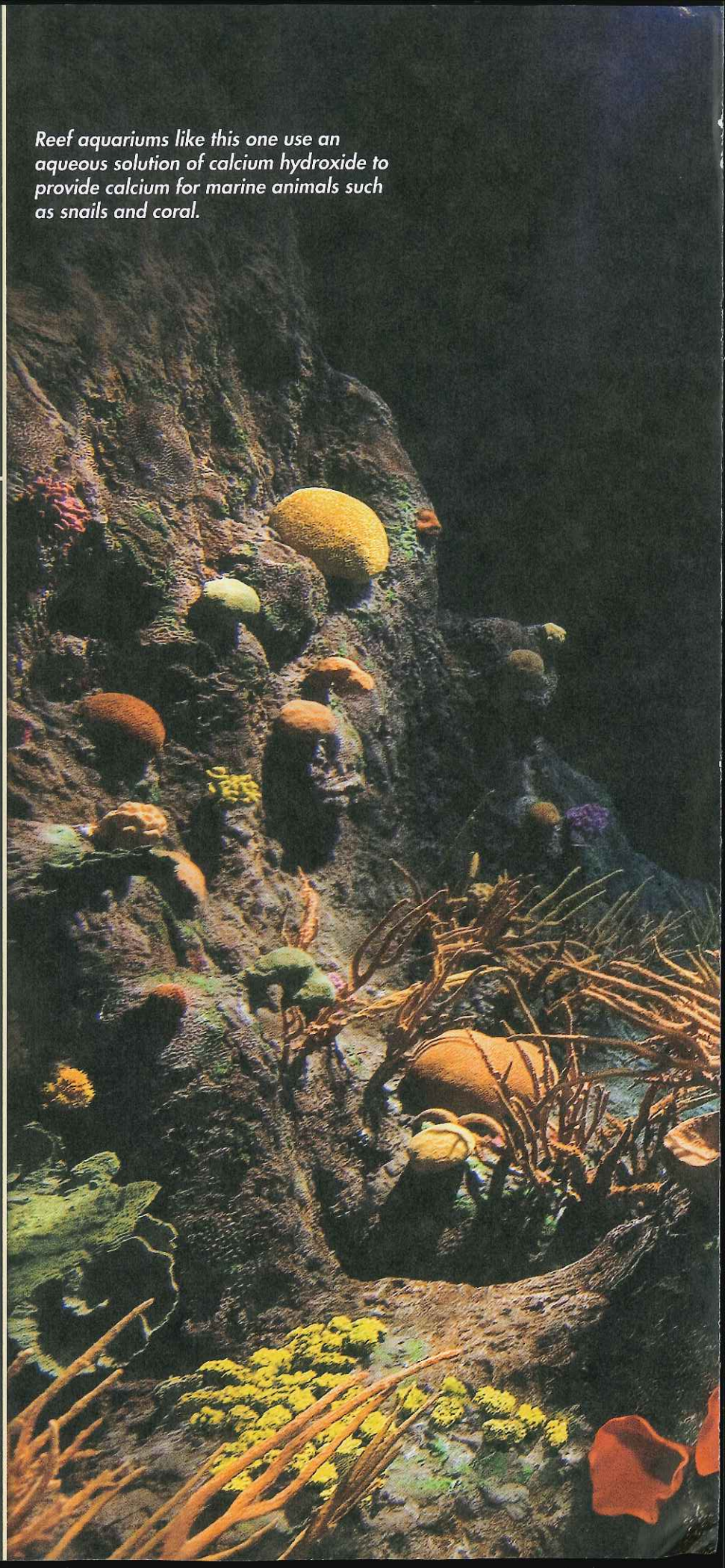
11 Chemical Reactions



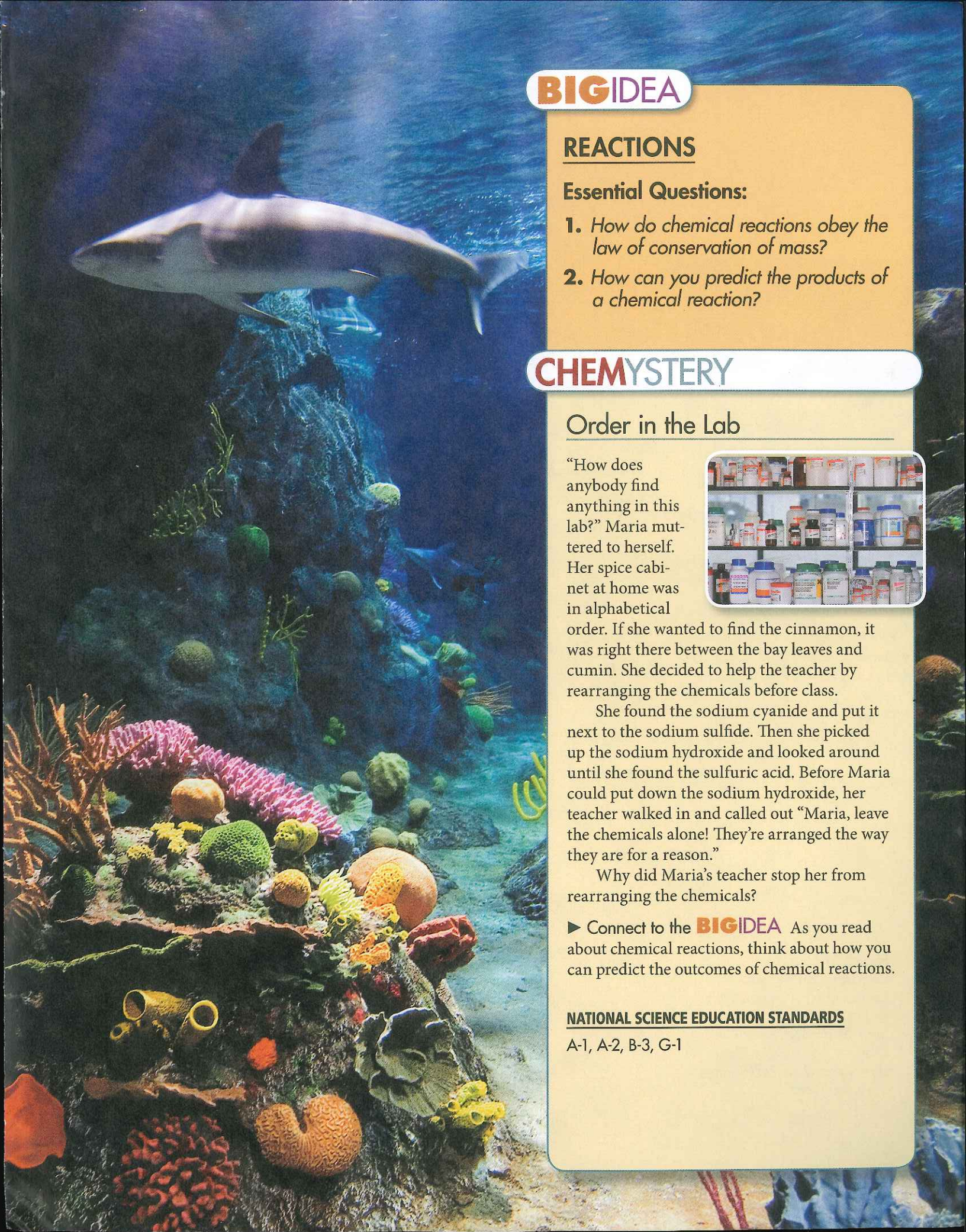
Reef aquariums like this one use an aqueous solution of calcium hydroxide to provide calcium for marine animals such as snails and coral.

INSIDE:

PearsonChem.com

CONCEPTS IN ACTION · KINETIC ART · VIRTUAL LAB

MATH +/− TUTOR · ONLINE PROBLEMS · CHEM TUTOR



BIG IDEA

REACTIONS

Essential Questions:

1. *How do chemical reactions obey the law of conservation of mass?*
2. *How can you predict the products of a chemical reaction?*

CHEMYSTERY

Order in the Lab

"How does anybody find anything in this lab?" Maria muttered to herself. Her spice cabinet at home was in alphabetical order. If she wanted to find the cinnamon, it was right there between the bay leaves and cumin. She decided to help the teacher by rearranging the chemicals before class.

She found the sodium cyanide and put it next to the sodium sulfide. Then she picked up the sodium hydroxide and looked around until she found the sulfuric acid. Before Maria could put down the sodium hydroxide, her teacher walked in and called out "Maria, leave the chemicals alone! They're arranged the way they are for a reason."

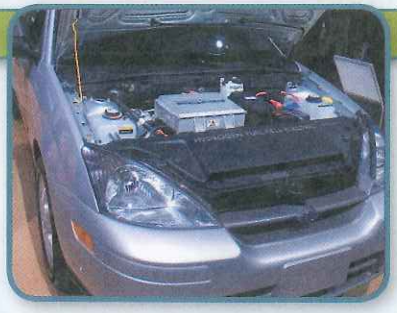
Why did Maria's teacher stop her from rearranging the chemicals?

▶ Connect to the BIG IDEA As you read about chemical reactions, think about how you can predict the outcomes of chemical reactions.

NATIONAL SCIENCE EDUCATION STANDARDS

A-1, A-2, B-3, G-1

11.1 Describing Chemical Reactions



CHEMISTRY & YOU

Q: *How is a chemical reaction going to change the way you drive?* You've probably heard about hydrogen fuel-cell cars. Fuel cells produce electricity through a chemical reaction without any of the combustion that you find in typical gasoline engines. In this lesson, you'll learn how to write and balance the equations that represent chemical reactions.

Key Questions

- ***How do you write a skeleton equation?***
- ***What are the steps for writing and balancing a chemical equation?***

Vocabulary

- chemical equation
- skeleton equation
- catalyst
- coefficient
- balanced equation

Introduction to Chemical Equations

How do you write a skeleton equation?

Every minute of the day chemical reactions take place—both inside you and around you. After a meal, a series of chemical reactions take place as your body digests food. Similarly, plants use sunlight to drive the photosynthetic processes needed to produce plant growth. Although the chemical reactions involved in photosynthesis and digestion are different, both chemical reactions are necessary to sustain life. All chemical reactions, whether simple or complex, involve changing substances.

In a chemical reaction, one or more reactants change into one or more products. Cooking food always involves a chemical reaction. In order to bake muffins, you begin with a recipe and ingredients, as shown in Figure 11.1. The recipe tells you which ingredients to mix together and how much of each to use. Chemical reactions take place when the ingredients or reactants are mixed together and heated in the oven. The product, in this case, is a batch of muffins. Chemists use a chemical equation—a quick, shorthand notation—to convey as much information as possible about what happens in a chemical reaction.

Figure 11.1
Reactants and Products
Reactants in the ingredients undergo chemical changes to form the product, the muffins.
Observing ***What evidence shows that chemical changes have occurred?***

Figure 11.2 Examples of Reactions
Three common chemical reactions are shown below.

Iron turns to red-brown rust (iron(III) oxide) in the presence of oxygen.

Water and oxygen form when hydrogen peroxide is poured on a cut.

The products of burning methane are carbon dioxide and water.

Word Equations How do you describe what happens in a chemical reaction? Recall from Chapter 2 the shorthand method for writing a description of a chemical reaction. In this method, the reactants were written on the left and the products on the right. An arrow separated them. You read the arrow as *yields, gives,* or *reacts to produce.*

$$\text{Reactants} \longrightarrow \text{products}$$

How could you describe the rusting of iron shown in Figure 11.2a? You could say: "Iron reacts with oxygen to produce iron(III) oxide (rust)." Although that is a perfectly good description, it's quicker to identify the reactants and product by means of a word equation.

$$\text{Iron} + \text{oxygen} \longrightarrow \text{iron(III) oxide}$$

In a word equation, write the names of the reactants to the left of the arrow, separated by plus signs; write the names of the products to the right of the arrow, also separated by plus signs. Notice that no plus sign is needed on the product side of this equation because iron(III) oxide is the only product.

Have you ever poured the antiseptic hydrogen peroxide on an open cut? Bubbles of oxygen gas form rapidly, as shown in Figure 11.2b. The production of a new substance, a gas, is evidence of a chemical change. Two new substances are produced in this reaction, oxygen gas and liquid water. You could describe this reaction by saying, "Hydrogen peroxide decomposes to form water and oxygen gas." But, you could also write a word equation.

$$\text{Hydrogen peroxide} \longrightarrow \text{water} + \text{oxygen}$$

When you light a burner on your stove, methane gas bursts into flames and produces the energy needed to heat your soup. Methane is the major component of natural gas, a common fuel for heating homes and cooking food. The burning of methane, as shown in Figure 11.2c, is a chemical reaction. How would you write the word equation for this reaction? Burning a substance typically requires oxygen, so methane and oxygen are the reactants. The products are water and carbon dioxide. Thus, the word equation is as follows:

$$\text{Methane} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water}$$

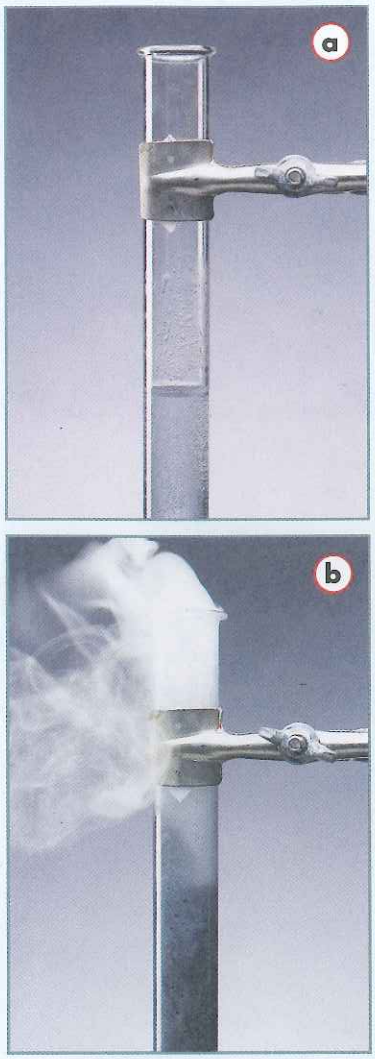


Figure 11.3
Speeding Up a Reaction
Hydrogen peroxide decomposes to form water and oxygen gas. **a.** Bubbles of oxygen appear slowly as decomposition proceeds. **b.** With the addition of the catalyst manganese(IV) oxide (MnO_2), decomposition speeds up. The white "smoke" is condensed water vapor.

