reactive metals. Very few nonmetals are involved in single-displacement reactions. In fact, only Group 17 nonmetals participate in single-displacement reactions.

Reading Check **Why can one element sometimes replace another element in a single-displacement reaction?**

INTERNET ACTIVITY

For another activity related to this chapter, go to **go.hrw.com** and type in the keyword **HP5REAW.**

QUICK LAB

Identifying Reactions

1. Study each of the following equations:

$4Na + O_2 \rightarrow 2Na_2O$ $\qquad$ $P_4 + 5O_2 \rightarrow 2P_2O_5$

$2Ag_3N \rightarrow 6Ag + N_2$ $\qquad$ $Zn + 2HCl \rightarrow ZnCl_2 + H_2$

2. Build models of each of these reactions using **colored clay.** Choose a different color of clay to represent each kind of atom.
3. Identify each type of reaction as a synthesis, decomposition, or single-displacement reaction.

Double-Displacement Reactions

A **double-displacement reaction** is a reaction in which ions from two compounds exchange places. One of the products of this type of reaction is often a gas or a precipitate. A dance model of a double-displacement reaction would be two couples dancing and then trading partners, as shown in **Figure 5.**

double-displacement reaction
a reaction in which a gas, a solid precipitate, or a molecular compound forms from the exchange of ions between two compounds

$$NaCl + AgF \longrightarrow NaF + AgCl$$

Figure 5 *A double-displacement reaction occurs when sodium chloride reacts with silver fluoride to form sodium fluoride and silver chloride (a precipitate).*

SECTION Review

Summary

- A synthesis reaction is a reaction in which two or more substances combine to form a compound.
- A decomposition reaction is a reaction in which a compound breaks down to form two or more simpler substances.
- A single-displacement reaction is a reaction in which an element takes the place of another element that is part of a compound.
- A double-displacement reaction is a reaction in which ions in two compounds exchange places.

Using Key Terms

1. In your own words, write a definition for each of the following terms: *synthesis reaction* and *decomposition reaction.*

Understanding Key Ideas

2. What type of reaction does the following equation represent?

$$FeS + 2HCl \longrightarrow FeCl_2 + H_2S$$

   a. synthesis reaction
   b. double-displacement reaction
   c. single-displacement reaction
   d. decomposition reaction

3. Describe the difference between single- and double-displacement reactions.

Math Skills

4. Write the balanced equation in which potassium iodide, KI, reacts with chlorine to form potassium chloride, KCl, and iodine.

Critical Thinking

5. **Analyzing Processes** The first reaction below is a single-displacement reaction that could occur in a laboratory. Explain why the second single-displacement reaction could not occur.

$$CuCl_2 + Fe \longrightarrow FeCl_2 + Cu$$

$$CaS + Al \longrightarrow \text{no reaction}$$

6. **Making Inferences** When two white compounds are mixed in a solution, a yellow solid forms. What kind of reaction has taken place? Explain your answer.

SECTION 4

Energy and Rates of Chemical Reactions

What is the difference between eating a meal and running a mile? You could say that a meal gives you energy, while running "uses up" energy.

Chemical reactions can be described in the same way. Some reactions release energy, and other reactions absorb energy.

READING WARM-UP

Objectives

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

Terms to Learn

exothermic reaction
endothermic reaction
law of conservation of energy
activation energy
inhibitor
catalyst

READING STRATEGY

Paired Summarizing Read this section silently. In pairs, take turns summarizing the material. Stop to discuss ideas that seem confusing.

Reactions and Energy

Chemical energy is part of all chemical reactions. Energy is needed to break chemical bonds in the reactants. As new bonds form in the products, energy is released. By comparing the chemical energy of the reactants with the chemical energy of the products, you can decide if energy is released or absorbed in the overall reaction.

Exothermic Reactions

A chemical reaction in which energy is released is called an **exothermic reaction.** *Exo* means "go out" or "exit." *Thermic* means "heat" or "energy." Exothermic reactions can give off energy in several forms, as shown in **Figure 1.** The energy released in an exothermic reaction is often written as a product in a chemical equation, as in this equation:

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

Figure 1 **Types of Energy Released in Exothermic Reactions**

Light energy is released in the exothermic reaction that is taking place in these light sticks.

