SECTION 2

Types of Chemical Reactions

OBJECTIVES

- Define and give general equations for *synthesis, decomposition, single-displacement,* and *double-displacement* reactions.
- Classify a reaction as a synthesis, decomposition, single-displacement, double-displacement, or combustion reaction.
- List three kinds of synthesis reactions and six kinds of decomposition reactions.
- List four kinds of single-displacement reactions and three kinds of double-displacement reactions.
- Predict the products of simple reactions given the reactants.

Thousands of known chemical reactions occur in living systems, in industrial processes, and in chemical laboratories. Often it is necessary to predict the products formed in one of these reactions. Memorizing the equations for so many chemical reactions would be a difficult task. It is therefore more useful and realistic to classify reactions according to various similarities and regularities. This general information about reaction types can then be used to predict the products of specific reactions.

There are several ways to classify chemical reactions, and none are entirely satisfactory. The classification scheme described in this section provides an introduction to five basic types of reactions: synthesis, decomposition, single-displacement, double-displacement, and combustion reactions. In later chapters, you will be introduced to categories that are useful in classifying other types of chemical reactions.

Synthesis Reactions

In a **synthesis reaction,** *also known as a composition reaction, two or more substances combine to form a new compound.* This type of reaction is represented by the following general equation.

$$A + X \longrightarrow AX$$

A and X can be elements or compounds. AX is a compound. The following examples illustrate several kinds of synthesis reactions.

Reactions of Elements with Oxygen and Sulfur

One simple type of synthesis reaction is the combination of an element with oxygen to produce an *oxide* of the element. Almost all metals react with oxygen to form oxides. For example, when a thin strip of magnesium metal is placed in an open flame, it burns with bright white light. When the metal strip is completely burned, only a fine white powder of magnesium oxide is left. This chemical reaction, shown in **Figure 7** on the next page, is represented by the following equation.

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

The other Group 2 elements react in a similar manner, forming oxides with the formula MO, where M represents the metal. The Group 1 metals form oxides with the formula M_2O, for example, Li_2O. The Group 1 and Group 2 elements react similarly with sulfur, forming *sulfides* with the formulas M_2S and MS, respectively. Examples of these types of synthesis reactions are shown below.

$$16Rb(s) + S_8(s) \longrightarrow 8Rb_2S(s)$$
$$8Ba(s) + S_8(s) \longrightarrow 8BaS(s)$$

Some metals, such as iron, combine with oxygen to produce two different oxides.

$$2Fe(s) + O_2(g) \longrightarrow 2FeO(s)$$
$$4Fe(s) + 3O_2(g) \longrightarrow 2Fe_2O_3(s)$$

In the product of the first reaction, iron is in an oxidation state of +2. In the product of the second reaction, iron is in an oxidation state of +3. The particular oxide formed depends on the conditions surrounding the reactants. Both oxides are shown below in **Figure 8.**

Nonmetals also undergo synthesis reactions with oxygen to form oxides. Sulfur, for example, reacts with oxygen to form sulfur dioxide. And when carbon is burned in air, carbon dioxide is produced.

$$S_8(s) + 8O_2(g) \longrightarrow 8SO_2(g)$$
$$C(s) + O_2(g) \longrightarrow CO_2(g)$$

In a limited supply of oxygen, carbon monoxide is formed.

$$2C(s) + O_2(g) \longrightarrow 2CO(g)$$

Hydrogen reacts with oxygen to form dihydrogen monoxide, better known as water.

$$2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$$

(a) (b)

FIGURE 8 Iron, Fe, and oxygen, O_2, combine to form two different oxides: (a) iron(II) oxide, FeO, and (b) iron(III) oxide, Fe_2O_3.

(a) (b)

FIGURE 7 Magnesium, Mg, pictured in (a), undergoes a synthesis reaction with oxygen, O_2, in the air to produce magnesium oxide, MgO, as shown in (b).