Chemical Equations Word equations adequately describe chemical reactions, but they are cumbersome. It's easier to use the formulas for the reactants and products to write chemical equations. A **chemical equation** is a representation of a chemical reaction; the formulas of the reactants (on the left) are connected by an arrow with the formulas of the products (on the right). Here is a chemical equation for rusting:

$$Fe + O_2 \longrightarrow Fe_2O_3$$

Equations that show just the formulas of the reactants and products are called skeleton equations. A **skeleton equation** is a chemical equation that does not indicate the relative amounts of the reactants and products. The first step in writing a complete chemical equation is to write the skeleton equation. **To write a skeleton equation, write the chemical formulas for the reactants to the left of the yields sign (arrow) and the formulas for the products to the right.**

To add more information to the equation, you can indicate the physical states of substances by putting a symbol after each formula. Use (*s*) for a solid, (*l*) for a liquid, (*g*) for a gas, and (*aq*) for a substance in aqueous solution (a substance dissolved in water). Here is the unbalanced equation for rusting with symbols for the physical states added:

$$Fe(s) + O_2(g) \longrightarrow Fe_2O_3(s)$$

In many chemical reactions, a catalyst is added to the reaction mixture. A **catalyst** is a substance that speeds up the reaction but is not used up in the reaction. A catalyst is neither a reactant nor a product, so its formula is written above the arrow in a chemical equation. For example, Figure 11.3 shows that the compound manganese(IV) oxide ($MnO_2(s)$) catalyzes the decomposition of an aqueous solution of hydrogen peroxide ($H_2O_2(aq)$) to produce water and oxygen.

$$H_2O_2(aq) \xrightarrow{MnO_2} H_2O(l) + O_2(g)$$

Many of the symbols commonly used in writing chemical equations are listed below.

Table 11.1

Symbols Used in Chemical Equations

Symbol	Explanation
+	Separates two reactants or two products
$\longrightarrow$	"Yields," separates reactants from products
$\rightleftharpoons$	Used in place of $\longrightarrow$ for reversible reactions
(*s*), (*l*), (*g*)	Designates a reactant or product in the solid state, liquid state, and gaseous state; placed after the formula
(*aq*)	Designates an aqueous solution; the substance is dissolved in water; placed after the formula
$\xrightarrow{\Delta}$ or $\xrightarrow{heat}$	Indicates that heat is supplied to the reaction
$\xrightarrow{Pt}$	A formula written above or below the yield sign indicates its use as a catalyst (in this example, platinum).

Sample Problem 11.1

Writing a Skeleton Equation

Hydrochloric acid reacts with solid sodium hydrogen carbonate. The products formed are aqueous sodium chloride, water, and carbon dioxide gas. Write a skeleton equation for this chemical reaction.

1 Analyze **Identify the relevant concepts.**

Write the correct formula for each substance in the reaction. Indicate the state of each substance. Separate the reactants from the products with an arrow. Use plus signs to separate the two reactants and each of the three products.

2 Solve **Apply concepts to this problem.**

Start with the names of reactants and products. Include their physical states.

Reactants
sodium hydrogen carbonate (solid)
hydrochloric acid (aqueous)

Products
sodium chloride (aqueous)
water (liquid)
carbon dioxide (gas)

Write the correct formula for each reactant and each product.

Reactants
$NaHCO_3(s)$ $HCl(aq)$

Products
$NaCl(aq)$ $H_2O(l)$ $CO_2(g)$

Separate the reactants from the products with an arrow. Use plus signs to separate the reactants and the products.

$$NaHCO_3(s) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l) + CO_2(g)$$

1. Write a sentence that describes this chemical reaction:

$Na(s) + H_2O(l) \longrightarrow NaOH(aq) + H_2(g)$

2. Sulfur burns in oxygen to form sulfur dioxide. Write a skeleton equation for this chemical reaction.

Balancing Chemical Equations

What are the steps for writing and balancing a chemical equation?

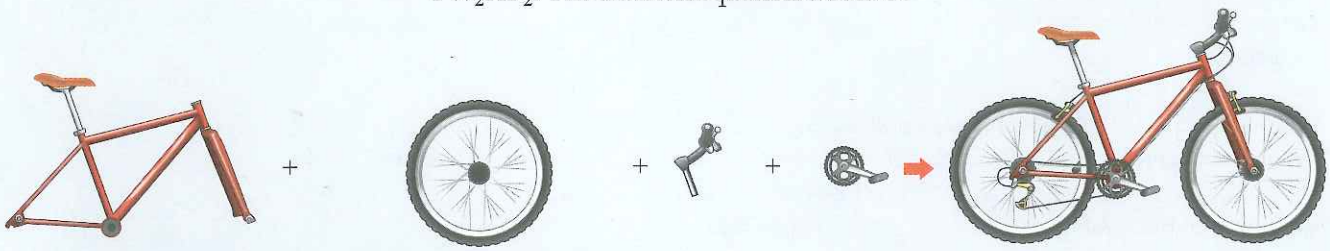
How would you write a word equation for the manufacture of bicycles? Simplify your task by limiting yourself to four major components: frames, wheels, handlebars, and pedals. Your word equation for making a bicycle could read like this.

$$\underset{\text{Reactants}}{\text{Frame} + \text{wheel} + \text{handlebar} + \text{pedal}} \longrightarrow \underset{\text{Product}}{\text{bicycle}}$$

Your word equation shows the reactants (the kinds of parts) and the product (a bicycle).

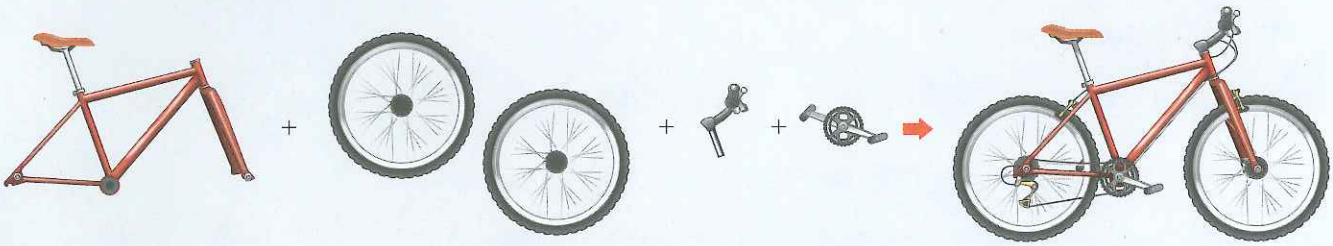
But if you were responsible for ordering parts to make a bicycle, this word equation would be inadequate because it does not indicate the quantity of each part needed to make one bicycle.

A standard bicycle is composed of one frame (F), two wheels (W), one handlebar (H), and two pedals (P). The formula for a bicycle would be FW_2HP_2. The skeleton equation would be



F + 1W + H + 1P ⟶ FW_2HP_2

This equation is unbalanced. An unbalanced equation does not indicate the quantity of the reactants needed to make the product. A complete description of the reaction must include not only the kinds of parts involved but also the quantities of parts required.



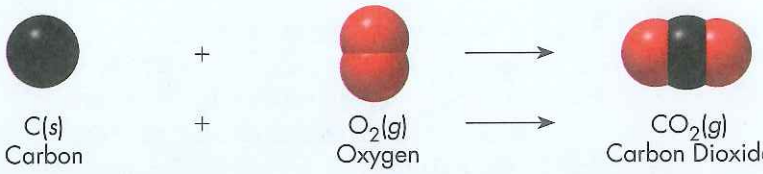
F + 2W + H + 2P ⟶ FW_2HP_2

This equation for making a bicycle is balanced. It tells you that one frame, two wheels, one handlebar, and two pedals produce one bicycle. To balance the equation, the number 2 was placed before wheels and pedals. The number 1 is understood to be in front of *frame, handlebar,* and *bicycle.* These numbers are called **coefficients**—small whole numbers that are placed in front of the formulas in an equation in order to balance it. In this balanced equation, the number of each bicycle part on the reactant side is the same as the number of those parts on the product side. A chemical reaction is also described by a **balanced equation** in which each side of the equation has the same number of atoms of each element and mass is conserved.

Recall that John Dalton's atomic theory states that as reactants are converted to products, the bonds holding the atoms together are broken, and new bonds are formed. The atoms themselves are neither created nor destroyed; they are merely rearranged.

This part of Dalton's theory explains the law of conservation of mass: In any chemical change, mass is conserved. The atoms in the products are the same atoms that were in the reactants—they are just rearranged. Representing a chemical reaction by a balanced chemical equation is a two-step process. **To write a balanced chemical equation, first write the skeleton equation. Then use coefficients to balance the equation so that it obeys the law of conservation of mass.** In every balanced equation, each side of the equation has the same number of atoms of each element.

Sometimes, though, a skeleton equation may already be balanced. For example, carbon burns in the presence of oxygen to produce carbon dioxide.



$C(s)$ + $O_2(g)$ → $CO_2(g)$

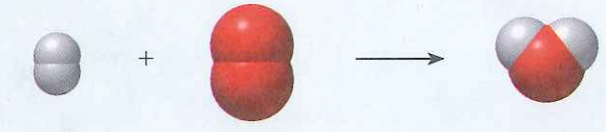
Carbon + Oxygen → Carbon Dioxide

Reactants
1 carbon atom, 2 oxygen atoms

Product
1 carbon atom, 2 oxygen atoms

This equation is balanced. One carbon atom and two oxygen atoms are on each side of the equation. You do not need to change the coefficients; they are all understood to be 1.

What about the equation for the reaction of hydrogen and oxygen gas? When hydrogen and oxygen are mixed, the product of the reaction is water. The skeleton equation is as follows:



$H_2(g)$ + $O_2(g)$ → $H_2O(l)$

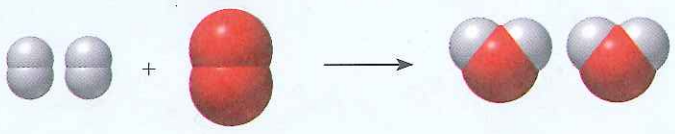
Hydrogen + Oxygen → Water

Reactants
2 hydrogen atoms
2 oxygen atoms

Product
2 hydrogen atoms
1 oxygen atom

The formulas for all the reactants and the product are correct, but this equation is not balanced. Count the atoms on both sides of the equation. Two oxygen atoms are on the reactant (left) side of the equation and only one oxygen atom is on the product (right) side. As written, the equation does not obey the law of conservation of mass, and so it does not describe quantitatively what really happens. What can you do to balance it?

To balance the equation for the reaction of hydrogen and oxygen, count the number of each kind of atom. Hydrogen is balanced, but oxygen is not. If you put the coefficient 2 in front of H_2O, the oxygen will be balanced. Now twice as many hydrogen atoms are in the product as are in the reactants. To correct this equation, put the coefficient 2 in front of H_2. Four hydrogen atoms and two oxygen atoms are on each side of the chemical equation. The equation is now balanced.



$2H_2(g)$ + $O_2(g)$ → $2H_2O(l)$

Hydrogen + Oxygen → Water

Reactants
4 hydrogen atoms
2 oxygen atoms

Products
4 hydrogen atoms
2 oxygen atoms

A few guidelines for writing and balancing equations are in the table on the next page.

CHEMISTRY & YOU

Q: *The reaction between oxygen and hydrogen in fuel cells produce the energy to power a car. What are the products of the reaction in a fuel cell that make the fuel-cell car a zero-emission car?*

See balancing equations animated online.

Rules for Writing and Balancing Equations

1. Determine the correct formulas for all the reactants and products.
2. Write the skeleton equation by placing the formulas for the reactants on the left and the formulas for the products on the right with a yields sign (⟶) in between. If two or more reactants or products are involved, separate their formulas with plus signs.
3. Determine the number of atoms of each element in the reactants and products. Count a polyatomic ion as a single unit if it appears unchanged on both sides of the equation.
4. Balance the elements one at a time by using coefficients. When no coefficient is written, it is assumed to be 1. Begin by balancing elements that appear only once on each side of the equation. Never balance an equation by changing the subscripts in a chemical formula. Each substance has only one correct formula.
5. Check each atom or polyatomic ion to be sure that the number is equal on both sides of the equation.
6. Make sure all the coefficients are in the lowest possible ratio.

CHEM TUTOR

SampleProblem 11.2

Balancing a Chemical Equation

Students suspended copper wire in an aqueous solution of silver nitrate. They noticed a deposit of silver crystals on the copper wire when the copper reacted with the silver nitrate. They recorded the equation for this reaction but didn't balance it. Balance their equation.

$$AgNO_3(aq) + Cu(s) \longrightarrow Cu(NO_3)_2(aq) + Ag(s)$$

1 Analyze **Identify the relevant concepts.**

Apply the rules for balancing equations. Because the nitrate polyatomic ion appears as a reactant and a product, this ion can be balanced as a unit.

2 Solve **Apply concepts to this problem.**

Remember that a coefficient must always go in front of a compound's formula, not in the middle of it.

Balance the nitrate ion. Put a coefficient 2 in front of $AgNO_3(aq)$.

$$2AgNO_3(aq) + Cu(s) \longrightarrow Cu(NO_3)_2(aq) + Ag(s)$$

Balance the silver. Put a coefficient 2 in front of $Ag(s)$.

$$2AgNO_3(aq) + Cu(s) \longrightarrow Cu(NO_3)_2(aq) + 2Ag(s)$$

3. Balance the equation:
$CO + Fe_2O_3 \longrightarrow Fe + CO_2$

4. Write the balanced chemical equation for the reaction of carbon with oxygen to form carbon monoxide.

Sample Problem 11.3

Balancing a Chemical Equation

Aluminum is a good choice for outdoor furniture because it reacts with oxygen in the air to form a thin protective coat of aluminum oxide. Balance the equation for this reaction.

$$Al(s) + O_2(g) \longrightarrow Al_2O_3(s)$$

1 Analyze **Identify the relevant concepts.**

Apply the rules for balancing equations. Notice the odd number of oxygen atoms in the product.

2 Solve **Apply concepts to this problem.**

First balance the aluminum by placing the coefficient 2 in front of Al(s).

$$2Al(s) + O_2(g) \longrightarrow Al_2O_3(s)$$

Any whole number coefficient placed in front of O_2 will always give an even number of oxygen atoms on the left.

