11.2

1 FOCUS

Objectives

11.2.1 Describe the five general types of reactions.

11.2.2 Predict the products of the five general types of reactions.

Guide for Reading

Build Vocabulary L2

Graphic Organizers Have students draw concept maps entitled "Types of chemical reactions." Have them include all the vocabulary terms in the concept map. Ask them to explain how the name of each reaction tells what occurs in the reaction.

Reading Strategy L2

Visualize As students read the section, have them visualize the process that occurs in each type of chemical reaction. Suggest that they sketch their visualizations.

2 INSTRUCT

Connecting to Your World

Have students study the photograph and read the text. Explain that an important product of combustion reactions is energy, which can be in the form of heat and/or light. **Where else can you observe combustion reactions on a daily basis?** *(Examples include natural gas stoves and heaters, butane lighters, acetylene torches, and automobile engines.)*

Go Online NSTA SCILINKS

Download a worksheet on **Reaction Types** for students to complete, and find additional teacher support from NSTA SciLinks.

11.2 Types of Chemical Reactions

Guide for Reading

Key Concepts

- What are the five general types of reactions?
- How can you predict the products of the five general types of reactions?

Vocabulary

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

Reading Strategy

Outlining As you read, make an outline of the most important ideas in this section. Use the red headings as the main topics and the blue headings as subtopics. Add a sentence or a note after each heading to provide key information about each topic.

Connecting to Your World

Often charcoal briquettes provide the heat for barbeque grills through the burning of carbon. Have you ever felt the heat and smelled the smoke coming from a burning charcoal grill? The heat and smoke are the products of a combustion reaction. Combustion is one of the five general types of chemical reactions. In this chapter, you will learn that if you can recognize a reaction as being a particular type, you may be able to predict the products of the reaction.

Classifying Reactions

The five general types of reaction are 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 11.5, 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. This 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 compound consisting of the metal cation and the nonmetal anion.

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

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.

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

Go Online NSTA SCILINKS

For: Links on Reaction Types
Visit: www.SciLinks.org
Web Code: cdn-1112

Section Resources

Print

- **Guided Reading and Study Workbook,** Section 11.2
- **Core Teaching Resources,** Section 11.2 Review
- **Laboratory Manual,** Labs 14, 15
- **Small-Scale Chemistry Laboratory Manual,** Lab 15
- **Transparencies,** T118–T120
- **Lab Practical** 11–1

Technology

- **Interactive Textbook with ChemASAP,** Simulation 12; Problem-Solving 11.14, 11.15, 11.17, 11.18, 11.21; Assessment 11.2
- **Go Online,** Section 11.2

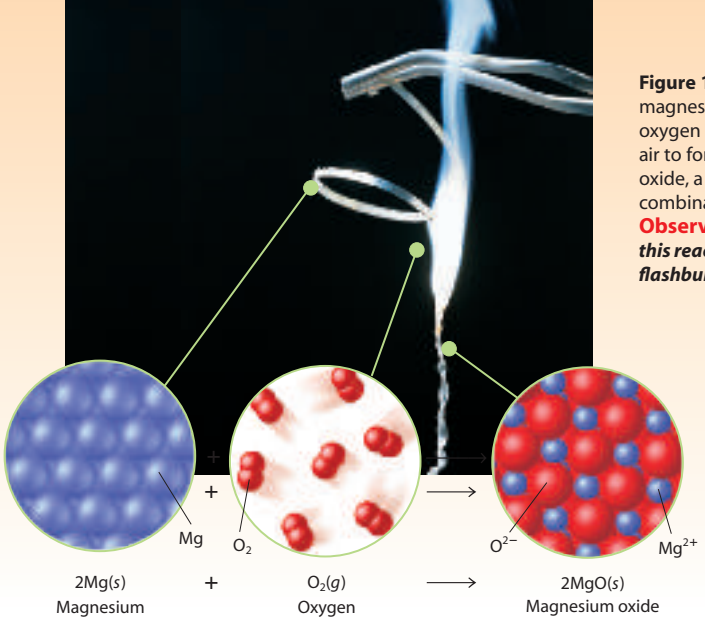

Figure 11.5 When ignited, magnesium ribbon reacts with oxygen in the surrounding air to form magnesium oxide, a white solid. This is a combination reaction.
Observing ***Why do you think this reaction was once used in flashbulbs for photography?***

CONCEPTUAL PROBLEM 11.4

Writing Equations for Combination Reactions

Copper and sulfur, shown in the photo, are the reactants in a combination reaction. Complete the equation for the reaction.

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

1 Analyze ***Identify the relevant concepts.***

Two reactions are possible because copper is a transition metal and has more than one common ionic charge (Cu^+ and Cu^{2+}). Determine the formulas for the two products. Balance the two possible equations.

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

Write the skeleton equation first, then apply the rules for balancing equations.