Reactions of Metals with Halogens

Most metals react with the Group 17 elements, the halogens, to form either ionic or covalent compounds. For example, Group 1 metals react with halogens to form ionic compounds with the formula MX, where M is the metal and X is the halogen. Examples of this type of synthesis reaction include the reactions of sodium with chlorine and potassium with iodine.

$$2Na(s) + Cl_2(g) \longrightarrow 2NaCl(s)$$
$$2K(s) + I_2(g) \longrightarrow 2KI(s)$$

Group 2 metals react with the halogens to form ionic compounds with the formula MX_2.

$$Mg(s) + F_2(g) \longrightarrow MgF_2(s)$$
$$Sr(s) + Br_2(l) \longrightarrow SrBr_2(s)$$

The halogens undergo synthesis reactions with many different metals. Fluorine in particular is so reactive that it combines with almost all metals. For example, fluorine reacts with sodium to produce sodium fluoride. Similarly, it reacts with cobalt to form cobalt(III) fluoride and with uranium to form uranium(VI) fluoride.

$$2Na(s) + F_2(g) \longrightarrow 2NaF(s)$$
$$2Co(s) + 3F_2(g) \longrightarrow 2CoF_3(s)$$
$$U(s) + 3F_2(g) \longrightarrow UF_6(g)$$

Sodium fluoride, NaF, is added to municipal water supplies in trace amounts to provide fluoride ions, which help to prevent tooth decay in the people who drink the water. Cobalt(III) fluoride, CoF_3, is a strong fluorinating agent. And natural uranium is converted to uranium(VI) fluoride, UF_6, as the first step in the production of uranium for use in nuclear power plants.

FIGURE 9 Calcium hydroxide, a base, can be used to *neutralize* hydrochloric acid in your stomach. You will read more about acids, bases, and neutralization in Chapter 14.

Synthesis Reactions with Oxides

Active metals are highly reactive metals. Oxides of active metals react with water to produce metal hydroxides. For example, calcium oxide reacts with water to form calcium hydroxide, an ingredient in some stomach antacids, as shown in **Figure 9**.

$$CaO(s) + H_2O(l) \longrightarrow Ca(OH)_2(s)$$

Calcium oxide, CaO, also known as lime or quicklime, is manufactured in large quantities. The addition of water to lime to produce $Ca(OH)_2$, which is also known as slaked lime, is a crucial step in the setting of cement.

Many oxides of nonmetals in the upper right portion of the periodic table react with water to produce oxyacids. For example, sulfur dioxide, SO_2, reacts with water to produce sulfurous acid.

$$SO_2(g) + H_2O(l) \longrightarrow H_2SO_3(aq)$$

In air polluted with SO_2, sulfurous acid further reacts with oxygen to form sulfuric acid, one of the main ingredients in *acid rain.*

$$2H_2SO_3(aq) + O_2(g) \longrightarrow 2H_2SO_4(aq)$$

Certain metal oxides and nonmetal oxides react with each other in synthesis reactions to form salts. For example, calcium sulfite is formed by the reaction of calcium oxide and sulfur dioxide.

$$CaO(s) + SO_2(g) \longrightarrow CaSO_3(s)$$

Decomposition Reactions

In a **decomposition reaction,** *a single compound undergoes a reaction that produces two or more simpler substances.* Decomposition reactions are the opposite of synthesis reactions and are represented by the following general equation.

$$AX \longrightarrow A + X$$

AX is a compound. A and X can be elements or compounds.

Most decomposition reactions take place only when energy in the form of electricity or heat is added. Examples of several types of decomposition reactions are given in the following sections.

Decomposition of Binary Compounds

The simplest kind of decomposition reaction is the decomposition of a binary compound into its elements. We have already examined one example of a decomposition reaction. **Figure 5** on page 270 shows that passing an electric current through water will decompose the water into its constituent elements, hydrogen and oxygen.