Multiply the formula with the odd number of oxygen atoms (on the right) by 2 to get an even number of oxygen atoms on the right.

$$2Al(s) + O_2(g) \longrightarrow 2Al_2O_3(s)$$

Balance the oxygens on the left by placing a 3 in front of O_2.

$$2Al(s) + 3O_2(g) \longrightarrow 2Al_2O_3(s)$$

Then rebalance the aluminum by changing the coefficient of Al(s) from 2 to 4.

$$4Al(s) + 3O_2(g) \longrightarrow 2Al_2O_3(s)$$

5. Balance each equation.

a. $FeCl_3 + NaOH \longrightarrow Fe(OH)_3 + NaCl$

b. $CS_2 + Cl_2 \longrightarrow CCl_4 + S_2Cl_2$

c. $KI + Pb(NO_3)_2 \longrightarrow PbI_2 + KNO_3$

d. $C_2H_2 + O_2 \longrightarrow CO_2 + H_2O$

6. Write and balance these equations.

a. calcium hydroxide + sulfuric acid ⟶ calcium sulfate + water

b. sodium + water ⟶ sodium hydroxide + hydrogen

Suppose the equation for the formation of aluminum oxide was written this way:

$$8Al(s) + 6O_2(g) \longrightarrow 4Al_2O_3(s)$$

Each of the coefficients should be divided by 2 to get an equation with the lowest whole number ratio of coefficients.

Quick Lab

Materials

- aluminum foil, 20 cm × 20 cm
- large beaker or glass pan
- tarnished silver fork or spoon
- sodium hydrogen carbonate
- plastic tablespoon
- hot water

Removing Silver Tarnish

Procedure

1. Fill the beaker about three-quarters full of hot water and add 2 tablespoons of sodium hydrogen carbonate ($NaHCO_3$).
2. Crush the aluminum foil into a loose ball and place it in the beaker.
3. Write a brief description of the tarnished silver fork; then place it in the beaker so that it is touching the aluminum ball.
4. Allow the beaker to stand undisturbed for 30 minutes.
5. Remove the fork and aluminum ball and rinse them with water.

Analyze and Conclude

1. **Observe** Compare the silver fork with your observations before placing the fork in the water. What changes do you observe?
2. **Explain** Did a chemical reaction occur? How do you know?
3. **Explain** The tarnish on the silver fork is silver sulfide (Ag_2S). Silver becomes tarnished when it is exposed to air, egg yolk, or rubber bands. Each of these substances contains sulfur. Look carefully for a pale yellow precipitate of aluminum sulfide on the bottom of the beaker. Write the formula for aluminum sulfide.
4. **Apply Concepts** The unbalanced equation for the reaction is

$$Ag_2S(s) + Al(s) \longrightarrow Al_2S_3(s) + Ag(s)$$

Balance the equation.

11.1 LessonCheck

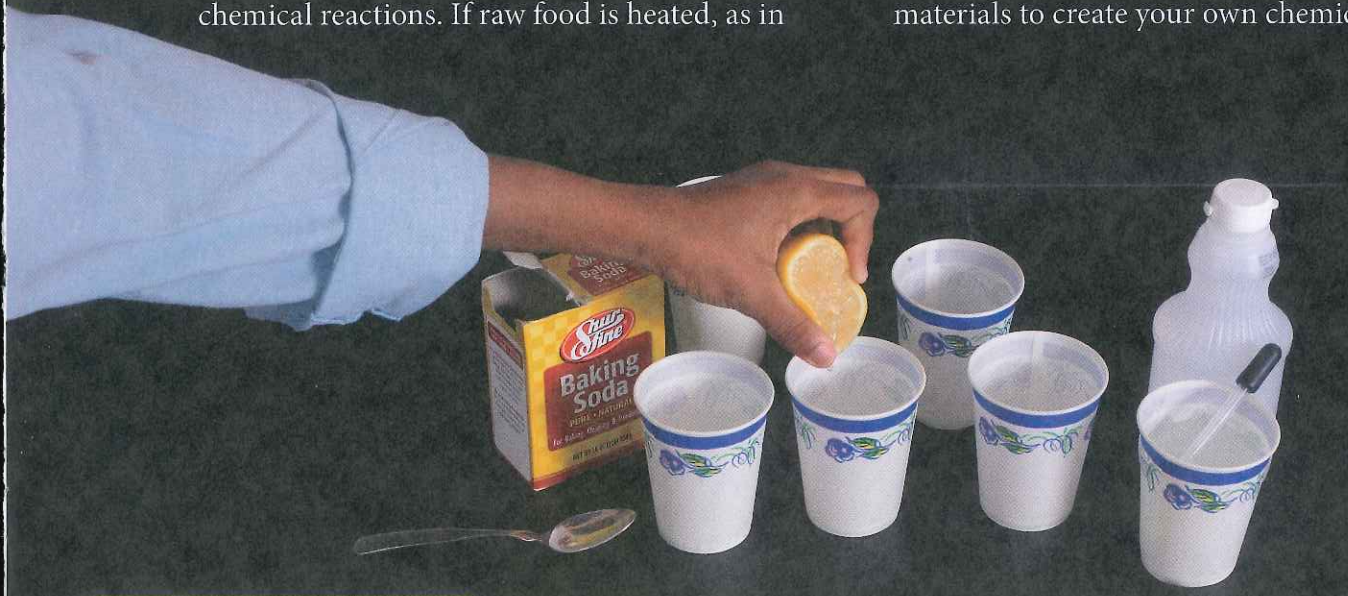
ONLINE PROBLEMS

7. **Explain** How do you write a skeleton equation?
8. **Summarize** Describe the steps in writing a balanced chemical equation.
9. **Describe** Write skeleton equations for these reactions.
   a. Heating copper(II) sulfide in the presence of diatomic oxygen produces pure copper and sulfur dioxide gas.
   b. When heated, baking soda (sodium hydrogen carbonate) decomposes to form the products sodium carbonate, carbon dioxide, and water.
10. **Apply Concepts** Balance the following equations:
    a. $SO_2(g) + O_2(g) \longrightarrow SO_3(g)$
    b. $Fe_2O_3(s) + H_2(g) \longrightarrow Fe(s) + H_2O(l)$
    c. $P(s) + O_2(g) \longrightarrow P_4O_{10}(s)$
    d. $Al(s) + N_2(g) \longrightarrow AlN(s)$
11. **Apply Concepts** Write and balance equations for the following reactions:
    a. Iron metal and chlorine gas react to form solid iron(III) chloride.
    b. Solid aluminum carbonate decomposes to form solid aluminum oxide and carbon dioxide gas.
    c. Solid magnesium reacts with aqueous silver nitrate to form solid silver and aqueous magnesium nitrate.

Kitchen Chemistry

Did you know that your kitchen is a good place to study chemistry? Food preparation generally involves a large number of chemical reactions. Compounds in raw food may combine, decompose, or oxidize to give the finished product. The acids in vinegars, lemon juice, or anything acidic used to marinate meat helps break down the connective tissue of the meat through chemical reactions. If raw food is heated, as in frying and baking, chemical reactions produce many complex compounds. When you eat the cooked food, your body performs another series of chemical reactions that allow the nutrients in the food to nourish your body.

In this lesson, you learned how to describe chemical reactions and write balanced chemical equations. Now you can use ordinary kitchen materials to create your own chemical reactions.



On Your Own

1. For this activity, you'll need a few **paper cups, baking soda, water, vinegar,** and **lemon juice.** You'll also need a **spoon** and an **eyedropper.**

2. Spoon a little bit of baking soda into four cups.

3. Using the eyedropper, add a few drops of water to the first cup. Watch what happens. Then record your observations in a chart similar to the one below.

4. Repeat the process for each substance in the chart.

What Did You See?	
Substance	What's the Reaction?
Water	
Vinegar	
Lemon juice	
Your own choice	

Think About It

1. Draw Conclusions What clues tell you that a chemical reaction occurred?

2. Apply Concepts The skeleton equation for the reaction between baking soda and vinegar is:

$$NaHCO_3 + HC_2H_3O_2 \longrightarrow NaC_2H_3O_2 + H_2O + CO_2$$

Is this equation balanced? Explain.

3. Connect to the BIG IDEA How does the law of conservation of mass apply to this experiment?

11.2 Types of Chemical Reactions

CHEMISTRY & YOU

Q: *What happens to the wax when you burn a candle?* You probably have noticed that you have less candle after burning than before, but you may not know that a candle will not burn unless oxygen is present. When you burn a candle, a chemical reaction called combustion takes place. In this lesson, you will learn that if you can recognize the type of reaction, you may be able to predict the products of the reaction.

Key Questions

What are the five general types of reactions?

Vocabulary

- combination reaction
- decomposition reaction
- single-replacement reaction
- activity series
- double-replacement reaction
- combustion reaction

Classifying Reactions

What are the five general types of reactions?

By classifying chemical reactions, you can more easily predict what products are likely to form. One classification system identifies five general types. **The five general types of reactions include combination, decomposition, single-replacement, double-replacement, and combustion.** Not all chemical reactions fit uniquely into only one category. Occasionally, a reaction may fit equally well into two categories. Nevertheless, recognizing a reaction as a particular type is useful. Patterns of chemical behavior will become apparent and allow you to predict the products of reactions.

Combination Reactions The first type of reaction is the combination, or synthesis, reaction. A **combination reaction** is a chemical change in which two or more substances react to form a single new substance. As shown in Figure 11.4, magnesium metal and oxygen gas combine to form the compound magnesium oxide.

$$2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$$

Notice that in this reaction, as in all combination reactions, the product is a single substance (MgO), which is a compound. The reactants in this combination reaction (Mg and O_2) are two elements, which is often the case. But two compounds may also combine to form a single substance.

When a Group A metal and a nonmetal react, the product is a binary ionic compound.

$$2K(s) + Cl_2(g) \longrightarrow 2KCl(s)$$

When two nonmetals react in a combination reaction, more than one product is often possible.

$$S(s) + O_2(g) \longrightarrow SO_2(g) \text{ sulfur dioxide}$$

$$2S(s) + 3O_2(g) \longrightarrow 2SO_3(g) \text{ sulfur trioxide}$$

More than one product may also result from the combination reaction of a transition metal and a nonmetal.

$$Fe(s) + S(s) \longrightarrow FeS(s) \text{ iron(II) sulfide}$$

$$2Fe(s) + 3S(s) \longrightarrow Fe_2S_3(s) \text{ iron(III) sulfide}$$

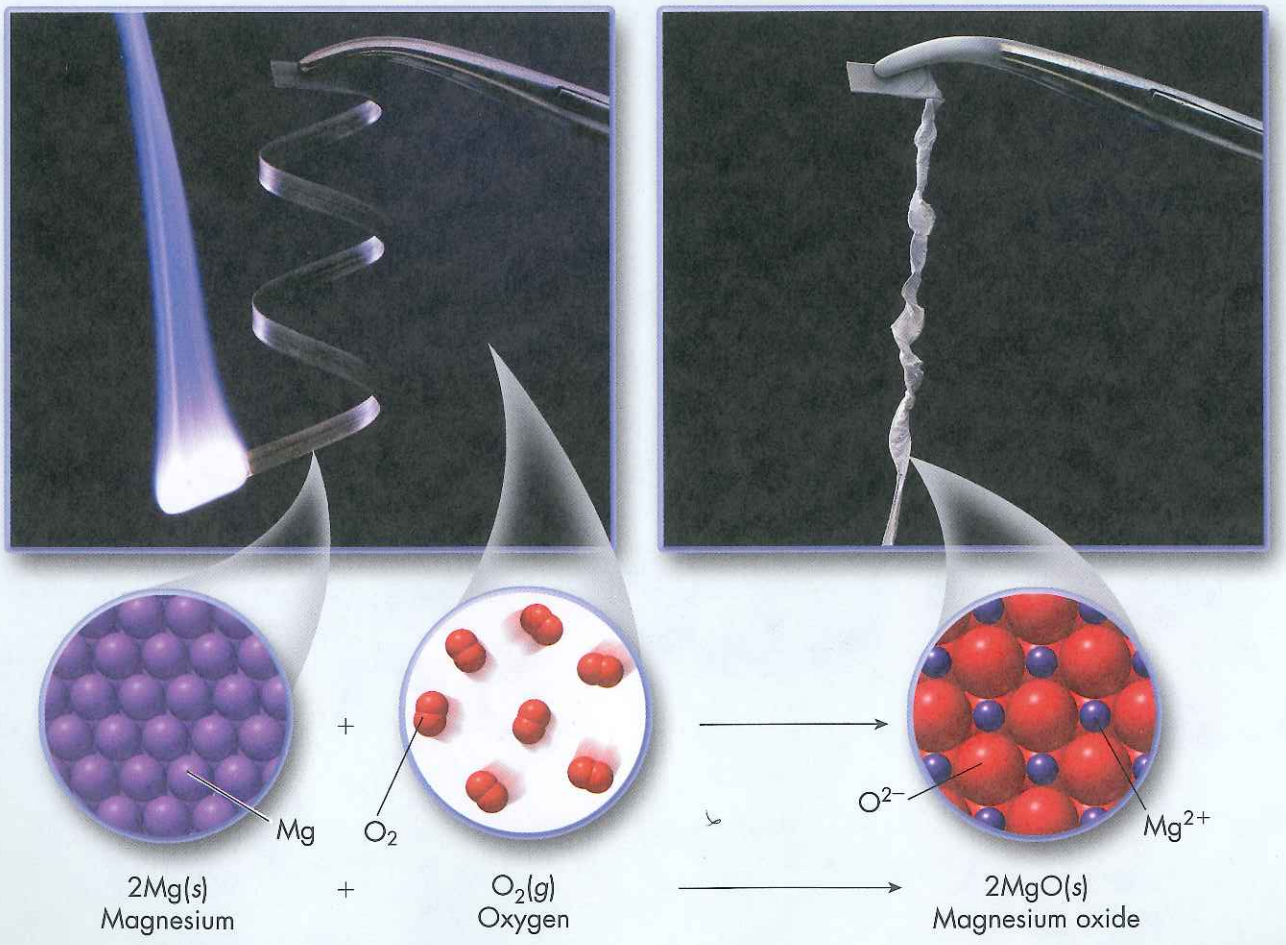
Some nonmetal oxides react with water to produce an acid, a compound that produces hydrogen ions in aqueous solution. You will learn about acids in Chapter 19.

$$SO_2(g) + H_2O(l) \longrightarrow H_2SO_3(aq) \text{ sulfurous acid}$$

Some metallic oxides react with water to give a base, or a compound containing hydroxide ions. Again in this case, you can use the ionic charges to derive the formula for the product.

$$CaO(s) + H_2O(l) \longrightarrow Ca(OH)_2(aq) \text{ calcium hydroxide}$$

Figure 11.4 Combination Reaction
When ignited, magnesium ribbon reacts with oxygen in the surrounding air to form magnesium oxide, a white solid. This reaction is a combination reaction.



Decomposition Reactions Some chemical reactions are the opposite of combination reactions. These kinds of reactions are classified as decomposition reactions. When mercury(II) oxide is heated, it decomposes or breaks down into two simpler substances, as shown in Figure 11.5.