For copper(II):

$Cu(s) + S(s) \longrightarrow CuS(s)$ (balanced)

For copper(I):

$Cu(s) + S(s) \longrightarrow Cu_2S(s)$

$2Cu(s) + S(s) \longrightarrow Cu_2S(s)$ (balanced)

Practice Problems

13. Complete and balance this equation for a combination reaction.

$Be + O_2 \longrightarrow$

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

Interactive Textbook
Problem-Solving 11.14 Solve Problem 14 with the help of an interactive guided tutorial.
with ChemASAP

Classifying Reactions

CONCEPTUAL PROBLEM 11.4

Answers

13. $2Be + O_2 \rightarrow 2BeO$

14. $3Mg + N_2 \rightarrow Mg_3N_2$

Practice Problems Plus L2

Write and balance an equation for the formation of aluminum chloride ($AlCl_3$) from its elements.

($2Al + 3Cl_2 \rightarrow 2AlCl_3$)

Discuss L2

Write a number of equations for combination reactions on the board and have students practice balancing them. Point out that many combination reactions release large amounts of energy. Rewrite some of the equations with the product on the reactant side and the reactants on the product side. Ask, **Is it possible to reverse the process?** *(yes)* **What is the name of the reverse process?** *(a decomposition reaction)* **Why is energy usually needed for a decomposition reaction to occur?** *(Decomposition involves the breaking of bonds, which requires energy.)*

Differentiated Instruction

Gifted and Talented L3

Combination reactions are sometimes referred to as synthesis reactions, but synthesis reactions and combination reactions are no longer considered to be synonymous. Have students research the meaning of *synthesis*. Have them investigate the synthesis of polymers and the process of photosynthesis. Point out that synthesis involves making a final product from other substances, but not all synthesis processes—such as those in photosynthesis—are true combination reactions.

Answers to...

Figure 11.5 The reaction produces bright, white light.

CONCEPTUAL PROBLEM 11.5

Answers

15. $2HI \rightarrow H_2 + I_2$
16. HBr

Use Visuals L1

Conceptual Problem 11.5 Have students study the photograph in the problem. Explain that the explosive properties of dynamite are due to the rapid production of large amounts of gases. A related reaction is the decomposition of trinitrotoluene (TNT). Write the equation for the decomposition of TNT on the board: $2C_7H_5N_3O_6(s) \rightarrow 3N_2(g) + 7CO(g) + 5H_2O(g) + 7C(s)$. Point out to students that for every 2 mol of TNT that decompose, 15 mol of hot, expanding gases are produced.

Discuss L2

Help students create a list of criteria for identifying decomposition and combination reactions. For example, decomposition reactions are characterized by one molecule on the reactant side and smaller molecules or elements on the product side. Students should supplement their lists later, when they study single-replacement, double-replacement, and combustion reactions.

Discuss L2

Emphasize to students that decomposition reactions consist of one substance forming two or more different substances. Students tend to limit decomposition reactions to the decomposition of a compound into its component elements. A compound can also break down into an element and a compound or two or more compounds. Provide students with the following chemical equations as examples of decomposition reactions that result in products other than elements: $2H_2O_2 \rightarrow 2H_2O + O_2$ and $H_2CO_3 \rightarrow H_2O + CO_2$.

Figure 11.6 When orange-colored mercury(II) oxide is heated, it decomposes into its constituent elements: liquid mercury and gaseous oxygen.
Comparing and Contrasting ***How are the reactions pictured in Figures 11.5 and 11.6 similar? How are they different?***

Decomposition Reactions When mercury(II) oxide is heated, it decomposes or breaks down into two simpler compounds, as shown in Figure 11.6.

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

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.

CONCEPTUAL PROBLEM 11.5

Writing the Equation for a Decomposition Reaction

Decomposition reactions that produce gases and heat are sometimes explosive, as the photo shows. Write a balanced equation for the following decomposition reaction.

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

1 Analyze ***Identify the relevant concepts.***
Water, a binary compound, breaks down into its elements. Balance the equation, remembering that hydrogen and oxygen are both diatomic molecules.

2 Solve ***Apply concepts to this situation.***
Write the skeleton equation, then apply the rules for balancing equations.

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

Practice Problems

15. Complete and balance this decomposition reaction.
$HI \longrightarrow$
16. Write the formula for the binary compound that decomposes to the products H_2 and Br_2.

Interactive Textbook
Problem-Solving 11.15
Solve Problem 15 with the help of an interactive guided tutorial.
with ChemASAP

Single-Replacement Reactions Dropping a small piece of potassium into a beaker of water creates the vigorous reaction shown in Figure 11.7. 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 $Zn(NO_3)_2$.

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:

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

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

	Name	Symbol
Decreasing reactivity ↓	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.