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

The decomposition of a substance by an electric current is called **electrolysis.**

Oxides of the less-active metals, which are located in the lower center of the periodic table, decompose into their elements when heated. Joseph Priestley discovered oxygen through such a decomposition reaction in 1774, when he heated mercury(II) oxide to produce mercury and oxygen.

$$2HgO(s) \xrightarrow{\Delta} 2Hg(l) + O_2(g)$$

This reaction is shown in **Figure 10** on the following page.

FIGURE 10 When mercury(II) oxide (the red-orange substance in the bottom of the test tube) is heated, it decomposes into oxygen and metallic mercury, which can be seen as droplets on the inside wall of the test tube.

Decomposition of Metal Carbonates

When a metal carbonate is heated, it breaks down to produce a metal oxide and carbon dioxide gas. For example, calcium carbonate decomposes to produce calcium oxide and carbon dioxide.

$$CaCO_3(s) \xrightarrow{\Delta} CaO(s) + CO_2(g)$$

Decomposition of Metal Hydroxides

All metal hydroxides except those containing Group 1 metals decompose when heated to yield metal oxides and water. For example, calcium hydroxide decomposes to produce calcium oxide and water.

$$Ca(OH)_2(s) \xrightarrow{\Delta} CaO(s) + H_2O(g)$$

Decomposition of Metal Chlorates

When a metal chlorate is heated, it decomposes to produce a metal chloride and oxygen. For example, potassium chlorate, $KClO_3$, decomposes in the presence of the catalyst $MnO_2(s)$ to produce potassium chloride and oxygen.

$$2KClO_3(s) \xrightarrow[MnO_2(s)]{\Delta} 2KCl(s) + 3O_2(g)$$

Decomposition of Acids

Certain acids decompose into nonmetal oxides and water. Carbonic acid is unstable and decomposes readily at room temperature to produce carbon dioxide and water.

$$H_2CO_3(aq) \longrightarrow CO_2(g) + H_2O(l)$$

When heated, sulfuric acid decomposes into sulfur trioxide and water.

$$H_2SO_4(aq) \xrightarrow{\Delta} SO_3(g) + H_2O(l)$$

Sulfurous acid, H_2SO_3, decomposes similarly.

Single-Displacement Reactions

In a **single-displacement reaction,** *also known as a replacement reaction, one element replaces a similar element in a compound.* Many single-displacement reactions take place in aqueous solution. The amount of energy involved in this type of reaction is usually smaller than the amount involved in synthesis or decomposition reactions. Single-displacement reactions can be represented by the following general equations.

$$A + BX \longrightarrow AX + B$$
or
$$Y + BX \longrightarrow BY + X$$

A, B, X, and Y are elements. AX, BX, and BY are compounds.

Displacement of a Metal in a Compound by Another Metal

Aluminum is more active than lead. When solid aluminum is placed in aqueous lead(II) nitrate, $Pb(NO_3)_2(aq)$, the aluminum replaces the lead. Solid lead and aqueous aluminum nitrate are formed.

$$2Al(s) + 3Pb(NO_3)_2(aq) \longrightarrow 3Pb(s) + 2Al(NO_3)_3(aq)$$

Displacement of Hydrogen in Water by a Metal

The most-active metals, such as those in Group 1, react vigorously with water to produce metal hydroxides and hydrogen. For example, sodium reacts with water to form sodium hydroxide and hydrogen gas.

$$2Na(s) + 2H_2O(l) \longrightarrow 2NaOH(aq) + H_2(g)$$

Less-active metals, such as iron, react with steam to form a metal oxide and hydrogen gas.

$$3Fe(s) + 4H_2O(g) \longrightarrow Fe_3O_4(s) + 4H_2(g)$$

Displacement of Hydrogen in an Acid by a Metal

The more-active metals react with certain acidic solutions, such as hydrochloric acid and dilute sulfuric acid, replacing the hydrogen in the acid. The reaction products are a metal compound (a salt) and hydrogen gas. For example, when solid magnesium reacts with hydrochloric acid, as shown in **Figure 11,** the reaction products are hydrogen gas and aqueous magnesium chloride.