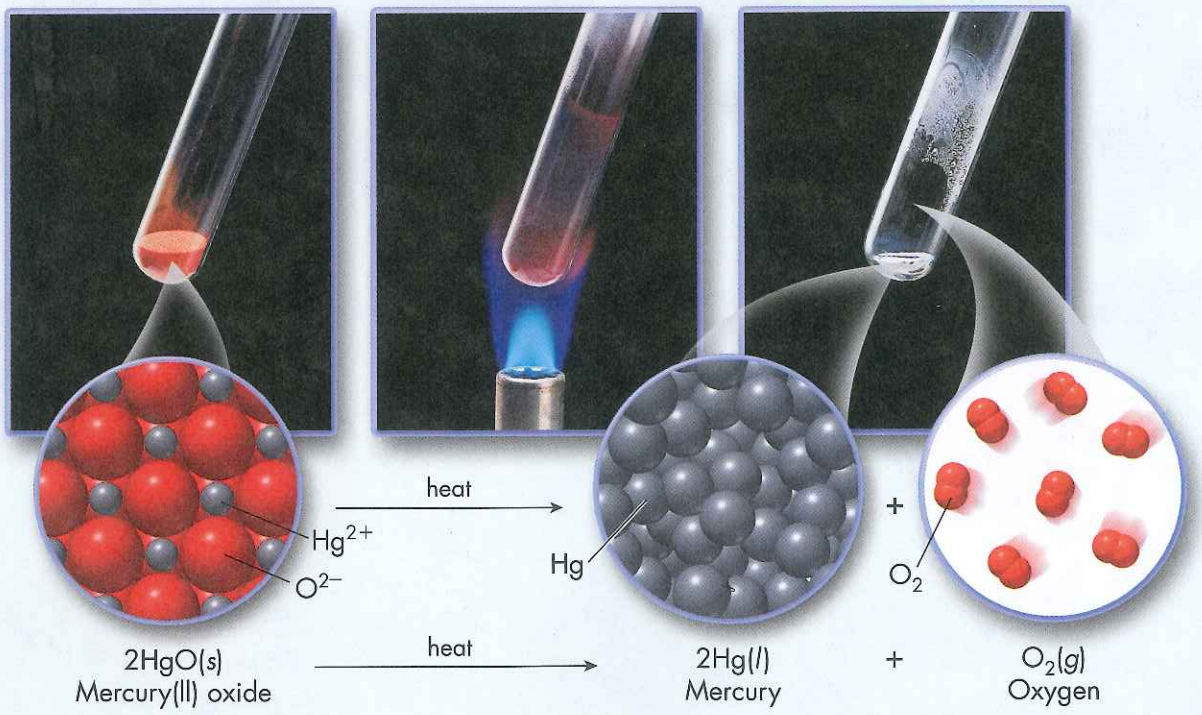
$$2HgO(s) \longrightarrow 2Hg(l) + O_2(g)$$

A **decomposition reaction** is a chemical change in which a single compound breaks down into two or more simpler products. Decomposition reactions involve only one reactant and two or more products. The products can be any combination of elements and compounds. It is usually difficult to predict the products of decomposition reactions. However, when a simple binary compound such as HgO breaks down, you know that the products must be the constituent elements Hg and O_2. Most decomposition reactions require energy in the form of heat, light, or electricity.

Did you know that a decomposition reaction happens when an automobile air bag inflates? A device that can trigger the reaction is placed into the air bag along with sodium azide (NaN_3) pellets. When the device is triggered, the sodium azide pellets decompose and release nitrogen gas, which inflates the air bag quickly.

$$2NaN_3(s) \longrightarrow 2Na(s) + 3N_2(g)$$

Figure 11.5 Decomposition Reaction
When orange-colored mercury(II) oxide is heated, it decomposes into its constituent elements: liquid mercury and gaseous oxygen.
Compare and Contrast ***How are the reactions pictured in Figures 11.4 and 11.5 similar? How are they different?***



SampleProblem 11.4

Writing Equations for Combination and Decomposition Reactions

Write a balanced equation for each of the following reactions.

a. Combination of copper and sulfur:

$Cu(s) + S(s) \longrightarrow$ (two reactions possible)

b. Decomposition of water:

$H_2O(l) \xrightarrow{\text{electricity}}$

1 Analyze **Identify the relevant concepts.** Two combination reactions are possible because copper is a transition metal and has more than one common ionic charge (Cu^+ and Cu^{2+}).

2 Solve **Apply the concepts to this problem.**

Write the formula for the product(s) in each reaction.

a. Copper(I) sulfide $Cu_2S(s)$
Copper(II) sulfide $CuS(s)$

Note that Cu_2S and CuS represent different products from different reactions.

b. $H_2(g)$
$O_2(g)$

Write a skeleton equation for each reaction.

For Copper(I):
$Cu(s) + S(s) \longrightarrow Cu_2S(s)$
For Copper(II):
$Cu(s) + S(s) \longrightarrow CuS(s)$

$H_2O(l) \xrightarrow{\text{electricity}} H_2(g) + O_2(g)$

The hydrogen is balanced but the oxygen is not. After balancing the oxygen, you must rebalance the hydrogen atoms.

Apply the rules for balancing equations.

For Copper(I):
$2Cu(s) + S(s) \longrightarrow Cu_2S(s)$ (balanced)
For Copper(II): the skeleton equation is already balanced.
$Cu(s) + S(s) \longrightarrow CuS(s)$ (balanced)

$2H_2O(l) \xrightarrow{\text{electricity}} H_2(g) + O_2(g)$
$2H_2O(l) \xrightarrow{\text{electricity}} 2H_2(g) + O_2(g)$

12. Write the formula for the binary compound that decomposes to the products H_2 and Br_2.

13. Complete and balance this decomposition reaction.

$HI \longrightarrow$

14. Write and balance the equation for the formation of magnesium nitride (Mg_3N_2) from its elements.

Single-Replacement Reactions Dropping a small piece of potassium into a beaker of water creates the vigorous reaction shown in Figure 11.6 The reaction produces hydrogen gas and a large quantity of heat. The released hydrogen gas can ignite explosively.

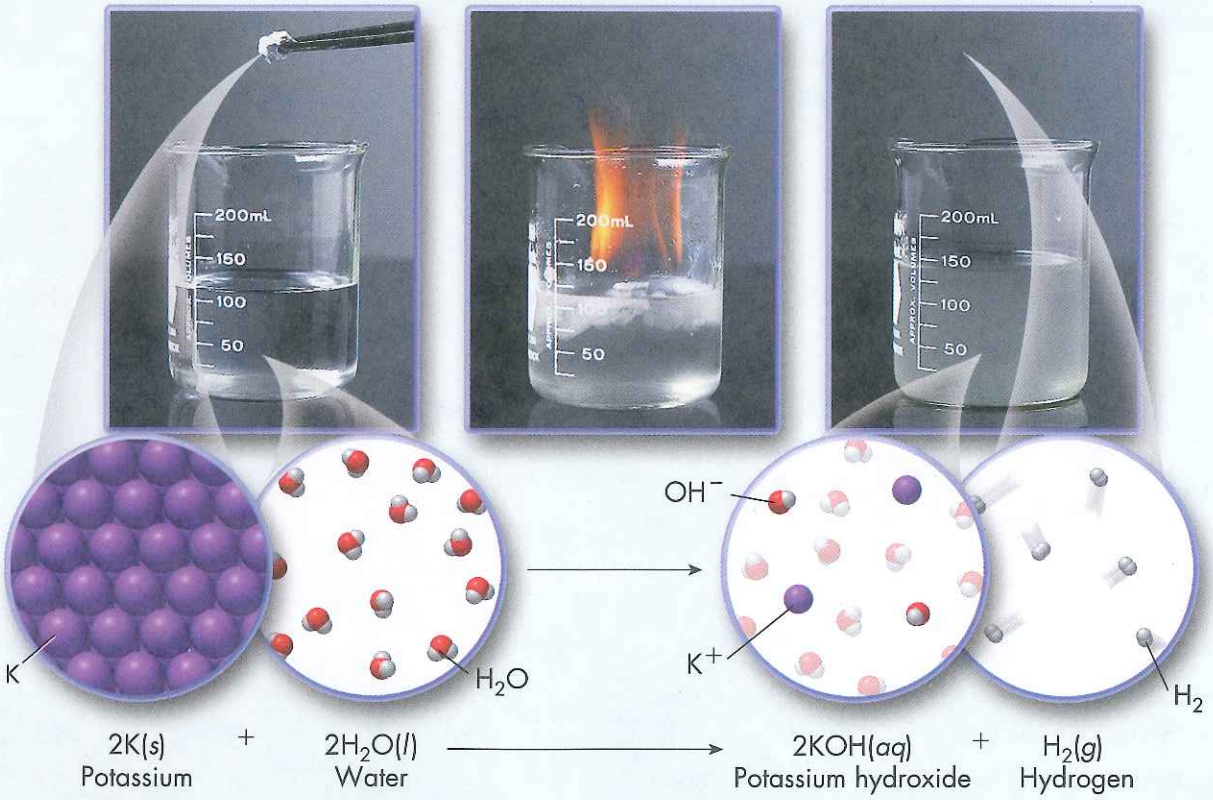
$$2K(s) + 2H_2O(l) \longrightarrow 2KOH(aq) + H_2(g)$$

Similar but less spectacular reactions can occur. For example, if you drop a piece of zinc into a solution of copper nitrate, this reaction occurs:

$$Zn(s) + Cu(NO_3)_2(aq) \longrightarrow Cu(s) + Zn(NO_3)_2(aq)$$

These equations describe two examples of single-replacement reactions. A **single-replacement reaction** is a chemical change in which one element replaces a second element in a compound. You can identify a single-replacement reaction by noting that both the reactants and the products consist of an element and a compound. In the equation above, zinc and copper change places. The reacting element Zn replaces copper in the reactant compound $Cu(NO_3)_2$. The products are the element Cu and the compound $Zn(NO_3)_2$.

Figure 11.6 Single-Replacement Reaction
The alkali metal potassium displaces hydrogen from water and forms a solution of potassium hydroxide in a single-replacement reaction. The heat of the reaction is often sufficient to ignite the hydrogen.
Inferring ***Why are alkali metals stored under mineral oil or kerosene?***



SampleProblem 11.5

Writing Equations for Single-Replacement Reactions

Write a balanced equation for the single-replacement reaction.

$$Cl_2(aq) + NaBr(aq) \longrightarrow$$

1 Analyze **Identify the relevant concepts.** Chlorine is more reactive than bromine and displaces bromine from its compounds.

2 Solve **Apply concepts to this problem.**

Hint: You're starting with an unequal number of atoms:
- reactants
- 2 chlorine atoms
- 1 sodium atom
- 1 bromine atom
- products
- 1 chlorine atom
- 1 sodium atom
- 2 bromine atoms

Write the skeleton equation. → $Cl_2(aq) + NaBr(aq) \longrightarrow NaCl(aq) + Br_2(aq)$

Apply the rules for balancing equations. → $Cl_2(aq) + 2NaBr(aq) \longrightarrow 2NaCl(aq) + Br_2(aq)$ (balanced)

15. Complete the equations for these single-replacement reactions in aqueous solution. Balance each equation. Write "no reaction" if a reaction does not occur.

a. $Fe(s) + Pb(NO_3)_2(aq) \longrightarrow$
b. $Cl_2(aq) + NaI(aq) \longrightarrow$
c. $Ca(s) + H_2O(l) \longrightarrow$
d. $Zn(s) + H_2SO_4(aq) \longrightarrow$

Hint: Look at Table 11.2. Zinc displaces hydrogen from an acid and takes its place.

Whether one metal will displace another metal from a compound depends upon the relative reactivities of the two metals. The **activity series** of metals, given in Table 11.2, lists metals in order of decreasing reactivity. A reactive metal will replace any metal listed below it in the activity series. Thus, iron will displace copper from a copper compound in solution, but iron does not similarly displace zinc or calcium.

A halogen can also replace another halogen from a compound. The activity of the halogens decreases as you go down Group 7A of the periodic table—fluorine, chlorine, bromine, and iodine. Bromine is more active than iodine, so this reaction occurs:

$$Br_2(aq) + 2NaI(aq) \longrightarrow 2NaBr(aq) + I_2(aq)$$

But bromine is less active than chlorine, so this reaction does not occur:

$$Br_2(aq) + NaCl(aq) \longrightarrow \text{No reaction}$$

Table 11.2

Activity Series of Metals

Decreasing reactivity ↓

Name	Symbol
Lithium	Li
Potassium	K
Calcium	Ca
Sodium	Na
Magnesium	Mg
Aluminum	Al
Zinc	Zn
Iron	Fe
Lead	Pb
(Hydrogen)	(H)*
Copper	Cu
Mercury	Hg
Silver	Ag

*Metals from Li to Na will replace H from acids and water; from Mg to Pb they will replace H from acids only.

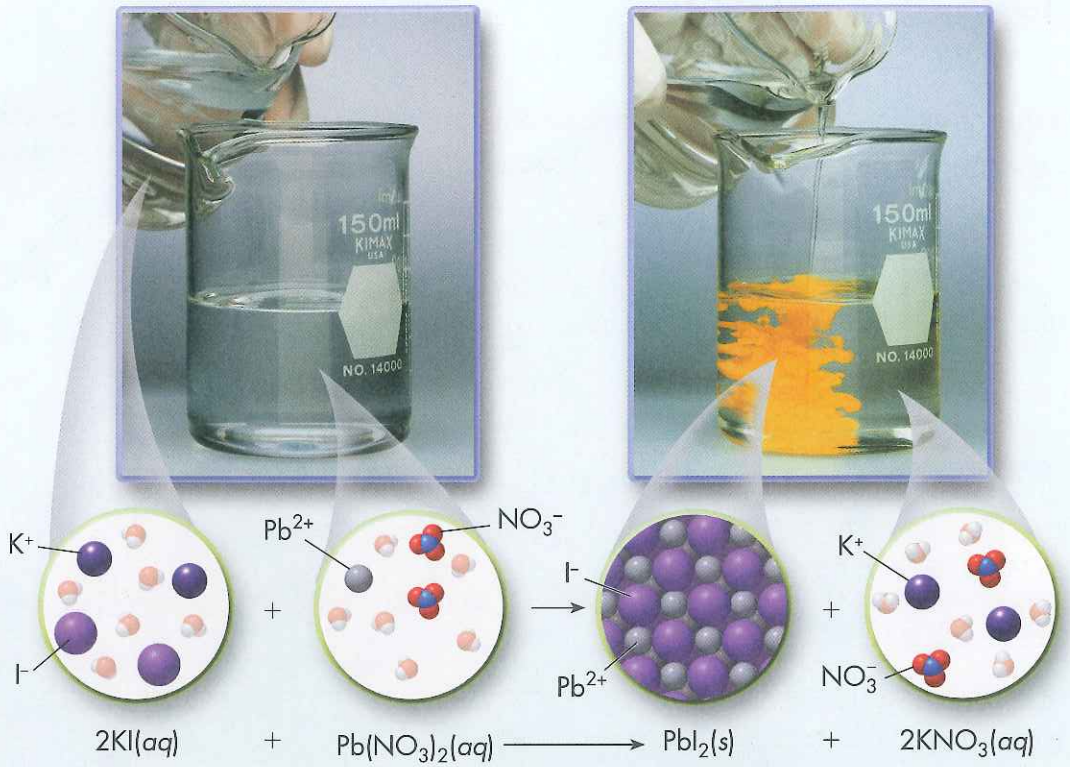


Figure 11.7
Double-Replacement Reaction
Aqueous solutions of potassium iodide and lead(II) nitrate react in a double-replacement reaction to form the yellow precipitate lead(II) iodide.