Electrical energy is released in the exothermic reaction that will take place in this battery.

Light and thermal energy are released in the exothermic reaction taking place in this campfire.

Endothermic Reactions

A chemical reaction in which energy is taken in is called an **endothermic reaction.** *Endo* means "go in." The energy that is taken in during an endothermic reaction is often written as a reactant in a chemical equation. Energy as a reactant is shown in the following equation:

$$2H_2O + energy \rightarrow 2H_2 + O_2$$

An example of an endothermic process is photosynthesis. In photosynthesis, plants use light energy from the sun to produce glucose. Glucose is a simple sugar that is used for nutrition. The equation that describes photosynthesis is the following:

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

exothermic reaction a chemical reaction in which heat is released to the surroundings

endothermic reaction a chemical reaction that requires heat

law of conservation of energy the law that states that energy cannot be created or destroyed but can be changed from one form to another

Reading Check **What is an endothermic reaction?** (*See the Appendix for answers to Reading Checks.*)

The Law of Conservation of Energy

Neither mass nor energy can be created or destroyed in chemical reactions. The **law of conservation of energy** states that energy cannot be created or destroyed. However, energy can change forms. And energy can be transferred from one object to another in the same way that a baton is transferred from one runner to another runner, as shown in **Figure 2.**

The energy released in exothermic reactions was first stored in the chemical bonds in the reactants. And the energy taken in during endothermic reactions is stored in the products. If you could 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.

Figure 2 *Energy can be transferred from one object to another object in the same way that a baton is transferred from one runner to another runner in a relay race.*

Endo Alert

1. Fill a **plastic cup** half full with **calcium chloride solution.**
2. Measure the temperature of the solution by using a **thermometer.**
3. Carefully add **1 tsp of baking soda.**
4. Record your observations.
5. When the reaction has stopped, record the temperature of the solution.
6. What evidence that an endothermic reaction took place did you observe?

Figure 3 *Chemical reactions need energy to get started in the same way that a bowling ball needs a push to get rolling.*

Rates of Reactions

A reaction takes place only if the particles of reactants collide. But there must be enough energy to break the bonds that hold particles together in a molecule. The speed at which new particles form is called the *rate of a reaction*.

Activation Energy

Before the bowling ball in **Figure 3** can roll down the alley, the bowler must first put in some energy to start the ball rolling. A chemical reaction must also get a boost of energy before the reaction can start. This boost of energy is called activation energy. **Activation energy** is the smallest amount of energy that molecules need to react.

activation energy the minimum amount of energy required to start a chemical reaction

Another example of activation energy is striking a match. Before a match can be used to light a campfire, the match has to be lit! A strike-anywhere match has all the reactants it needs to burn. The chemicals on a match react and burn. But, the chemicals will not light by themselves. You must strike the match against a surface. The heat produced by this friction provides the activation energy needed to start the reaction.

Reading Check **What is activation energy?**

Sources of Activation Energy

Friction is one source of activation energy. In the match example, friction provides the energy needed to break the bonds in the reactants and allow new bonds to form. An electric spark in a car's engine is another source of activation energy. This spark begins the burning of gasoline. Light can also be a source of activation energy for a reaction. **Figure 4** shows how activation energy relates to exothermic reactions and endothermic reactions.