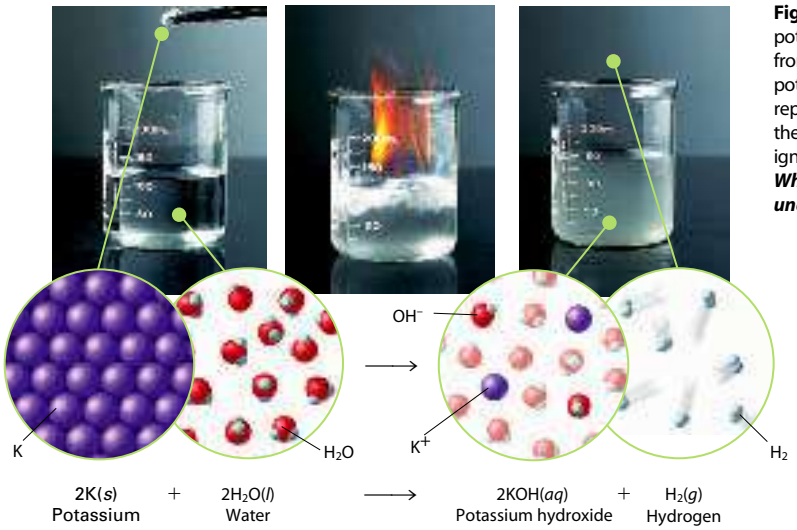

Figure 11.7 The alkali metal potassium displaces hydrogen from water and forms a solution of potassium hydroxide in a single-replacement reaction. The heat of the reaction is often sufficient to ignite the hydrogen. **Inferring** ***Why are alkali metals stored under mineral oil or kerosene?***

Differentiated Instruction

Gifted and Talented L3

Encourage students to devise general statements to represent each of the first four types of chemical reactions discussed in this section. For example: X + Y → XY, XY → X + Y, X + CD → XD + C, AB + CD → AD + CB.

Use Visuals L1

Table 11.2 With Table 11.2 displayed on an overhead projector, review the definition of a single-replacement reaction on the board. Explain that single-replacement reactions can be compared to partners cutting in on each other at a dance. A person who is alone approaches a couple and cuts in. The person replaces one member of the couple, who is now left alone. In a chemical reaction, however, only certain substances can replace other substances in a given compound. The activity series of metals tells us which metals can replace other metals in a given compound. Review the reactions on this page. Show students how to use Table 11.2 to predict whether a reaction will occur.

TEACHER Demo

Single-Replacement Reactions L2

Purpose Students observe single-replacement reactions.

Materials magnesium ribbon, 10-mL graduated cylinder, 1*M* HCl, sodium, 2 beakers, tongs, water

Safety HCl(*aq*) is corrosive and can cause severe burns. The piece of sodium should be no larger than a match head. Wear plastic gloves and use tongs to avoid contact between sodium and your skin.

Procedure Place a 2-cm piece of magnesium ribbon in 10 mL of 1*M* HCl. Using tongs, place a small piece of sodium in 250 mL of cold water.

Expected Outcomes In both reactions, the metal replaces hydrogen in a compound. Hydrogen gas is released. The reaction using sodium is much more dramatic and rapid than the reaction involving magnesium.

Answers to...

Figure 11.6 Both involve two elements and one compound. In Figure 11.5, a compound is being formed from the elements; in Figure 11.6, a compound is being decomposed to its elements.

Figure 11.7 to prevent their reaction with water vapor and oxygen in the air

CONCEPTUAL PROBLEM 11.6

Answers

17. a. $Fe(s) + Pb(NO_3)_2(aq) \rightarrow Fe(NO_3)_2(aq) + Pb(s)$

b. $Cl_2(aq) + 2NaI(aq) \rightarrow 2NaCl(aq) + I_2(aq)$

c. $Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$

Practice Problems Plus L2

Complete the equation for this single-replacement reaction that takes place in aqueous solution. Balance the equation. If a reaction does not occur , write "no reaction." (Use the activity series.)

$K(s) + H_2SO_4(aq) \rightarrow$

$(2K(s) + H_2SO_4(aq) \rightarrow K_2SO_4(aq) + H_2(g))$

Discuss L2

Explain to students that a double-replacement reaction always involves two ionic compounds in aqueous solution. In addition, one of the products must be a precipitate, a gas, or a molecular compound.

TEACHER Demo

A Double-Replacement Reaction L1

Purpose Students observe double-replacement reactions.

Materials equimolar solutions of $BaCl_2$, Na_2SO_4, Na_3PO_4, $CaCl_2$, $Pb(NO_3)_2$, and KI

Procedure Mix equimolar solutions of the following ionic compounds: $BaCl_2$ and Na_2SO_4; Na_3PO_4 and $CaCl_2$; and $Pb(NO_3)_2$ and KI. Ask, **What evidence of a double-replacement reaction do you observe?** *(a precipitate)* Write the formula of each precipitate formed in the reactions.

Expected Outcome Precipitates of $BaSO_4$, $Ca_3(PO_4)_2$, and PbI_2 form.

CONCEPTUAL PROBLEM 11.6

Writing Equations for Single-Replacement Reactions

The photo shows the reaction between $Zn(s)$ and $H_2SO_4(aq)$. Write a balanced chemical equation for each single-replacement reaction. The reactions take place in aqueous solution.

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

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

1 Analyze ***Identify the relevant concepts.***

a. According to the activity series of metals, zinc displaces hydrogen from an acid and takes its place. Balance the equation, remembering that elemental hydrogen is diatomic.

b. Chlorine is more reactive than bromine and displaces bromine from its compounds. Balance the equation. Bromine is diatomic.