Double-Replacement Reactions Sometimes, when two solutions of ionic compounds are mixed, nothing happens. At other times, the ions in the two solutions react. Figure 11.7 shows that mixing aqueous solutions of potassium iodide and lead(II) nitrate results in a chemical reaction in which a yellow precipitate of solid lead(II) iodide is formed. Potassium nitrate, the other product of the reaction, remains in solution. This reaction is an example of a **double-replacement reaction,** which is a chemical change involving an exchange of positive ions between two compounds. Double-replacement reactions are also referred to as double-displacement reactions. They generally take place in aqueous solution and often produce a precipitate, a gas, or a molecular compound such as water. For a double-replacement reaction to occur, one of the following is usually true:

1. One of the products is only slightly soluble and precipitates from solution. For example, the reaction of aqueous solutions of sodium sulfide and cadmium nitrate produces a yellow precipitate of cadmium sulfide.

$$Na_2S(aq) + Cd(NO_3)_2(aq) \longrightarrow CdS(s) + 2NaNO_3(aq)$$

2. One of the products is a gas. Poisonous hydrogen cyanide gas is produced when aqueous sodium cyanide, also a poison, is mixed with sulfuric acid.

$$2NaCN(aq) + H_2SO_4(aq) \longrightarrow 2HCN(g) + Na_2SO_4(aq)$$

3. One product is a molecular compound such as water. Combining solutions of calcium hydroxide and hydrochloric acid produces water.

$$Ca(OH)_2(aq) + 2HCl(aq) \longrightarrow CaCl_2(aq) + 2H_2O(l)$$

Sample Problem 11.6

Writing Equations for Double-Replacement Reactions

A precipitate of barium carbonate is formed when an aqueous solution of barium chloride reacts with aqueous potassium carbonate. Write a balanced chemical equation for the double-replacement reaction.

$$K_2CO_3(aq) + BaCl_2(aq) \longrightarrow$$

1 Analyze **Identify the relevant concepts.**

The driving force behind the reaction is the formation of a precipitate. Write correct formulas of the products using ionic charges. Then balance the equation.

2 Solve **Apply concepts to this problem.**

Write the skeleton equation. → $K_2CO_3(aq) + BaCl_2(aq) \longrightarrow KCl(aq) + BaCO_3(s)$

Apply the rules for balancing equations. → $K_2CO_3(aq) + BaCl_2(aq) \longrightarrow 2KCl(aq) + BaCO_3(s)$ (balanced)

16. Write the products of these double-replacement reactions. Then balance each equation.

a. $NaOH(aq) + Fe(NO_3)_3(aq) \longrightarrow$ (Iron(III) hydroxide is a precipitate.)

b. $Ba(NO_3)_2(aq) + H_3PO_4(aq) \longrightarrow$ (Barium phosphate is a precipitate.)

c. $FeS(s) + HCl(aq) \longrightarrow$ (Hydrogen sulfide gas (H_2S) is formed.)

17. Write a balanced equation for each reaction.

a. $KOH(aq) + H_3PO_4(aq) \longrightarrow$ (Water is formed.)

b. $AgNO_3(aq) + NaCl(s) \longrightarrow$ (Silver chloride is a precipitate.)

c. $Ca(OH)_2(aq) + H_3PO_4(aq) \longrightarrow$ (Water is formed.)

d. $KI(aq) + Pb(NO_3)_2(aq) \longrightarrow$ (Lead(II) iodide is a precipitate.)

e. $H_2SO_4(aq) + Al(OH)_3(aq) \longrightarrow$ (Water is formed.)

Hint: Use ionic charges to write the correct formula of the other product.

Combustion Reactions The flames of a campfire, candle, or a gas grill are evidence that a combustion reaction is taking place. A **combustion reaction** is a chemical change in which an element or a compound reacts with oxygen, often producing energy in the form of heat and light. A combustion reaction always involves oxygen as a reactant. Often the other reactant is a hydrocarbon, which is a compound composed of hydrogen and carbon. The complete combustion of a hydrocarbon produces carbon dioxide and water. But if the supply of oxygen is limited during a reaction, the combustion will not be complete. Elemental carbon (soot) and toxic carbon monoxide gas may be additional products.

CHEMISTRY & YOU

Q: *Materials such as candle wax contain hydrogen and carbon. One type of wax has a formula of $C_{25}H_{52}$. The wax reacts with oxygen in the air. So, what happens to the wax as it burns?*

The complete combustion of a hydrocarbon releases a large amount of energy as heat. That's why hydrocarbons such as methane (CH_4), propane (C_3H_8), and butane (C_4H_{10}) are important fuels. The combustion reaction for methane is shown in Figure 11.8. Gasoline is a mixture of hydrocarbons that can be approximately represented by the formula C_8H_{18}. The complete combustion of gasoline in a car engine is shown by this equation.

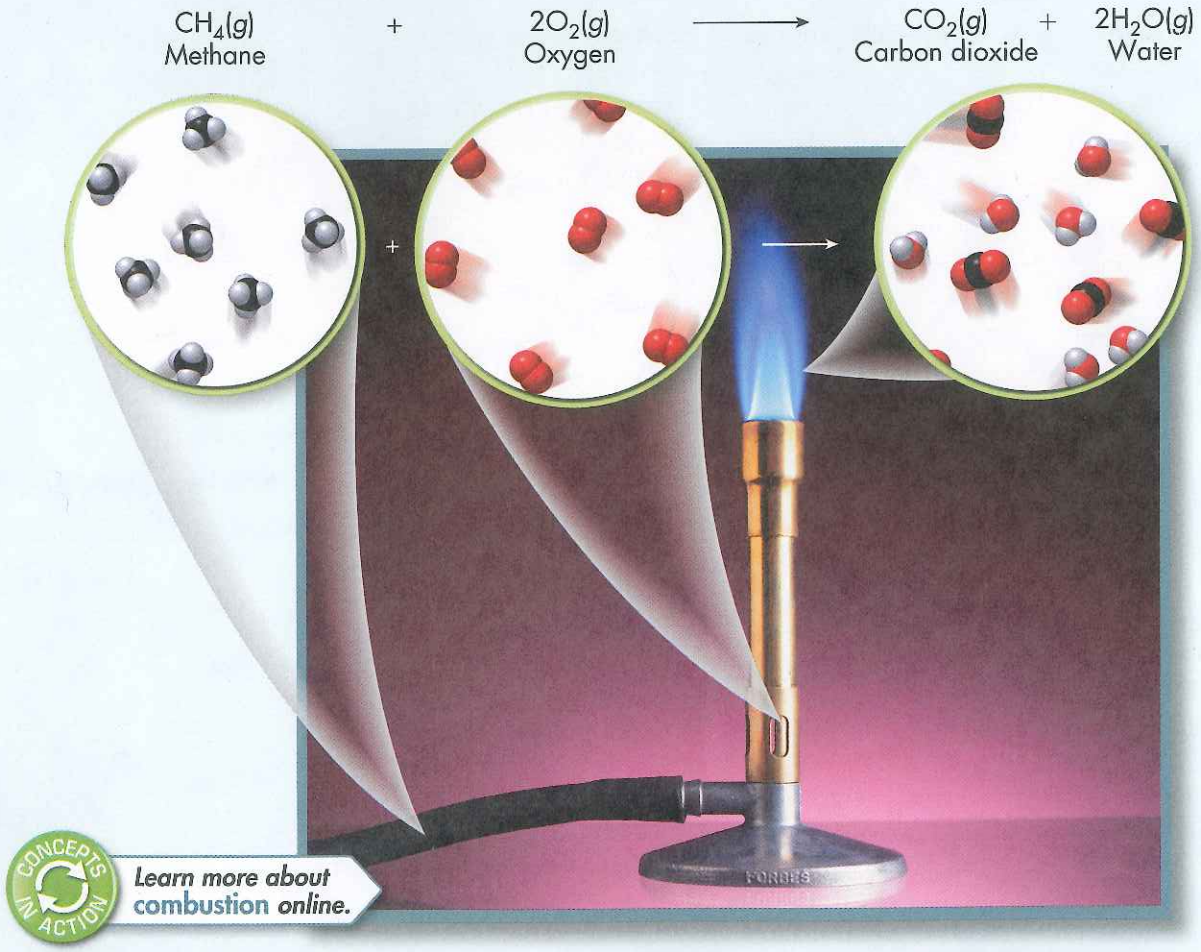
$$2C_8H_{18}(l) + 25O_2(g) \longrightarrow 16CO_2(g) + 18H_2O(g)$$

The reactions between oxygen and some elements other than carbon are also examples of combustion reactions. For example, both magnesium and sulfur will burn in the presence of oxygen. As you look at these combustion equations, notice that the reactions could also be classified as combination reactions.

$$2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$$

$$S(s) + O_2(g) \longrightarrow SO_2(g)$$

Figure 11.8 Combustion Reaction
Methane gas reacts with oxygen from the surrounding air in a combustion reaction to produce carbon dioxide and water.
Infer ***What else is produced in this reaction?***



Sample Problem 11.7

Writing Equations for Combustion Reactions

An alcohol lamp often uses ethanol as its fuel. Write a balanced equation for the complete combustion of ethanol.

$$C_2H_6O(l)$$

1 Analyze **Identify the relevant concepts.**

Oxygen is the other reactant in a combustion reaction. The products are CO_2 and H_2O.

2 Solve **Apply concepts to this problem.**

Write the skeleton equation.

$$C_2H_6O(l) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$$

Apply the rules for balancing equations.

$$C_2H_6O(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(g)$$

(balanced)

18. Write a balanced equation for the complete combustion of each compound.

- **a.** formaldehyde ($CH_2O(g)$)
- **b.** heptane ($C_7H_{16}(l)$)
- **c.** benzene ($C_6H_6(l)$)

19. Write a balanced equation for the complete combustion of

- **a.** glucose ($C_6H_{12}O_6(s)$)
- **b.** acetone ($C_3H_6O(l)$)
- **c.** pentanol ($C_5H_{12}O(l)$)

Now that you have learned about some of the basic reaction types, you can predict the products of many reactions. The number of elements and/or compounds reacting is a good indicator of possible reaction type and, thus, possible products.

For example, in a combination reaction, two or more reactants (elements or compounds) combine to form a single product. In a decomposition reaction, a single compound is the reactant; two or more substances are the products. An element and a compound are the reactants in a single-replacement reaction. A different element and a new compound are the products. In a double-replacement reaction, two ionic compounds are the reactants; two new compounds are the products. The reactants in a combustion reaction are oxygen and usually a hydrocarbon. The products of most combustion reactions are carbon dioxide and water.

1 Combination Reaction

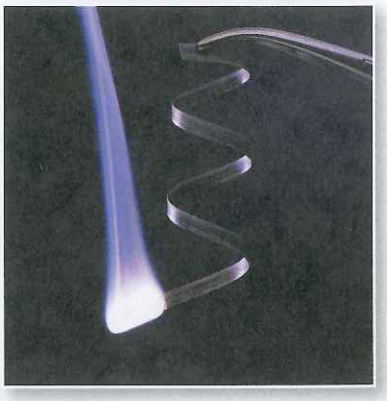
General Equation: R + S ⟶ RS

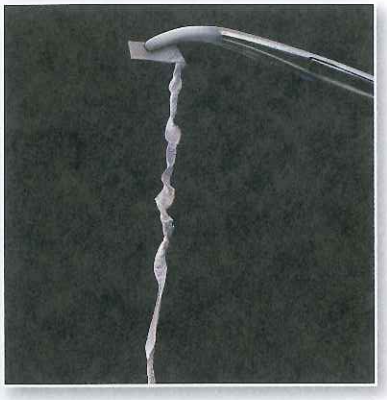
Reactants: Generally two elements, or two compounds (where at least one compound is a molecular compound)

Probable Products: A single compound

Example: Burning magnesium in air

KINETIC ART *See reactions animated online.*





$2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$

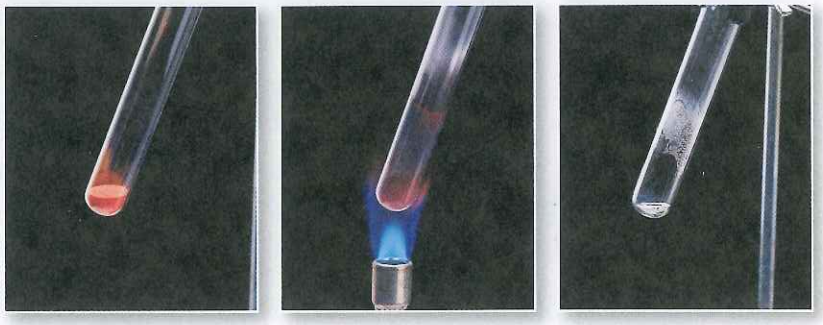
2 Decomposition Reaction

General Equation: RS ⟶ R + S

Reactants: Generally a single binary compound or a compound with a polyatomic ion

Probable Products: Two elements (for a binary compound), or two or more elements and/or compounds (for a compound with a polyatomic ion)

Example: Heating mercury(II) oxide



$2HgO(s) \longrightarrow 2Hg(l) + O_2(g)$

3 Single-Replacement Reaction

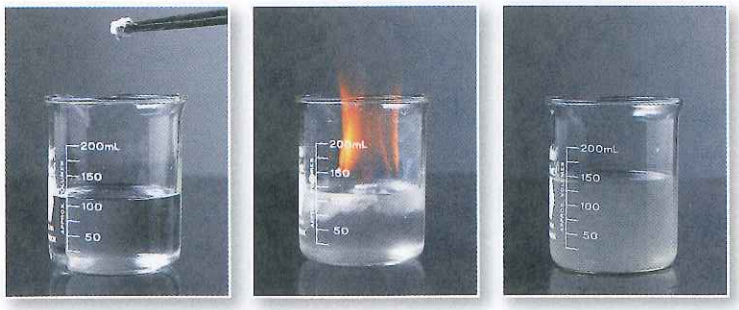
General Equation: T + RS ⟶ TS + R

Reactants: An element and a compound

In a single-replacement reaction, an element replaces another element from a compound in aqueous solution. For a single-replacement reaction to occur, the element that is replaced must be less active than the element that is doing the replacing.