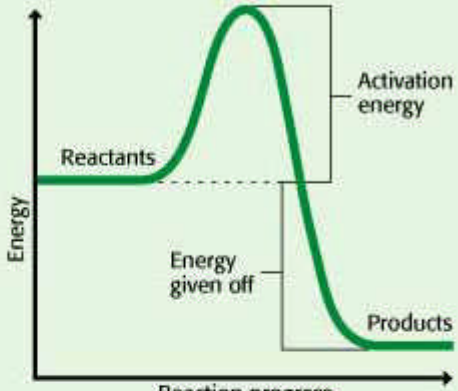
CONNECTION TO Social Studies

WRITING SKILL **The Strike-Anywhere Match**

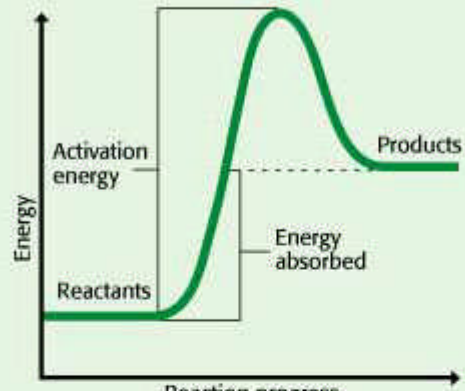
Research the invention of the strike-anywhere match. Find out who invented it, who patented it, and when the match was introduced to the public. In your **science journal,** write a short report about what you learn from your research.

Figure 4 **Energy Diagrams**

Exothermic Reaction Once an exothermic reaction starts, it can continue. The energy given off as the product forms continues to supply the activation energy needed for the substances to react.



Endothermic Reaction An endothermic reaction continues to absorb energy. Energy must be used to provide the activation energy needed for the substances to react.



Factors Affecting Rates of Reactions

The rate of a reaction is a measure of how fast the reaction takes place. Recall that the rate of a reaction depends on how fast new particles form. There are four factors that affect the rate of a reaction. These factors are: temperature, concentration, surface area, and the presence of an inhibitor or catalyst.

Temperature

A higher temperature causes a faster rate of reaction, as shown in **Figure 5.** At high temperatures, particles of reactants move quickly. The rapid movement causes the particles to collide often and with a lot of energy. So, many particles have the activation energy to react. And many reactants can change into products in a short time.

Figure 5 *The light stick on the right glows brighter than the one on the left because the one on the right is warmer. The higher temperature causes the rate of the reaction to increase.*

Which Is Quicker?

1. Fill a **clear plastic cup** with **250 mL of warm water.** Fill a **second clear plastic cup** with **250 mL of cold water.**
2. Place **one-quarter of an effervescent tablet** in each of the two cups of water at the same time. Using a **stopwatch,** time each reaction.
3. Observe each reaction, and record your observations.
4. In which cup did the reaction occur at a faster rate?

Figure 6 Concentration of Solutions

▼ When the amount of copper sulfate crystals dissolved in water is **small,** the concentration of the copper sulfate solution is **low.**

▼ When the amount of copper sulfate crystals dissolved in water is **large,** the concentration of the copper sulfate solution is **high.**

Concentration

In general, a high concentration of reactants causes a fast rate of a reaction. *Concentration* is a measure of the amount of one substance dissolved in another substance, as shown in **Figure 6.** When the concentration is high, there are many reactant particles in a given volume. So, there is a small distance between particles. The particles run into each other often. Thus, the particles react faster.

Reading Check **How does a high concentration of reactants increase the rate of a reaction?**

Surface Area

Surface area is the amount of exposed surface of a substance. Increasing the surface area of solid reactants increases the rate of a reaction. Grinding a solid into a powder makes a larger surface area. Greater surface area exposes more particles of the reactant to other reactant particles. This exposure to other particles causes the particles of the reactants to collide with each other more often. So, the rate of the reaction is increased.

CONNECTION TO Biology

Enzymes and Inhibitors
Enzymes are proteins that speed up reactions in your body. Sometimes, chemicals called *inhibitors* stop the action of enzymes. Research how inhibitors are beneficial in reactions in the human body. Make a poster or a model that explains what you have learned, and present it to your class.

ACTIVITY

Inhibitors

inhibitor a substance that slows down or stops a chemical reaction

catalyst a substance that changes the rate of a chemical reaction without being used up or changed very much

An **inhibitor** is a substance that slows down or stops a chemical reaction. Slowing down or stopping a reaction may sometimes be useful. For example, preservatives are added to foods to slow down the growth of bacteria and fungi. The preservatives prevent bacteria and fungi from producing substances that can spoil food. Some antibiotics are examples of inhibitors. For example, penicillin prevents certain kinds of bacteria from making a cell wall. So, the bacteria die.