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

Write the skeleton equation first, then apply the rules for balancing equations.

a. $Zn(s) + H_2SO_4(aq) \longrightarrow ZnSO_4(aq) + H_2(g)$ (balanced)

b. $Cl_2(aq) + NaBr(aq) \longrightarrow NaCl(aq) + Br_2(aq)$

$Cl_2(aq) + 2NaBr(aq) \longrightarrow 2NaCl(aq) + Br_2(aq)$ (balanced)

Practice Problem

17. 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. $Ca(s) + H_2O(l) \longrightarrow$

Interactive Textbook

Problem-Solving 11.17 Solve Problem 17 with the help of an interactive guided tutorial.

with ChemASAP

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 11.8 shows that mixing aqueous solutions of potassium carbonate and barium chloride results in a chemical reaction. A white precipitate of solid barium carbonate is formed. Potassium chloride, the other product of the reaction, remains in solution. This 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 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.

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

Differentiated Instruction

Gifted and Talented L3

When hydrochloric acid (HCl) is dropped on calcium carbonate ($CaCO_3$) a double-replacement reaction occurs. Ask, **What are the products of this reaction?** *($CaCl_2$ and H_2CO_3)* Neither of these products is a gas, but bubbles of gas are released during this reaction. Ask students to infer the identity of the gas. *(CO_2)* Ask, **What type of reaction could produce this gas?** *(The decomposition reaction $H_2CO_3 \rightarrow H_2O + CO_2$ releases carbon dioxide gas.)*

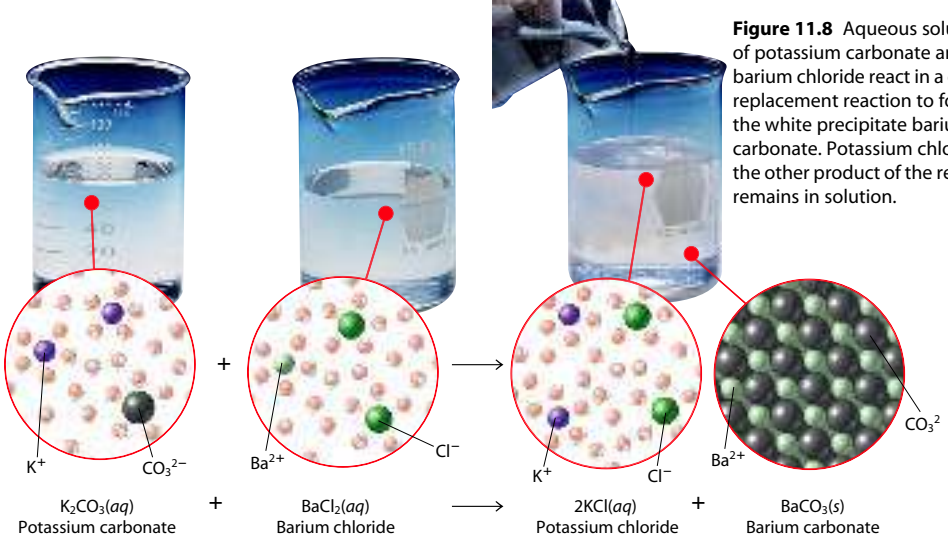

Figure 11.8 Aqueous solutions of potassium carbonate and barium chloride react in a double-replacement reaction to form the white precipitate barium carbonate. Potassium chloride, the other product of the reaction, remains in solution.

CONCEPTUAL PROBLEM 11.7

Writing Equations for Double-Replacement Reactions

Write a balanced chemical equation for each double-replacement reaction.

a. $CaBr_2(aq) + AgNO_3(aq) \longrightarrow$ (A precipitate of silver bromide is formed.)

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

1 Analyze ***Identify the relevant concepts.***

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

b. A gas is formed. Use ionic charges to write the correct formula of the other product. Then balance the equation.

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

For each reaction, write the skeleton equation first, then apply the rules for balancing equations.

a. $CaBr_2(aq) + AgNO_3(aq) \longrightarrow AgBr(s) + Ca(NO_3)_2(aq)$

$CaBr_2(aq) + 2AgNO_3(aq) \longrightarrow 2AgBr(s) + Ca(NO_3)_2(aq)$ (balanced)

b. $FeS(s) + HCl(aq) \longrightarrow H_2S(g) + FeCl_2(aq)$

$FeS(s) + 2HCl(aq) \longrightarrow H_2S(g) + FeCl_2(aq)$ (balanced)

Practice Problems

18. 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.)

19. Write a balanced equation for each reaction.

a. $KOH(aq) + H_3PO_4(aq) \longrightarrow$

b. $H_2SO_4(aq) + Al(OH)_3(aq) \longrightarrow$

Interactive Textbook

Problem-Solving 11.18 Solve Problem 18 with the help of an interactive guided tutorial.

with ChemASAP

Facts and Figures

Launching the Space Shuttle

Decomposition and displacement reactions supply the energy needed for launching the space shuttle into space. Have students research what fuels are used to propel the space shuttle orbiter. Have volunteers describe the reactions that occur and how the products provide the thrust necessary to launch vehicles.