Probable Products: A different element and a new compound

Example: Potassium in water



$2K(s) + 2H_2O(l) \longrightarrow 2KOH(aq) + H_2(g)$

4 Double-Replacement Reaction

General Equation: $R^+ S^- + T^+ U^- \longrightarrow R^+ U^- + T^+ S^-$

Reactants: Two ionic compounds

In a double-replacement reaction, two ionic compounds react by exchanging cations to form two different compounds.

Probable Products: Two new compounds

Double-replacement reactions are driven by the formation of a precipitate, a gaseous product, or water.

Example: Reaction of aqueous solutions of potassium iodide and lead(II) nitrate.

$2KI(aq) + Pb(NO_3)_2(aq) \longrightarrow PbI_2(s) + 2KNO_3(aq)$

5 Combustion Reaction

General Equation: $C_x H_y + (x + y/4)\, O_2 \longrightarrow xCO_2 + (y/2)H_2O$

Reactants: Oxygen and a compound of C, H, (O)

When oxygen reacts with an element or compound, combustion may occur.

Probable Products: CO_2 and H_2O

With incomplete combustion, C and CO may also be products.

Example: The combustion of methane gas in air

$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(g)$

ONLINE PROBLEMS

11.2 LessonCheck

20. Review What are the five types of chemical reactions?

21. Apply Concepts Classify each reaction and balance the equations.

a. $C_3H_6(g) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$

b. $Al(OH)_3(s) \longrightarrow Al_2O_3(s) + H_2O(l)$

c. $Li(s) + O_2(g) \longrightarrow Li_2O(s)$

d. $Zn(s) + AgNO_3(aq) \longrightarrow Ag(s) + Zn(NO_3)_2(aq)$

22. Identify Which of the five general types of reaction would most likely occur, given each set of reactants? What are the probable products?

a. an aqueous solution of two ionic compounds

b. a single compound

c. two elements

d. oxygen and a compound of carbon and hydrogen

23. Apply Concepts Complete and balance an equation for each reaction.

a. $CaI_2(aq) + Hg(NO_3)_2(aq) \longrightarrow$ (HgI_2 precipitates.)

b. $Al(s) + Cl_2(g) \longrightarrow$

c. $Ag(s) + HCl(aq) \longrightarrow$

d. $C_2H_2(g) + O_2(g) \longrightarrow$

BIG IDEA REACTIONS

24. After wood burns, the ash weighs much less than the original wood. Explain why the law of conservation of mass is not violated in this situation.

The History of Dynamite

In 1846, Ascanio Sobrero added glycerol to a mixture of concentrated nitric and sulfuric acids. The resulting oily liquid, known as nitroglycerin, turned out to be such a powerful explosive that a small bottle could blow up a building. Unfortunately, it was also extremely unstable, and tended to explode after being handled roughly, or a temperature change.

Alfred Nobel (1833–1896), a Swedish chemist and industrialist, began experimenting with nitroglycerin, looking for a way to make it safe to use. In 1866, Nobel discovered that he could mix nitroglycerine with a fine sand called *kieselguhr* to turn the liquid into paste that could be shaped into rods. The rods were then packed into cylinders made of paper. He named these rods "dynamite."

Originally, Nobel marketed dynamite as Nobel's Blasting Powder.

To safely ignite dynamite and control the timing of a detonation, Nobel also invented blasting caps, which create a small explosion that triggers the larger explosion in the dynamite itself.

Today, ammonium nitrate is used in place of nitroglycerin. This dynamite is stronger, safer, and cheaper than Nobel's original invention.

When he died in 1896, Alfred Nobel left a nine million dollar fortune to be used to fund different fields of study. The Nobel Prize is still awarded to people whose work helps humanity.

BIG BLASTS Nobel began manufacturing the explosive, which was used to blast out dam sites, canal beds, mines, and the foundations for large buildings.

Take It Further

1. Classify The equation for the detonation of nitroglycerin is shown below. What kind of reaction is it?

$$4C_3H_5N_3O_9 \longrightarrow 12CO_2 + 10H_2O + 6N_2 + O_2$$

2. Research Fireworks are another kind of explosive. How are dynamite explosions different from fireworks explosions?

11.3 Reactions in Aqueous Solution

CHEMISTRY & YOU

Q: *How did soda straws get into limestone caves?* These "soda straws" are really stalactites in a limestone cave. Soda straws grow on cave ceilings as thin-walled hollow tubes that result from chemical reactions involving water. In this lesson, you will learn to predict the formation of precipitates and write equations to describe the reactions that produce them.

Key Questions

What does a net ionic equation show?

How can you predict the formation of a precipitate in a double-replacement reaction?

Vocabulary

- complete ionic equation
- spectator ion
- net ionic equation

Net Ionic Equations

What does a net ionic equation show?

Your world is water based. More than 70 percent of Earth's surface is covered by water, and about 66 percent of the adult human body is water. It is not surprising, then, that many important chemical reactions take place in water—that is, in aqueous solution. The reaction of aqueous solutions of silver nitrate with sodium chloride to form solid silver chloride and aqueous sodium nitrate is a double-replacement reaction. The reaction is shown in Figure 11.9.

$$AgNO_3(aq) + NaCl(aq) \longrightarrow AgCl(s) + NaNO_3(aq)$$

The equation above reflects the way you have been writing equations involving aqueous solutions of ionic compounds. However, the equation does not show that, like most ionic compounds, the reactants and one of the products dissociate, or separate, into cations and anions when they dissolve in water.

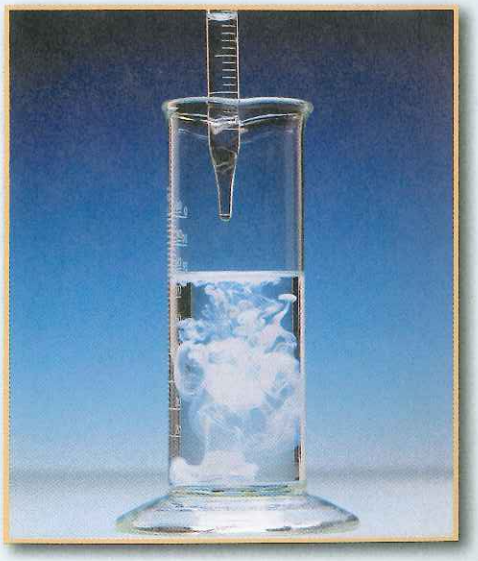


Figure 11.9 Precipitate in a Double Replacement Reaction
A precipitate of silver chloride forms when aqueous solutions of silver nitrate and sodium chloride are mixed.
Inferring ***Which ions do not participate in the reaction?***

READING SUPPORT

Build Vocabulary: *Word Origins* The word *spectator* comes from the Latin verb *spectare,* meaning "to watch." Thus, a spectator ion can be thought of as only watching a reaction, not participating. ***During a football game, what analogy can you draw to the people in the seats and the football players on the field?***

For example, when sodium chloride dissolves in water, it separates into sodium ions ($Na^+(aq)$) and chloride ions ($Cl^-(aq)$). Similarly, when dissolved in water, silver nitrate dissociates into silver ions ($Ag^+(aq)$) and nitrate ions ($NO_3^-(aq)$). You can use these ions to write a **complete ionic equation,** an equation that shows dissolved ionic compounds as dissociated free ions.

$$Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Cl^-(aq) \longrightarrow AgCl(s) + Na^+(aq) + NO_3^-(aq)$$

Notice that the nitrate ion and the sodium ion appear unchanged on both sides of the equation. The equation can be simplified by eliminating these ions because they don't participate in the reaction.

$$Ag^+(aq) + \cancel{NO_3^-(aq)} + \cancel{Na^+(aq)} + Cl^-(aq) \longrightarrow AgCl(s) + \cancel{Na^+(aq)} + \cancel{NO_3^-(aq)}$$

An ion that appears on both sides of an equation and is not directly involved in the reaction is called a **spectator ion.** When you rewrite an equation leaving out the spectator ions, you have the net ionic equation. The **net ionic equation** is an equation for a reaction in solution that shows only those particles that are directly involved in the chemical change.

$$Ag^+(aq) + Cl^-(aq) \longrightarrow AgCl(s)$$

In writing balanced net ionic equations, you must make sure that the ionic charge is balanced. For the previous reaction, the net ionic charge on each side of the equation is zero and is therefore balanced. But consider the skeleton equation for the reaction of lead with silver nitrate.

$$Pb(s) + AgNO_3(aq) \longrightarrow Ag(s) + Pb(NO_3)_2(aq)$$

The nitrate ion is the spectator ion in this reaction. The net ionic equation is as follows:

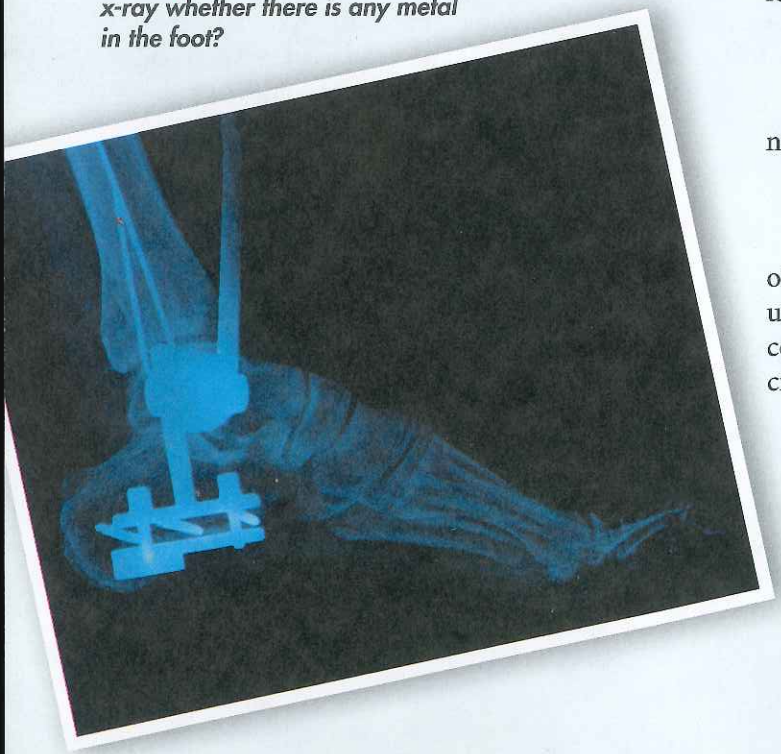
$$Pb(s) + Ag^+(aq) \longrightarrow Ag(s) + Pb^{2+}(aq) \text{ (unbalanced)}$$

Why is this equation unbalanced? Notice that a single unit of positive charge is on the reactant side of the equation. Two units of positive charge are on the product side. Placing the coefficient 2 in front of $Ag^+(aq)$ balances the charge. A coefficient of 2 in front of Ag(s) rebalances the atoms.

$$Pb(s) + 2Ag^+(aq) \longrightarrow 2Ag(s) + Pb^{2+}(aq) \text{ (balanced)}$$

A net ionic equation shows only those particles involved in the reaction and is balanced with respect to both mass and charge. Of the five types of reactions identified in this chapter, both single- and double-replacement reactions can be written as net ionic equations.

Figure 11.10 Silver Halide and Medical X-rays Small crystals of a silver halide, usually silver bromide, are embedded in the coating on film used to record medical X-rays. The crystals darken when exposed to X-rays that pass through the human body. Dense parts like bones absorb more X-rays; relatively few rays pass through these parts, which appear as light areas on the developed film. More rays pass through soft tissue, which shows up as darker areas on the developed film. Metals also strongly absorb X-rays.
Identify ***How can you determine from this x-ray whether there is any metal in the foot?***



SampleProblem 11.8

Writing and Balancing Net Ionic Equations

Aqueous solutions of iron(III) chloride and potassium hydroxide are mixed. A precipitate of iron(III) hydroxide forms. Identify the spectator ions and write a balanced net ionic equation for the reaction.

1 Analyze **Identify the relevant concepts.** Write the complete ionic equation. Eliminate aqueous ions that appear in both the reactants and products. Then balance the equation with respect to both mass and charge.

2 Solve **Apply the concepts to this problem.**

Write the complete ionic equation for the reaction, showing any soluble ionic compounds as individual ions.

$$Fe^{3+}(aq) + 3Cl^-(aq) + 3K^+(aq) + 3OH^-(aq) \longrightarrow Fe(OH)_3(s) + 3K^+(aq) + 3Cl^-(aq)$$

Eliminate aqueous ions that appear as both reactants and products. The spectator ions are K^+ and Cl^-.

$$Fe^{3+}(aq) + \cancel{3Cl^-(aq)} + \cancel{3K^+(aq)} + 3OH^-(aq) \longrightarrow Fe(OH)_3(s) + \cancel{3K^+(aq)} + \cancel{3Cl^-(aq)}$$

Balance the net ionic equation.

$$Fe^{3+}(aq) + 3OH^-(aq) \longrightarrow Fe(OH)_3(s)$$

25. Write the balanced net ionic equation for this reaction.

$$Ca^{2+}(aq) + OH^-(aq) + H^+(aq) + PO_4^{3-}(aq) \longrightarrow Ca^{2+}(aq) + PO_4^{3-}(aq) + H_2O(l)$$

26. Write the complete ionic equation and net ionic equation for the reaction of aqueous calcium hydroxide with phosphoric acid. The products are calcium phosphate and water.

Predicting the Formation of a Precipitate

How can you predict the formation of a precipitate in a double-replacement reaction?

You have seen that mixing solutions of two ionic compounds can sometimes result in the formation of an insoluble salt called a precipitate. Some combinations of solutions produce precipitates, while others do not. Whether or not a precipitate forms depends upon the solubility of the new compounds that form. **By using the general rules for solubility of ionic compounds, you can predict the formation of a precipitate.** These general rules are shown in Table 11.3.