$$Mg(s) + 2HCl(aq) \longrightarrow H_2(g) + MgCl_2(aq)$$

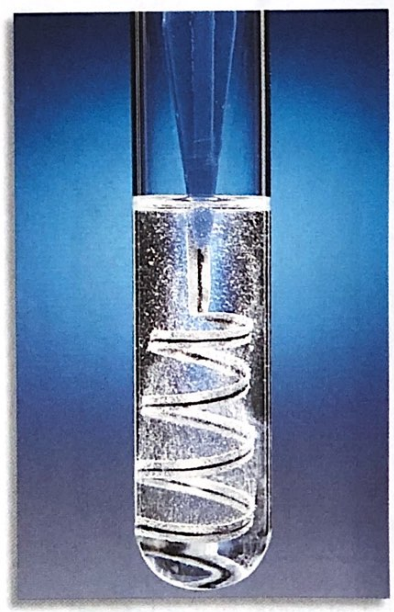

FIGURE 11 In this single-displacement reaction, the hydrogen in hydrochloric acid, HCl, is replaced by magnesium, Mg.

Displacement of Halogens

In another type of single-displacement reaction, one halogen replaces another halogen in a compound. Fluorine is the most-active halogen. As such, it can replace any of the other halogens in their compounds. Each halogen is less active than the one above it in the periodic table. Therefore, in Group 17 each element can replace any element below it, but not any element above it. For example, while chlorine can replace bromine in potassium bromide, it cannot replace fluorine in potassium fluoride. The reaction of chlorine with potassium bromide produces bromine and potassium chloride, whereas the combination of fluorine and sodium chloride produces sodium fluoride and solid chlorine.

$$Cl_2(g) + 2KBr(aq) \longrightarrow 2KCl(aq) + Br_2(l)$$
$$F_2(g) + 2NaCl(aq) \longrightarrow 2NaF(aq) + Cl_2(g)$$
$$Br_2(l) + KCl(aq) \longrightarrow \text{no reaction}$$

Double-Displacement Reactions

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Topic: Precipitate
Code: HC61201

In **double-displacement reactions,** *the ions of two compounds exchange places in an aqueous solution to form two new compounds.* One of the compounds formed is usually a precipitate, an insoluble gas that bubbles out of the solution, or a molecular compound, usually water. The other compound is often soluble and remains dissolved in solution. A double-displacement reaction is represented by the following general equation.

$$AX + BY \longrightarrow AY + BX$$

A, X, B, and Y in the reactants represent ions. AY and BX represent ionic or molecular compounds.

Formation of a Precipitate

The formation of a precipitate occurs when the cations of one reactant combine with the anions of another reactant to form an insoluble or slightly soluble compound. For example, when an aqueous solution of potassium iodide is added to an aqueous solution of lead(II) nitrate, the yellow precipitate lead(II) iodide forms. This is shown in **Figure 12.**

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

The precipitate forms as a result of the very strong attractive forces between the Pb^{2+} cations and the I^- anions. The other product is the water-soluble salt potassium nitrate, KNO_3. The potassium and nitrate ions do not take part in the reaction. They remain in solution as aqueous ions. The guidelines that help identify which ions form a precipitate and which ions remain in solution are developed in Chapter 13.