CONCEPTUAL PROBLEM 11.7

Answers

18. a. $3NaOH(aq) + Fe(NO_3)_3(aq) \rightarrow Fe(OH)_3(s) + 3NaNO_3(aq)$

b. $3Ba(NO_3)_2(aq) + 2H_3PO_4(aq) \rightarrow Ba_3(PO_4)_2(s) + 6HNO_3(aq)$

19. a. $3KOH(aq) + H_3PO_4(aq) \rightarrow K_3PO_4(aq) + 3H_2O(l)$

b. $3H_2SO_4(aq) + 2Al(OH)_3(aq) \rightarrow Al_2(SO_4)_3(aq) + 6H_2O(l)$

Practice Problems Plus

L2

Write the products for this double-replacement reaction. Then balance the equation. $Pb(NO_3)_2(aq) + NaI(aq) \rightarrow$ (lead iodide is a precipitate)

$(Pb(NO_3)_2(aq) + 2NaI(aq) \rightarrow PbI_2(s) + 2NaNO_3(aq))$

TEACHER Demo

Law of Conservation of Mass

L2

Purpose Demonstrate the law of conservation of mass using a double-replacement reaction.

Materials 50 mL 1.0*M* K_2CrO_4, 250-mL Erlenmeyer flask, 5 mL dilute $AgNO_3$ solution, small test tube, stopper, 50-mL graduated cylinder

Safety Avoid skin contact with silver nitrate.

Procedure Place 50 mL of 1.0*M* potassium chromate (K_2CrO_4) in a 250-mL Erlenmeyer flask. Place about 5 mL of dilute silver nitrate solution ($AgNO_3$) in a small test tube that will fit inside the flask. Stopper the flask and determine the mass of the system. Invert the flask sufficiently so that the two solutions mix. Ask students to note any evidence of chemical changes. Measure the mass of the flask after the reaction. Flush the products down the drain with excess water.

Expected Outcomes A bright red precipitate forms. The mass has not changed.

Discuss L2

Point out to students that an important product of most combustion reactions is energy, which is usually in the form of heat or light. Emphasize that one of the reactants must be oxygen. Relate this fact to everyday experience by recalling how removing oxygen from a combustion reaction—for example, snuffing out a candle—causes the reaction to stop.

Relate L2

Ask students to infer why it is important that combustion reactions, such as those used to heat a home or run an automobile, take place in properly ventilated areas. *(Without proper ventilation and enough available oxygen, the combustion may be incomplete, and poisonous carbon monoxide may be produced.)*

Use Visuals L1

Figure 11.9 Have students study the figure. Remind them that the complete combustion of a hydrocarbon, such as methane, always produces water, carbon dioxide, heat, and light. Use a disposable lighter to show students the combustion of butane. Ask students to write the balanced equation for the combustion of butane (C_4H_8). Have them use the diagram and chemical equation on this page as an aid.

Discuss L2

Explain that some combustion reactions are also combination reactions in which an element or a compound combines with oxygen to form a single product plus energy. For example: $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$, and $4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$.

Go Online NSTA SciLinks

Download a worksheet on **Combustion** for students to complete, and find additional teacher support from NSTA SciLinks.

Go Online NSTA SciLinks
For: Links on Combustion
Visit: www.SciLinks.org
Web Code: cdn-1114

Combustion Reactions The flames of a campfire 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. 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 11.9. 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.

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

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.

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

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

Checkpoint ***What are the products of the combustion of a hydrocarbon?***

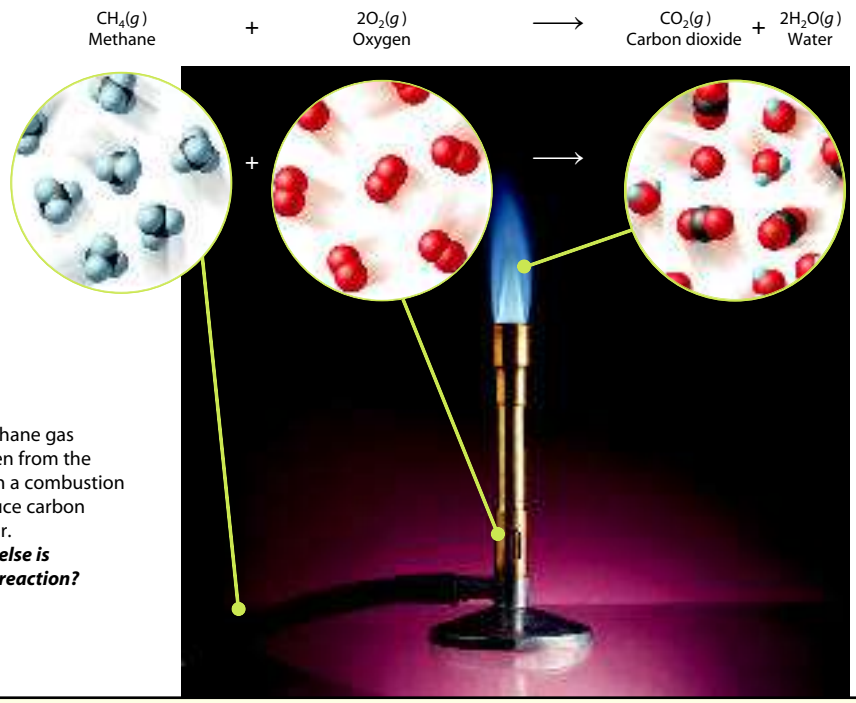

Figure 11.9 Methane gas reacts with oxygen from the surrounding air in a combustion reaction to produce carbon dioxide and water.
Inferring ***What else is produced in this reaction?***