CHEMISTRY & YOU

Q: *How did the soda straws, which are composed of calcium carbonate, get into the cave?*

Table 11.3

Solubility Rules for Ionic Compounds

Compounds	Solubility	Exceptions
Salts of alkali metals and ammonia	Soluble	Some lithium compounds
Nitrate salts and chlorate salts	Soluble	Few exceptions
Sulfate salts	Soluble	Compounds of Pb, Ag, Hg, Ba, Sr, and Ca
Chloride salts	Soluble	Compounds of Ag and some compounds of Hg and Pb
Carbonates, phosphates, chromates, sulfides, and hydroxides	Most are insoluble	Compounds of the alkali metals and of ammonia

Will a precipitate form when aqueous solutions of $Na_2CO_3(aq)$ and $Ba(NO_3)_2(aq)$ are mixed?

$$2Na^+(aq) + CO_3^{2-}(aq) + Ba^{2+}(aq) + 2NO_3^-(aq) \longrightarrow ?$$

VIRTUAL LAB *Learn how to identify ions in solution online.*

When these four ions are mixed, the cations could change partners. If they did, the two new compounds that would form are $NaNO_3$ and $BaCO_3$. These are the only new combinations of cation and anion possible. To find out if an exchange will occur, refer to Table 11.3, which gives guidelines for determining whether ion combinations are soluble. Recall that sodium is an alkali metal. Rows 1 and 2 tell you that sodium nitrate will not form a precipitate because alkali metal salts and nitrate salts are soluble. Row 5 indicates that carbonates in general are insoluble. Barium carbonate will precipitate. In this reaction, Na^+ and NO_3^- are spectator ions. The net ionic equation for this reaction is as follows:

$$Ba^{2+}(aq) + CO_3^{2-}(aq) \longrightarrow BaCO_3(s)$$

Figure 11.11
Formation of a Precipitate
A precipitate forms when aqueous solutions of sodium sulfate (Na_2SO_4) and barium nitrate ($Ba(NO_3)_2$) are mixed. The net ionic equation for this reaction is as follows:

$Ba^{2+}(aq) + SO_4^{2-}(aq) \longrightarrow BaSO_4(s)$

Apply Concepts ***Which ions are present in the final solution but are not part of the net ionic equation?***

SampleProblem 11.9

Writing and Balancing Net Ionic Equations

Aqueous potassium carbonate reacts with aqueous strontium nitrate. Identify the precipitate formed and write the net ionic equation for the reaction.

1 Analyze **Identify the relevant concepts.** Write the reactants. Look at possible new pairings of cation and anion that give an insoluble substance. Eliminate the spectator ions.

2 Solve **Apply the concepts to this problem.**

Use the solubility rules in Table 11.3 to identify the precipitate formed.

Write the reactants, showing each as dissociated free ions.

$2K^+(aq) + CO_3^{2-}(aq) + Sr^{2+}(aq) + 2NO_3^-(aq) \longrightarrow ?$

Look at possible new pairings of cation and anion that give an insoluble substance.

Of the two possible combinations, KNO_3 is soluble and $SrCO_3$ is insoluble.

Eliminate the spectator ions and write the net ionic equation.

$CO_3^{2-}(aq) + Sr^{2+}(aq) \longrightarrow SrCO_3(s)$

27. Identify the precipitate formed when solutions of these compounds are mixed. Write the net ionic equation.

$NH_4Cl(aq) + Pb(NO_3)_2(aq) \longrightarrow$

28. Write a complete ionic equation and a net ionic equation for the reaction of aqueous solutions of iron(III) nitrate and sodium hydroxide.

11.3 LessonCheck

29. Review What is a net ionic equation?

30. Explain How can you predict the formation of a precipitate in a double-replacement reaction?

31. Apply Concepts Write a balanced net ionic equation for each reaction.

a. $Pb(NO_3)_2(aq) + H_2SO_4(aq) \longrightarrow PbSO_4(s) + HNO_3(aq)$

b. $Pb(C_2H_3O_2)_2(aq) + HCl(aq) \longrightarrow PbCl_2(s) + HC_2H_3O_2(aq)$

c. $Na_3PO_4(aq) + FeCl_3(aq) \longrightarrow NaCl(aq) + FePO_4(s)$

d. $(NH_4)_2S(aq) + Co(NO_3)_2(aq) \longrightarrow CoS(s) + NH_4NO_3(aq)$

32. Identify List the precipitate formed when solutions of these ionic compounds are mixed.

a. $H_2SO_4 + BaCl_2 \longrightarrow$

b. $Al_2(SO_4)_3 + NH_4OH \longrightarrow$

c. $AgNO_3 + H_2S \longrightarrow$

d. $CaCl_2 + Pb(NO_3)_2 \longrightarrow$

e. $Ca(NO_3)_2 + Na_2CO_3 \longrightarrow$

33. Apply Concepts Hard water contains calcium and magnesium ions. One way to soften water is to add sodium phosphate. Write complete and net ionic equations for the reaction of these two alkaline earth ions with aqueous sodium phosphate.

Small-Scale Lab

Precipitation Reactions: Formation of Solids

Purpose

To observe, identify, and write balanced equations for precipitation reactions

Materials

- pencil
- paper
- ruler
- reaction surface
- chemicals shown in the grid to the right

	$AgNO_3$ (Ag^+)	$Pb(NO_3)_2$ (Pb^{2+})	$CaCl_2$ (Ca^{2+})
Na_2CO_3 (CO_3^{2-})	a	f	k
Na_3PO_4 (PO_4^{3-})	b	g	l
NaOH (OH^-)	c	h	m
Na_2SO_4 (SO_4^{2-})	d	i	n
NaCl (Cl^-)	e	j	o

Procedure

1. Copy the grid on two sheets of paper.
2. Make each square 2 cm on each side.
3. Draw large black Xs on one of the grids.
4. Place a reaction surface over the grid with black Xs and add the chemicals as shown. Use the other grid as a data table to record your observations for each solution.

Analyze

Using your experimental data, record your answers to the following in the space below your data table.

1. Explain Translate the following word equations into balanced chemical equations and explain how the equations represent what happens in grid spaces *a* and *g*.

a. In grid space *a*, sodium carbonate reacts with silver nitrate to produce sodium nitrate and solid silver carbonate.

b. In grid space *g*, sodium phosphate reacts with lead(II) nitrate to produce sodium nitrate and solid lead(II) phosphate.

2. Describe Write a word equation to represent what happens in grid space *m*.

3. Explain What happens in grid space *d*? Which other mixings gave similar results? Is it necessary to write an equation when no reaction occurs?

4. Describe Write balanced equations for the other precipitation reactions you observed.

5. Describe Write balanced net ionic equations for the other precipitation reactions you observed.

You're the Chemist

The following small-scale activities allow you to develop your own procedures and analyze the results.

1. Explain Mix a solution of potassium iodide (KI) with silver nitrate. Then mix potassium iodide solution with lead(II) nitrate. Describe your results. Write balanced equations and net ionic equations for each reaction.

2. Design an Experiment Table salt is mostly sodium chloride. Design and carry out an experiment to find out if table salt will form a precipitate with either lead(II) nitrate or silver nitrate. Interpret your results.

3. Design an Experiment Design and carry out an experiment to show that iodized table salt contains potassium iodide.

11 Study Guide

BIG IDEA REACTIONS

The law of conservation of mass states that mass is neither created nor destroyed. In order to show that mass is conserved during a reaction, a chemical equation must be balanced. You can predict the products of most chemical reactions by identifying the reaction type. To determine the reaction type, consider the number of reacting elements and compounds.

11.1 Describing Chemical Reactions

- To write a skeleton equation, write the formulas for the reactants to the left of the yields sign and the formulas for the products to the right.
- After writing the skeleton equation, use coefficients to balance the equation so that it obeys the law of conservation of mass.

- chemical equation (348)
- skeleton equation (348)
- catalyst (348)
- coefficient (350)
- balanced equation (350)

11.2 Types of Chemical Reactions

- The five general types of reactions are combination, decomposition, single-replacement, double-replacement, and combustion.
- The number of elements and/or compounds reacting is a good indicator of possible reaction type and, thus, possible products.
- In a combination reaction, there is always a single product.
- A decomposition reaction involves the breakdown of a single compound into two or more simpler substances.
- In a single-replacement reaction, both the reactants and the products are an element and a compound.
- A double-replacement reaction generally takes place between two ionic compounds in aqueous solution.
- A combustion reaction always involves oxygen as a reactant.

- combination reaction (356)
- decomposition reaction (358)
- single-replacement reaction (360)
- activity series (361)
- double-replacement reaction (362)
- combustion reaction (363)

11.3 Reactions in Aqueous Solution

- A net ionic equation shows only those particles involved in the reaction and is balanced with respect to mass and charge.
- By using the general rules for solubility of ionic compounds, you can predict the formation of a precipitate.

- complete ionic equation (370)
- spectator ion (370)
- net ionic equation (370)

Skills Tune-Up: Balancing Chemical Equations

Problem	❶ Analyze	❷ Solve
Write the balanced equation for the following reaction: $C_2H_4 + O_2 \longrightarrow$	The reactants are a hydrocarbon and oxygen. The hydrocarbon tells you that the products must be CO_2 and H_2O. The oxygen tells you that this is a combustion reaction.	First write a skeleton equation. $C_2H_4 + O_2 \longrightarrow CO_2 + H_2O$ (unbalanced) Balance the C atoms and the H atoms first. $C_2H_4 + O_2 \longrightarrow 2CO_2 + 2H_2O$ (unbalanced) Balance the O atoms next. $C_2H_4 + 3O_2 \longrightarrow 2CO_2 + 2H_2O$ (balanced)
Write the balanced equation for the following reaction: $Al + Cu(NO_3)_2 \longrightarrow$ A subscript in a polyatomic ion moves with the ion. So the 3 in NO_3 stays with the ion. But the subscript 2 is there only to balance the charges. It's not part of the ion and doesn't move with it.	$Cu(NO_3)_2$ is an ionic compound, and Al is an element. This is a single-replacement reaction. Check Table 11.2 to be sure a reaction will take place.	First write a skeleton equation. $Al + Cu(NO_3)_2 \longrightarrow Al(NO_3)_3 + Cu$ (unbalanced) Balance the equation. $2Al + 3Cu(NO_3)_2 \longrightarrow 2Al(NO_3)_3 + 3Cu$ (balanced)
Write the balanced equation for the following reaction: $Na(OH)(aq) + Ba(NO_3)_2(aq) \longrightarrow$ Use the solubility rules in Table 11.3 to identify the precipitate formed.	Both reactants are ionic compounds, so this is a double-replacement reaction. In a double-replacement reaction, two compounds exchange positive ions. They often produce a gas, a precipitate, or another molecular compound such as water.	Write the reactants, showing each as dissociated free ions. $Na^+(aq) + OH^-(aq) + Ba^{2+}(aq) + 2NO_3^-(aq) \longrightarrow$ Look at the possible new pairings of cation and anion that give an insoluble substance. Of the two possible combinations, $Na(NO)_3$ is soluble and $Ba(OH)_2$ is insoluble. Balance the equation. $2NaOH(aq) + Ba(NO_3)_2(aq) \longrightarrow 2NaNO_3(aq) + Ba(OH)_2(s)$ (balanced)

11 Assessment

* Solutions appear in Appendix E

Lesson by Lesson

11.1 Describing Chemical Reactions

34. Identify the reactants and products in each chemical reaction.

a. Hydrogen gas and sodium hydroxide are formed when sodium is dropped into water.

b. In photosynthesis, carbon dioxide and water react to form oxygen gas and glucose.

35. Write sentences that completely describe each of the chemical reactions shown in these skeleton equations.

a. $NH_3(g) + O_2(g) \xrightarrow{Pt} NO(g) + H_2O(g)$

b. $H_2SO_4(aq) + BaCl_2(aq) \longrightarrow BaSO_4(s) + HCl(aq)$

c. $N_2O_3(g) + H_2O(l) \longrightarrow HNO_2(aq)$

36. The equation for the formation of water from its elements, $H_2(g) + O_2(g) \longrightarrow H_2O(l)$, can be "balanced" by changing the formula of the product to H_2O_2. Explain why this is incorrect.

***37.** Balance the following equations:

a. $PbO_2(s) \longrightarrow PbO(s) + O_2(g)$

b. $Fe(OH)_3(s) \longrightarrow Fe_2O_3(s) + H_2O(s)$

c. $(NH_4)_2CO_3(s) \longrightarrow NH_3(g) + H_2O(g) + CO_2(g)$

d. $CaCl_2(aq) + H_2SO_4(aq) \longrightarrow CaSO_4(s) + HCl(aq)$

11.2 Types of Chemical Reactions

***38.** Write balanced chemical equations for the following combination reactions:

a. $Mg(s) + O_2(g) \longrightarrow$

b. $P(s) + O_2(g) \longrightarrow$ diphosphorus pentoxide

c. $Ca(s) + S(s) \longrightarrow$

39. Write a balanced chemical equation for each decomposition reaction.

a. $Ag_2O(s) \xrightarrow{\Delta}$

b. ammonium nitrate $\xrightarrow{\Delta}$ dinitrogen monoxide + water

40. Use the activity series of metals to write a balanced chemical equation for each single-replacement reaction.

a. $Au(s) + KNO_3(aq) \longrightarrow$

b. $Zn(s) + AgNO_3(aq) \longrightarrow$

c. $Al(s) + H_2SO_4(aq) \longrightarrow$

41. Write a balanced equation for each of the following double-replacement reactions:

a. $H_2C_2O_4(aq) + KOH(aq) \longrightarrow$

b. $CdBr_2(aq) + Na_2S(aq) \longrightarrow$ (Cadmium sulfide is a precipitate.)

42. Write a balanced equation for the complete combustion of each compound.

a. butene (C_4H_8) **b.** propanal (C_3H_6O)

43. Balance each equation and identify its type.

a. $Hf(s) + N_2(g) \longrightarrow Hf_3N_4(s)$

b. $Mg(s) + H_2SO_4(aq) \longrightarrow MgSO_4(aq) + H_2(g)$

c. $C_2H_6(g) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$

d. $Pb(NO_3)_2(aq) + NaI(aq) \longrightarrow PbI_2(s) + NaNO_3(aq)$

44. What is a distinguishing feature of every decomposition reaction?

11.3 Reactions in Aqueous Solution

45. What is a spectator ion?

***46.** Write a balanced net ionic equation for the following reactions:

a. $HCl(aq) + Ca(OH)_2(aq) \longrightarrow$

b. $AgNO_3(aq) + AlCl_3(aq) \longrightarrow$ (Silver chloride is a precipitate.)