Catalysts

Some chemical 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. Because it is not changed, a catalyst is not a reactant. A catalyst lowers the activation energy of a reaction, which allows the reaction to happen more quickly. Catalysts called *enzymes* speed up most reactions in your body. Catalysts are even found in cars, as seen in **Figure 7.** The catalytic converter decreases air pollution. It does this by increasing the rate of reactions that involve the harmful products given off by cars.

Figure 7 *This catalytic converter contains platinum and palladium. These two catalysts increase the rate of reactions that make the car's exhaust less harmful.*

SECTION Review

Summary

- Energy is given off in exothermic reactions.
- Energy is absorbed in an endothermic reaction.
- The law of conservation of energy states that energy is neither created nor destroyed.
- Activation energy is the energy needed for a reaction to occur.
- The rate of a chemical reaction is affected by temperature, concentration, surface area, and the presence of an inhibitor or catalyst.

Using Key Terms

The statements below are false. For each statement, replace the underlined term to make a true statement.

1. An exothermic reaction absorbs energy.
2. The rate of a reaction can be increased by adding an inhibitor.

Understanding Key Ideas

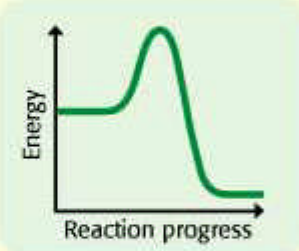
3. Which of the following will not increase the rate of a reaction?
   a. adding a catalyst
   b. increasing the temperature of the reaction
   c. decreasing the concentration of reactants
   d. grinding a solid into powder
4. How does the concentration of a solution affect the rate of reaction?

Critical Thinking

5. **Making Comparisons** Compare exothermic and endothermic reactions.
6. **Applying Concepts** Explain how chewing your food thoroughly can help your body digest food.

Interpreting Graphics

Use the diagram below to answer the questions that follow.



7. Does this energy diagram show an exothermic or an endothermic reaction? How can you tell?
8. A catalyst lowers the amount of activation energy needed to get a reaction started. What do you think the diagram would look like if a catalyst were added?

SCILINKS. NSTA

For a variety of links related to this chapter, go to www.scilinks.org

Topic: Exothermic and Endothermic Reactions

SciLinks code: HSM0555

Using Scientific Methods

Skills Practice Lab

Speed Control

The reaction rate (how fast a chemical reaction happens) is an important factor to control. Sometimes, you want a reaction to take place rapidly, such as when you are removing tarnish from a metal surface. Other times, you want a reaction to happen very slowly, such as when you are depending on a battery as a source of electrical energy.

In this lab, you will discover how changing the surface area and concentration of the reactants affects reaction rate. In this lab, you can estimate the rate of reaction by observing how fast bubbles form.

OBJECTIVES

Describe how the surface area of a solid affects the rate of a reaction.

Explain how concentration of reactants will speed up or slow down a reaction.

MATERIALS

- funnels (2)
- graduated cylinders, 10 mL (2)
- hydrochloric acid, concentrated
- hydrochloric acid, dilute
- strips of aluminum, about 5 cm x 1 cm each (6)
- scissors
- test-tube rack
- test tubes, 30 mL (6)