Differentiated Instruction

English Learners L1

Make sure that students understand clearly the five terms that describe general types of chemical reactions: combination, decomposition, single-replacement, double-replacement, and combustion. Help them to spell and pronounce each term as well as to define it. Encourage them to ask questions about any term they do not fully understand.

CONCEPTUAL PROBLEM 11.8

Writing Equations for Combustion Reactions

An alcohol lamp often uses ethanol as its fuel. Write balanced equations for the complete combustion of these compounds.

a. benzene ($C_6H_6(l)$) **b.** ethanol ($CH_3CH_2OH(l)$)

1 Analyze ***Identify the relevant concepts.***

Oxygen is the other reactant in these combustion reactions. The products are CO_2 and H_2O. Write the skeleton equation for each reaction, then balance the equation.

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

For each reaction, write the skeleton equation, then apply the rules for balancing equations.

a. $C_6H_6(l) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$

$2C_6H_6(l) + 15O_2(g) \longrightarrow 12CO_2(g) + 6H_2O(g)$ (balanced)

b. $CH_3CH_2OH(l) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$

$CH_3CH_2OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(g)$ (balanced)

Practice Problems

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

a. formic acid (HCOOH)

b. heptane (C_7H_{16})

21. Write a balanced equation for the complete combustion of glucose ($C_6H_{12}O_6$).

Interactive Textbook

Problem-Solving 11.21
Solve Problem 21 with the help of an interactive guided tutorial.

with ChemASAP

Predicting the Products of a Chemical Reaction

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.

Interactive Textbook

Simulation 12 Practice classifying reactions according to reaction type.

with ChemASAP

Differentiated Instruction

Gifted and Talented L3

Have students choose a particular chemical compound, such as NaOH, H_2SO_4, or CH_3OH, and research how it is produced commercially. A report or poster should be presented describing in as much detail as possible the reactions that are necessary to produce the compound.

CONCEPTUAL PROBLEM 11.8

Practice Problems Answers

20. a. $2HCOOH + O_2 \rightarrow 2CO_2 + 2H_2O$

b. $C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$

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

Practice Problems Plus L2

Write a balanced equation for the complete combustion of ethanol (C_2H_5OH). *($C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$)*

Predicting the Products of a Chemical Reaction

TEACHER Demo

Combustion of Iron L1

Purpose Students observe the combustion of iron.

Materials superfine steel wool, plastic sandwich bag, balance, ring stand, utility clamp, matches

Safety Steel wool burns readily.

Procedure Place a superfine steel wool pad in a plastic sandwich bag, measure the mass, and write the value on the board. Take the steel wool out of the bag and unfold it to full length. Clamp it to a ring stand with a utility clamp. Set the steel wool on fire. Ask students to predict what effect the burning will have on the mass of the sample. As soon as the steel wool stops burning and is cool, place the remains in the same plastic sandwich bag and measure the mass again. Write the new value on the board next to the original mass. Discuss why the sample gained mass.

Expected Outcomes Two elements, Fe*(s)* and $O_2(g)$, combined in a combustion reaction to form a binary compound, Fe_2O_3. The sample gained mass because initially only the mass of the iron was determined. During the reaction, oxygen from the air combined with the iron.

Answers to...

Figure 11.9 energy in the form of heat and light

Checkpoint carbon dioxide and water, plus energy

Figure 11.10 The five types of chemical reactions discussed in this chapter are summarized here.

1 Combination Reaction

General Equation: $R + S \longrightarrow RS$

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

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

2 Decomposition Reaction

General Equation: $RS \longrightarrow R + S$

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: $T + RS \longrightarrow TS + R$

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 displaced must be less active than the element that is doing the displacing.
Probable Products: A different element and a new compound
Example: Potassium in water

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

TEACHER Demo

A Combination Reaction L2

Purpose Students observe a combination reaction.

Materials magnesium ribbon, large crucible, lab burner, cobalt blue glass or exposed photographic film, crucible tongs, matches or igniter

Safety Students should not look directly at burning magnesium. Have them observe through pieces of cobalt blue glass or exposed photographic film. Another option is to conduct the reaction inside a large, metal can.

Procedure Explain to students that in a combination reaction, the reactants combine to make one new product. Measure a 5- to 7-cm strip of magnesium ribbon. Light the burner. Hold one end of the magnesium ribbon with a pair of crucible tongs. Ignite the magnesium and hold it above the crucible. Ask students to note any evidence of chemical change. Have students note the condition of the residue compared to the original magnesium. The product may be disposed of in the trash.