47. Complete each equation and then write a net ionic equation.

a. $Al(s) + H_2SO_4(aq) \longrightarrow$

b. $HCl(aq) + Ba(OH)_2(aq) \longrightarrow$

c. $Au(s) + HCl(aq) \longrightarrow$

Understand Concepts

48. Write a balanced chemical equation for each reaction. Use the necessary symbols from Table 11.1 to describe the reaction completely.

a. Bubbling chlorine gas through a solution of potassium iodide gives elemental iodine and a solution of potassium chloride.

b. Bubbles of hydrogen gas and aqueous iron(III) chloride are produced when metallic iron is dropped into hydrochloric acid.

c. Solid tetraphosphorus decaoxide reacts with water to produce phosphoric acid.

49. Each equation is incorrect. Find the errors, then rewrite and balance each equation.

a. $Cl_2 + NaI \longrightarrow NaCl_2 + I$
b. $NH_3 \longrightarrow N + H_3$
c. $Na + O_2 \longrightarrow NaO_2$

50. Write balanced chemical equations for these double-replacement reactions that occur in aqueous solution.

a. Zinc sulfide is added to sulfuric acid.
b. Sodium hydroxide reacts with nitric acid.
c. Solutions of potassium fluoride and calcium nitrate are mixed.

***51.** Write a balanced chemical equation for each combination reaction.

a. sodium oxide + water
b. hydrogen + bromine
c. dichlorine heptoxide + water

52. Write a balanced chemical equation for each single-replacement reaction that takes place in aqueous solution. Write "no reaction" if a reaction does not occur.

a. Steel wool (iron) is placed in sulfuric acid.
b. Mercury is poured into an aqueous solution of zinc nitrate.
c. Bromine reacts with aqueous barium iodide.

***53.** Pieces of sodium and magnesium are dropped into separate water-filled test tubes (A and B). There is vigorous bubbling in Tube A but not in Tube B.

a. Which tube contains the sodium metal?
b. Write an equation for the reaction in the tube containing the sodium metal. What type of reaction is occurring in this tube?

54. Write a balanced equation for the complete combustion of each compound. Assume that the products are carbon dioxide and water.

a. octane (C_8H_{18})
b. glucose ($C_6H_{12}O_6$)
c. ethanoic acid ($HC_2H_3O_2$)

55. Write balanced chemical equations for these decomposition reactions.

a. Aluminum is obtained from aluminum oxide with the addition of a large amount of electrical energy.
b. Heating tin(IV) hydroxide gives tin(IV) oxide and water.
c. Silver carbonate decomposes into silver oxide and carbon dioxide when it is heated.

56. Write a balanced net ionic equation for each reaction. The product that is not ionized is given.

a. $H_2C_2O_4 + KOH \longrightarrow [H_2O]$
b. $Na_2S + HCl \longrightarrow [H_2S]$
c. $NaOH + Fe(NO_3)_3 \longrightarrow [Fe(OH_3)]$

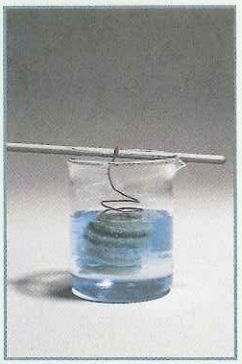
***57.** A yellow precipitate formed when aqueous solutions of sodium sulfide and cadmium nitrate were mixed in a beaker.

a. Write the formula of the yellow precipitate.
b. Identify the spectator ions in the solution.
c. Write the net ionic equation for the reaction.

Think Critically

58. Interpret Photos The photos show various types of reactions.

(1) 

(2) 

(3) 

(4) 

(1) Aluminum reacting with bromine

(2) The reaction of copper with aqueous silver nitrate

(3) Propane (C_3H_8) reacting with oxygen

(4) The reaction of lead(II) nitrate with potassium iodide

a. Identify each type of reaction.
b. Write the equation for each type of reaction.

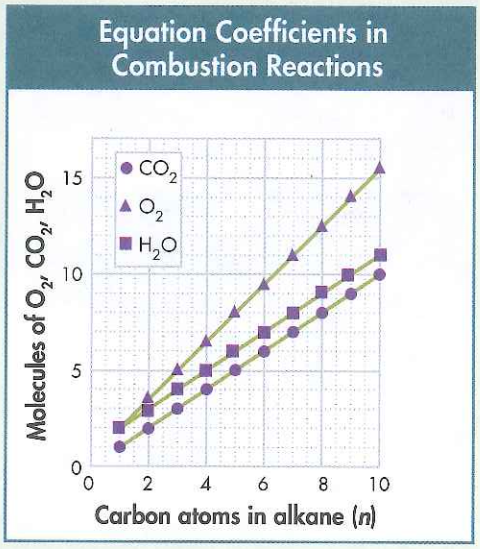
59. **Apply Concepts** Write a balanced chemical equation for each reaction. Classify each by type.
   a. Sodium iodide reacts with phosphoric acid.
   b. Potassium oxide reacts with water.
   c. Heating sulfuric acid produces water, oxygen, and sulfur dioxide.
   d. Aluminum reacts with sulfuric acid.
   e. Pentane (C_5H_{12}) reacts with oxygen.

*60. **Draw Conclusions** When pale yellow chlorine gas is bubbled through a clear, colorless solution of sodium iodide, the solution turns brown.
   a. What type of reaction is taking place?
   b. Write the net ionic equation.

Enrichment

61. **Interpret Graphs** Alkanes are hydrocarbon molecules that have the general formula C_nH_{2n+2}. The graph shows the number of oxygen, carbon dioxide, and water molecules needed to balance the equations for the complete combustion of every alkane having from one to ten carbon atoms.

$C_nH_{2n+2} + \_\_\_ O_2 \longrightarrow \_\_\_ CO_2 + \_\_\_ H_2O$



   a. Use the graph to write balanced equations for the combustion of C_5H_{12} and C_9H_{20}.
   b. Extrapolate the graph and write balanced equations for the combustion of $C_{12}H_{26}$ and $C_{17}H_{36}$.
   c. The coefficient for O_2 in the general equation is as follows:

$$n + \frac{n+1}{2}$$

What are the coefficients for CO_2 and H_2O?

*62. **Apply Concepts** Fill in the missing reactant, and then balance each equation.
   a. $K(s) + \_\_\_\_ \longrightarrow KOH(aq) + H_2(g)$
   b. $C_2H_5OH(l) + \_\_\_\_ \longrightarrow CO_2(g) + H_2O(g)$
   c. $Bi(NO_3)_3(aq) + \_\_\_\_ \longrightarrow Bi_2S_3(s) + HNO_3(aq)$
   d. $Al(s) + \_\_\_\_ \longrightarrow AlBr_3(s)$

Write About Science

63. **Explain** Research organisms such as fireflies and jellyfish that use bioluminescence, including information on the discovery of green fluorescent protein (GFP). In a pamphlet or poster, explain how bioluminescence works and how each organism uses it.

64. **Observe** Make a list of five chemical reactions that happen in your kitchen. Describe and name each reaction on your list.

*65. **Relate Cause and Effect** Why is smoking not permitted near an oxygen source? What would happen if a match were struck in a room filled with oxygen?

CHEMYSTERY

Order in the Lab

Chemicals should not be stored in alphabetical order because some chemicals that will react if mixed could end up next to each other. For example, acids should not be stored near cyanides, sulfides and other chemicals that produce toxic gases when combined. Acids should also not be stored near bases or active metals. Reactions between acids and bases produce heat. Acids and active metals react to produce gases and heat. Acids and flammables should have separate, dedicated storage areas.

66. Connect to the **BIG IDEA** Should sulfuric acid be stored next to sodium hydroxide? Explain your answer. If they should not be stored next to each other, write a balanced chemical equation to support your answer.

Cumulative Review

67. When you take a glass of cold liquid outside on a warm, humid day, drops of liquid soon form on the outside of the glass.

a. What is the liquid?
b. Where did the liquid come from?
c. Did a chemical or physical change occur?

68. Classify each of the following as an element, a compound, a homogeneous mixture, a heterogeneous mixture, or a substance. Some may fit in more than one category.

a. salt water
b. sodium chloride
c. air
d. salt and sand
e. gold
f. water with ice

69. A block of ice measures 25.0 cm × 42.0 cm × 38.0 cm. What is the mass of the ice in kilograms? The density of ice is 0.917 g/cm^3.

***70.** List the number of protons, neutrons, and electrons in this isotope of titanium: $^{50}_{22}Ti$.

71. Write electron configurations for the following ions.

a. Sr^{2+} **b.** S^{2-} **c.** Ga^{3+} **d.** Cu^{+}

72. Explain what is meant by *electronegativity*. How do electronegativity values change across a row of representative elements?

73. Are any of the following formulas for ionic compounds incorrect? If so, write the correct formulas.

a. K_2Br **b.** Na_2S **c.** CaN_2 **d.** Al_2O_3

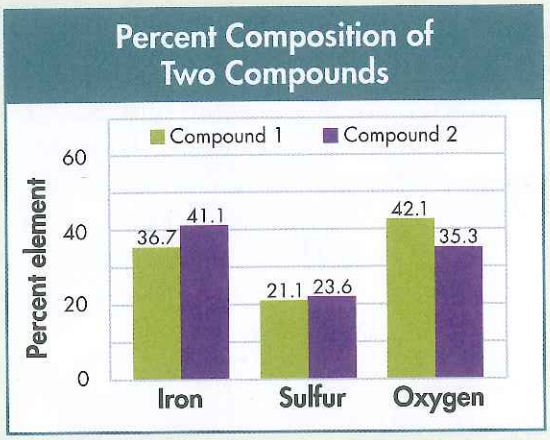
***74.** Give the name or formula for the following compounds:

a. potassium chromate
b. sodium hydrogen sulfite
c. $HMnO_4$
d. $K_2C_2O_4$

75. Calculate the number of moles in each substance.

a. 54.0 L of nitrogen dioxide (at STP)
b. 1.68 g of magnesium ions
c. 69.6 g of sodium hypochlorite
d. 4.27×10^{24} molecules of carbon monoxide

76. The graph shows the percent composition of two different compounds formed by the elements iron, oxygen, and sulfur.



a. Using the data on the graphs, calculate the empirical formula of each compound.
b. Name each compound.

***77.** Many coffees and colas contain the stimulant caffeine. The percent composition of caffeine is 49.5% C, 5.20% H, 16.5% O, and 28.9% N. What is the molecular formula of caffeine if its molar mass is 194.1 g/mol?

78. Calcium chloride ($CaCl_2$) is a white solid used as a drying agent. The maximum amount of water absorbed by different quantities of $CaCl_2$ is given in the table below.

$CaCl_2$ (g)	$CaCl_2$ (mol)	H_2O (g)	H_2O (mol)
17.3	a._____	5.62	e._____
48.8	b._____	15.8	f._____
124	c._____	40.3	g._____
337	d._____	109	h._____

a. Complete the table.
b. Plot the moles of water absorbed (y-axis) versus the moles of $CaCl_2$.
c. Based on your graph, how many molecules of water does each formula unit of $CaCl_2$ absorb?

If You Have Trouble With . . .

Question	67	68	69	70	71	72	73	74	75	76	77	78
See Chapter	2	2	3	4	5	6	7	9	10	10	10	10

Standardized Test Prep

Select the choice that best answers each question or completes each statement.

1. When the equation $Fe_2O_3 + H_2 \longrightarrow Fe + H_2O$ is balanced using whole-number coefficients, what is the coefficient of H_2?
   (A) 6 (B) 3 (C) 2 (D) 1

2. Identify the spectator ion in this reaction.
   $Ba(OH)_2(aq) + H_2SO_4(aq) \longrightarrow BaSO_4(s) + H_2O(l)$
   (A) Ba^{2+}
   (B) SO_4^{2-}
   (C) OH^-
   (D) H^+
   (E) There is no spectator ion.

3. Magnesium ribbon reacts with an aqueous solution of copper(II) chloride in a single-replacement reaction. Which are the products of the balanced net ionic equation for the reaction?
   (A) $Mg^{2+}(aq) + 2Cl^-(aq) + Cu(s)$
   (B) $Mg^+(aq) + Cl^-(aq) + Cu^+(aq)$
   (C) $Mg^{2+}(aq) + Cu(s)$
   (D) $Cu(s) + 2Cl^-(aq)$

Use the following description and data table to answer Questions 4–6.

Dropper bottles labeled P, Q, and R contain one of three aqueous solutions: potassium carbonate, K_2CO_3; hydrochloric acid, HCl; and calcium nitrate, $Ca(NO_3)_2$. The table shows what happens when pairs of solutions are mixed.

Solution	P	Q	R
P	—	Precipitate	No reaction
Q	Precipitate	—	Gas forms.
R	No reaction	Gas forms.	—

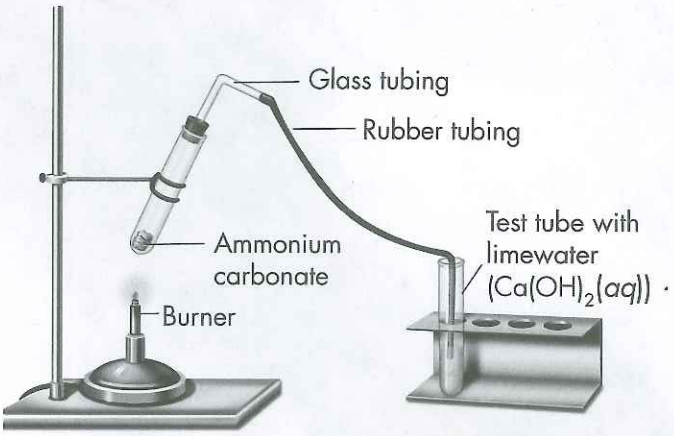
4. Identify the contents of each dropper bottle.
5. Write the net ionic equation for the formation of the precipitate.
6. Write the complete ionic equation for the formation of the gas.

7. Which are the expected products of the decomposition reaction of potassium oxide, K_2O?
   (A) $K^+(s)$ and $O^{2-}(g)$
   (B) $K^+(s)$ and $O_2(g)$
   (C) $K(s)$ and $O_2^{2-}(g)$
   (D) $K(s)$ and $O_2(g)$

Tips for Success

Interpreting Diagrams Before you answer questions about a diagram, study the diagram carefully. Read all captions and labels. Look at all the information in the diagram and think about how it all interrelates.

Use the diagram to answer Questions 8–11.



8. When ammonium carbonate is heated, water, ammonia, and carbon dioxide are produced. What type of chemical reaction is occurring?
9. Write formulas for the reaction products.
10. Write a balanced equation for the reaction. Include states for reactants and products.
11. Limewater is used to test for the presence of carbon dioxide gas. The products of the reaction of $Ca(OH)_2$ with CO_2 are calcium carbonate and water. Write a balanced equation for the reaction.

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10	11
See Lesson	11.2	11.3	11.2	11.3	11.3	11.3	11.2	11.2	11.1	11.2	11.2