SAFETY

Part A: Surface Area

Ask a Question

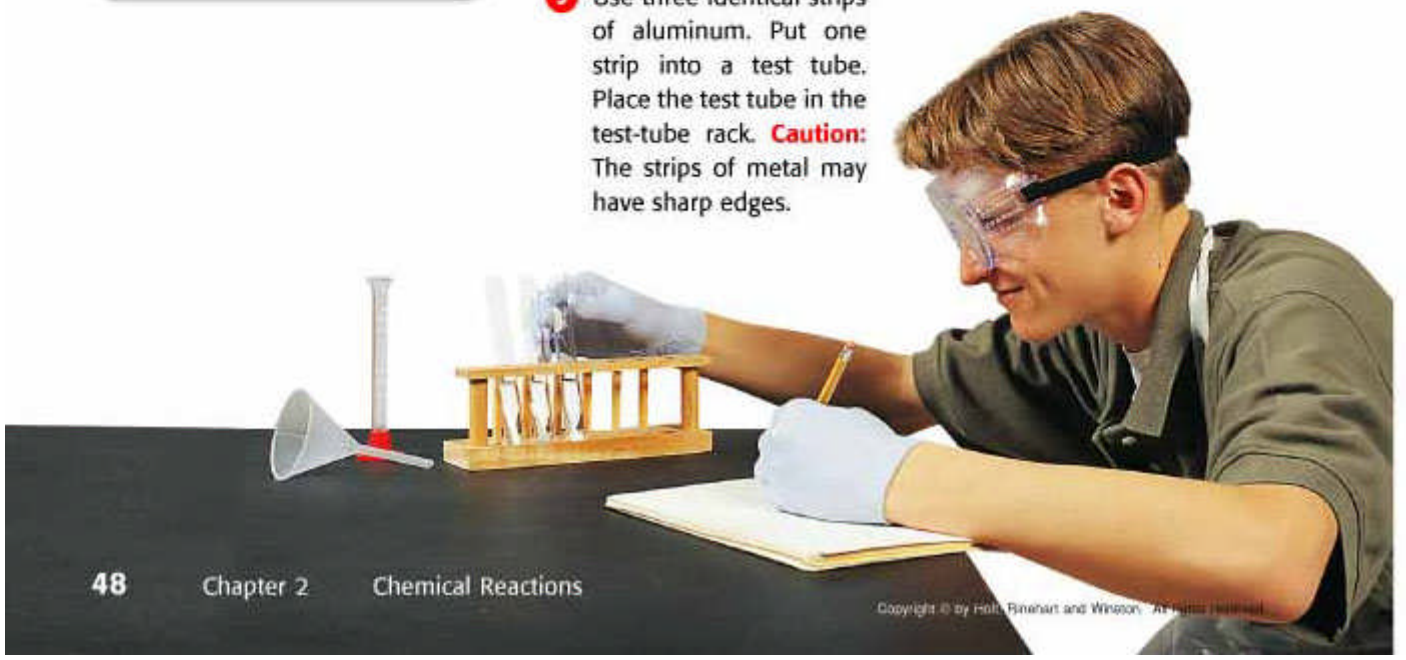
1. How does changing the surface area of a metal affect reaction rate?

Form a Hypothesis

2. Write a statement that answers the question above. Explain your reasoning.

Test the Hypothesis

3. Use three identical strips of aluminum. Put one strip into a test tube. Place the test tube in the test-tube rack. **Caution:** The strips of metal may have sharp edges.



4. Carefully fold a second strip in half and then in half again. Use a textbook or other large object to flatten the folded strip as much as possible. Place the strip in a second test tube in the test-tube rack.
5. Use scissors to cut a third strip of aluminum into the smallest possible pieces. Place all of the pieces into a third test tube, and place the test tube in the test-tube rack.
6. Use a funnel and a graduated cylinder to pour 10 mL of concentrated hydrochloric acid into each of the three test tubes. **Caution:** Hydrochloric acid is corrosive. If any acid should spill on you, immediately flush the area with water and notify your teacher.
7. Observe the rate of bubble formation in each test tube. Record your observations.

Analyze the Results

1. **Organizing Data** Which form of aluminum had the greatest surface area? the smallest surface area?
2. **Analyzing Data** The amount of aluminum and the amount of acid were the same in all three test tubes. Which form of the aluminum seemed to react the fastest? Which form reacted the slowest? Explain your answers.
3. **Analyzing Results** Do your results support the hypothesis you made? Explain.

Draw Conclusions

4. **Making Predictions** Would powdered aluminum react faster or slower than the forms of aluminum you used? Explain your answer.