Expected Outcomes Metallic magnesium and oxygen gas from the air form a white powder, magnesium oxide. Other evidence of chemical change includes release of energy as heat and light. Tell students that small amounts of magnesium nitride also form.

For Enrichment L3

Extend the demonstration on this page. Ask, **What are the reactants in this combination reaction?** *(Mg and O_2)* **What is the product of this reaction?** *(MgO)* **Does this reaction obey the law of conservation of mass? Explain.** *(Yes, the sum of the masses of magnesium and oxygen is equal to the mass of the magnesium oxide formed.)* Have students write the balanced equation for the reaction. *($2Mg(s) + O_2(g) \rightarrow 2MgO(s)$)* Challenge students to write the balanced equation for the formation of the small amount of magnesium nitride that forms during this reaction. *($3Mg(s) + N_2(g) \rightarrow Mg_3N_2(s)$)*.

Facts and Figures

Magnesium from Sea Water

Magnesium metal is an important component of alloys used to make consumer materials. The main commercial source of Mg(s) is seawater. The Mg^{2+} ion is the third most abundant dissolved ion in the oceans. A process for isolating magnesium from seawater depends on the fact that because of a double-replacement reaction, Mg^{2+} will precipitate when OH^- is added. Students can research the commercial process.

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 barium chloride and potassium carbonate

$K_2CO_3(aq) + BaCl_2(aq) \longrightarrow 2KCl(aq) + BaCO_3(s)$

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

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

11.2 Section Assessment

22. Key Concept What are the five types of chemical reactions?

23. Key Concept What are the keys to predicting the products of the five general types of reactions?

24. Classify each reaction and balance the equations.
a. $C_3H_6 + O_2 \longrightarrow CO_2 + H_2O$
b. $Al(OH)_3 \longrightarrow Al_2O_3 + H_2O$
c. $Li + O_2 \longrightarrow Li_2O$
d. $Zn + AgNO_3 \longrightarrow Ag + Zn(NO_3)_2$

25. 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

26. Complete and balance an equation for each reaction.
a. $CaI_2 + Hg(NO_3)_2 \longrightarrow$ (HgI_2 precipitates.)
b. $Al + Cl_2 \longrightarrow$
c. $Ag + HCl \longrightarrow$
d. $C_2H_2 + O_2 \longrightarrow$
e. $MgCl_2 \longrightarrow$

27. What are the three types of products that result from double-replacement reactions?

Connecting Concepts

Molecular Compounds Hydrogen peroxide is an antiseptic that undergoes a decomposition reaction in the presence of living cells. Refer to Section 8.1 and write a paragraph giving evidence that hydrogen peroxide is a molecular compound.

Interactive Textbook
Assessment 11.2 Test yourself on the concepts in Section 11.2.
with ChemASAP

Section 11.2 Assessment

22. combination, decomposition, single-replacement, double-replacement, and combustion

23. the number of elements and/or compounds reacting

24. **a.** combustion; $2C_3H_6 + 9O_2 \rightarrow 6CO_2 + 6H_2O$ **b.** decomposition; $2Al(OH)_3 \rightarrow Al_2O_3 + 3H_2O$ **c.** combination; $4Li + O_2 \rightarrow 2Li_2O$ **d.** single-replacement; $Zn + 2AgNO_3 \rightarrow 2Ag + Zn(NO_3)_2$

25. **a.** double replacement; two different compounds **b.** decomposition; two or more elements and/or compounds **c.** combination; a compound **d.** combustion; carbon dioxide and water

26. **a.** $CaI_2 + Hg(NO_3)_2 \rightarrow HgI_2 + Ca(NO_3)_2$
b. $2Al + 3Cl_2 \rightarrow 2AlCl_3$ **c.** no reaction
d. $2C_2H_2 + 5O_2 \rightarrow 4CO_2 + 2H_2O$
e. $MgCl_2 \xrightarrow{\text{electricity}} Mg + Cl_2$

27. gas, precipitate, and molecular compound

3 ASSESS

Evaluate Understanding L2

Ask students to give an example of each type of reaction discussed in this section. Write several chemical equations on the board and ask students to classify them. In addition, write only the products of combination, decomposition, and displacement reactions, and challenge students to fill in the reactants. Have students refer to Table 11.2 to answer the following questions. **What would happen if a piece of iron was placed in a solution of lead(II) nitrate?** *(Iron will displace lead.)* **What would happen if a piece of aluminum was placed in a solution of calcium chloride?** *(Nothing will happen because Al will not displace Ca.)*

Reteach L1

Help students develop a branched flowchart of chemical reactions similar to those used in qualitative analysis. Start by asking if there is a single reactant. If so, the reaction is a decomposition. If not, proceed to the next step. Ask if oxygen is one of the reactants. If so, the reaction is either combination or combustion. If not, proceed to the next step. Continue through the five general types of reactions.

Connecting Concepts

Paragraphs should include the information that hydrogen atoms and oxygen atoms tend to share electrons to become stable. Units formed when atoms share electrons are molecular compounds.

Interactive Textbook
If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 11.2.
with ChemASAP

Technology & Society

Discuss

L2

After students have read the article, ask, **What three things are necessary for a fire to burn?** *(fuel, oxygen, and energy to initiate combustion)* **Why is it not safe to use a single kind of fire extinguisher on all fires?** *(A fire extinguisher that controls one type of fire may actually enhance other types of combustion reactions. For example, water is not sprayed on burning magnesium because the intense heat can decompose water, producing flammable hydrogen and oxygen gases.)*

CLASS Activity

Classifying Fires

L2

Purpose Students classify fires according to type.

Materials research materials, graph paper

Procedure Have students find out what the letters A, B, C, and D refer to in classifying fires. Have them contact their local fire department to obtain statistics on how many class A, B, C, and D fires have occurred in their area during the past year or six months. As a class, have students graph the data and discuss any conclusions that can be drawn from the data.

Expected Outcomes Class A fires are those where ordinary combustibles, such as wood or plastic, are burning. Class B fires involve flammable liquids, such as gasoline. Class C fires are electrical. Class D fires are metal fires.

Relate

L1

Discuss with students the proper use of a fire extinguisher. Tell them to remember PASS. **P**ull the pin. **A**im the nozzle at the base of the fire. **S**queeze the handle. **S**weep the contents of the extinguisher from side to side until the fire is out. Then, they should shut off the fire extinguisher and watch to see that the fire does not rekindle.

Technology & Society

Combating Combustion

A fire has three requirements: oxygen, fuel, and a temperature high enough to initiate and sustain combustion. Firefighters put out fires by eliminating one or more of these requirements. When water is sprayed on a typical building fire, it stops the fire by lowering the temperature of the burning material and soaking it with noncombustible water. Steam from the vaporizing water also tends to displace air from around the fuel, which denies oxygen to the fuel. To improve the ability of water to saturate the fuel, for example, upholstered furniture and rugs, a substance called a surfactant is added to the water. **Inferring** ***How can it help to roll on the ground if your clothes are on fire?***

Water Water is the most important tool for firefighters. Water-based foams are more effective, but they are also more expensive.

Facts and Figures

Fire Extinguisher Labels

Fire extinguishers indicate on their labels what types of fires they are designed to extinguish. Some extinguishers might be labeled "AB," for example, indicating that they are effective on more than one type of fire. Many fire extinguishers now are labeled with pictures that show the type of fire. For example, a type A extinguisher might show a picture of burning wood. The extinguisher might also show what type of fire the extinguisher should not be used on by showing a picture of that type of fire in a circle with a black line through it.

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Forest fires Firefighters combat forest fires from the air by spreading substances that coat the surfaces of the trees to prevent burning. They can also cut the fire off from its fuel by using bulldozers to cut a clear path through the trees or by setting a controlled blaze.

Grease fires Water sprayed on a grease fire can spread the flames. A carbon-dioxide fire extinguisher produces a cloud of heavier-than-air CO_2 that blankets the fire and cuts off the oxygen supply.

Electrical fires Chemicals such as monoammonium phosphate (MAP), blown from a dry-chemical extinguisher, cover an electrical fire and cut off oxygen.

Differentiated Instruction

Gifted and Talented L3

Have students check the Internet to learn more about careers in fire science. Prepare a class list of each career, its description, and its requirements. Careers might include firefighter, arson investigator, or fire extinguisher manufacturer.

Answers to...

Inferring Rolling on the ground deprives the burning clothes of oxygen.

Relate L2

Fire extinguishers can be quite heavy. Purchasers of fire extinguishers should be sure that they can handle and operate an extinguisher effectively. Extinguishers must be recharged after each use, even if they are not entirely empty. Periodically, they should be checked to make sure they are operable and effective.

Discuss with students the requirements of a gas that might be used to put out a fire. The gas cannot itself burn or support the combustion of another material. It must be heavier than air so that it will settle on a fire, depriving it of oxygen. Discuss some specific gases in terms of these factors. For example, nitrogen and helium are relatively nonreactive, but they are not heavy enough. Hydrogen and methane will burn. Oxygen supports the burning of the fuel. Carbon dioxide will not burn or support combustion and is heavier than air. Ask, **Is a piece of paper combustible? Is it flammable?** *(Paper is combustible but not flammable.)* Explain that these two terms are often used synonymously, but combustible means that the material will burn, and flammable means a material may easily burst into flame.

TEACHER Demo

Model a Fire Extinguisher L1

Purpose Students observe the effect of carbon dioxide on a flame.

Materials calcium carbonate, dilute hydrochloric acid, 3 beakers, candle, matches

Safety Exert caution when using open flames or acid.

Procedure Place some calcium carbonate in a beaker. Add hydrochloric acid, and allow several minutes for the reaction to produce collectable amounts of carbon dioxide. Collect the carbon dioxide in a beaker. This gas will stay in the beaker because it is heavier than air. Light a candle, and place it in the third beaker. Pour the carbon dioxide over the flame, and observe what happens.

Expected Outcomes The carbon dioxide extinguishes the flame.