Part B: Concentration

Ask a Question

1. How does changing the concentration of acid affect the reaction rate?

Form a Hypothesis

2. Write a statement that answers the question above. Explain your reasoning.

Test the Hypothesis

3. Place one of the three remaining aluminum strips in each of the three clean test tubes. (Note: Do not alter the strips.) Place the test tubes in the test-tube rack.
4. Using the second funnel and graduated cylinder, pour 10 mL of water into one of the test tubes. Pour 10 mL of dilute acid into the second test tube. Pour 10 mL of concentrated acid into the third test tube.
5. Observe the rate of bubble formation in the three test tubes. Record your observations.

Analyze the Results

1. **Explaining Events** In this set of test tubes, the strips of aluminum were the same, but the concentration of the acid was different. Was there a difference between the test tube that contained water and the test tubes that contained acid? Which test tube formed bubbles the fastest? Explain.
2. **Analyzing Results** Do your results support the hypothesis you made? Explain.

Draw Conclusions

3. **Applying Conclusions** Why should spilled hydrochloric acid be diluted with water before it is wiped up?

Chapter Review

USING KEY TERMS

Complete each of the following sentences by choosing the correct term from the word bank.

subscript	exothermic reaction
inhibitor	synthesis reaction
coefficient	reactant

1. Adding a(n) ___ will slow down a chemical reaction.
2. A chemical reaction that gives off heat is called a(n) ___.
3. A chemical reaction that forms one compound from two or more substances is called a(n) ___.
4. The 2 in the formula Ag_2S is a (an) ___.

UNDERSTANDING KEY IDEAS

Multiple Choice

5. 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 example of
   - **a.** activation energy.
   - **b.** the law of conservation of energy.
   - **c.** the law of conservation of mass.
   - **d.** a double-displacement reaction.
6. Which of the following is the correct chemical formula for dinitrogen tetroxide?
   - **a.** N_4O_2
   - **b.** NO_2
   - **c.** N_2O_5
   - **d.** N_2O_4

7. In which type of reaction do ions in two compounds switch places?
   - **a.** a synthesis reaction
   - **b.** a decomposition reaction
   - **c.** a single-displacement reaction
   - **d.** a double-displacement reaction
8. Which of the following actions 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
9. Enzymes in your body act as catalysts. Thus, the role of enzymes is
   - **a.** to increase the rate of chemical reactions.
   - **b.** to decrease the rate of chemical reactions.
   - **c.** to help you breathe.
   - **d.** to inhibit chemical reactions.

Short Answer

10. Name the type of reaction that each of the following equations represents.
    - **a.** $2Cu + O_2 \rightarrow 2CuO$
    - **b.** $2Na + MgSO_4 \rightarrow Na_2SO_4 + Mg$
    - **c.** $Ba(CN)_2 + H_2SO_4 \rightarrow BaSO_4 + 2HCN$
11. Describe what happens to chemical bonds during a chemical reaction.
12. Name four ways that you can change the rate of a chemical reaction.
13. Describe four clues that signal that a chemical reaction is taking place.

Math Skills

14. Write balanced equations for the following:
    a. $Fe + O_2 \rightarrow Fe_2O_3$
    b. $Al + CuSO_4 \rightarrow Al_2(SO_4)_3 + Cu$
    c. $Mg(OH)_2 + HCl \rightarrow MgCl_2 + H_2O$

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

CRITICAL THINKING

16. **Concept Mapping** Use the following terms to create a concept map: *products, chemical reaction, chemical equation, chemical formulas, reactants, coefficients,* and *subscripts.*

17. **Evaluating Assumptions** Your friend is very worried by rumors that he has heard about a substance called *dihydrogen monoxide* in the city's water system. What could you say to your friend to calm his fears? (Hint: Write the formula of the substance.)

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

19. **Applying Concepts** You measured the mass of a steel pipe before leaving it outdoors. One month later, the pipe had rusted, and its mass had increased. Does this change violate the law of conservation of mass? Explain your answer.

20. **Applying Concepts** 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.

INTERPRETING GRAPHICS

Use the photo below to answer the questions that follow.

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

22. Is this reaction an exothermic or endothermic reaction? Explain your answer.

23. Draw and label an energy diagram of both an exothermic and endothermic reaction. Identify the diagram that describes the reaction shown in the photo above.