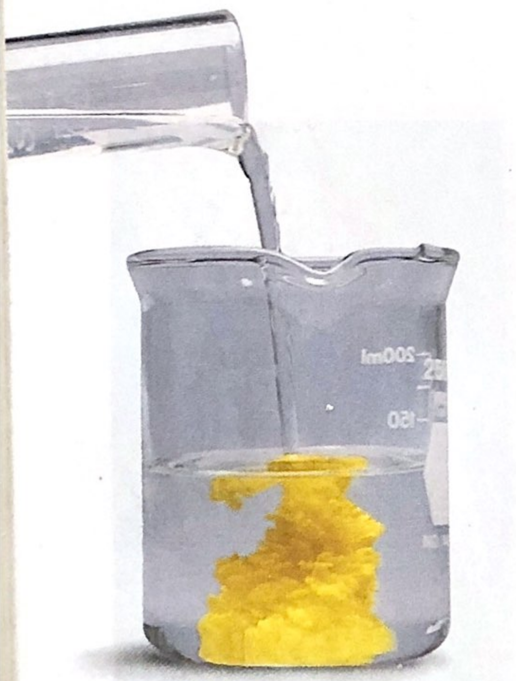

FIGURE 12 The double-displacement reaction between aqueous lead(II) nitrate, $Pb(NO_3)_2(aq)$, and aqueous potassium iodide, $KI(aq)$, yields the precipitate lead(II) iodide, $PbI_2(s)$.

Formation of a Gas

In some double-displacement reactions, one of the products is an insoluble gas that bubbles out of the mixture. For example, iron(II) sulfide reacts with hydrochloric acid to form hydrogen sulfide gas and iron(II) chloride.

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

Formation of Water

In some double-displacement reactions, a very stable molecular compound, such as water, is one of the products. For example, hydrochloric acid reacts with an aqueous solution of sodium hydroxide to yield aqueous sodium chloride and water.

$$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

Combustion Reactions

In a **combustion reaction,** *a substance combines with oxygen, releasing a large amount of energy in the form of light and heat.* The combustion of hydrogen is shown below in **Figure 13.** The reaction's product is water vapor.

$$2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$$

The burning of natural gas, propane, gasoline, and wood are also examples of combustion reactions. For example, the burning of propane, C_3H_8, results in the production of carbon dioxide and water vapor.

$$C_3H_8(g) + 5O_2(g) \longrightarrow 3CO_2(g) + 4H_2O(g)$$

(a) (b)

FIGURE 13 (a) The candle supplies heat to the hydrogen and oxygen in the balloon, triggering the explosive combustion reaction shown in (b).

Chemistry in Action

Fluoridation and Tooth Decay

The main component of tooth enamel is a mineral called hydroxyapatite, $Ca_5(PO_4)_3OH$. Some foods contain acids or produce acids in the mouth, and acid dissolves tooth enamel, which leads to tooth decay. One way to help prevent tooth decay is by using fluoride. Fluoride reacts with hydroxyapatite in a double-displacement reaction. It displaces the OH^- group in hydroxyapatite to produce fluorapatite, $Ca_5(PO_4)_3F$. Studies show that calcium fluorapatite is about 20% less soluble than hydroxyapatite in acid. Therefore, fluoride lowers the incidence of tooth decay.

QuickLAB

Wear safety goggles and an apron.

Balancing Equations Using Models

Question

How can molecular models and formula-unit ionic models be used to balance chemical equations and classify chemical reactions?

Procedure

Examine the partial equations in Groups A–E. Using different-colored gumdrops to represent atoms of different elements, make models of the reactions by connecting the appropriate "atoms" with toothpicks. Use your models to (1) balance equations (a) and (b) in each group, (2) determine the products for reaction (c) in each group, and (3) complete and balance each equation (c). Finally, (4) classify each group of reactions by type.

Group A

a. $H_2 + Cl_2 \longrightarrow HCl$

b. $Mg + O_2 \longrightarrow MgO$

c. $BaO + H_2O \longrightarrow$ ______

Group B

a. $H_2CO_3 \longrightarrow CO_2 + H_2O$

b. $KClO_3 \longrightarrow KCl + O_2$

c. $H_2O \xrightarrow{\text{electricity}}$ ______

Group C

a. $Ca + H_2O \longrightarrow Ca(OH)_2 + H_2$

b. $KI + Br_2 \longrightarrow KBr + I_2$

c. $Zn + HCl \longrightarrow$ ______

Group D

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

b. $FeS + HCl \longrightarrow FeCl_2 + H_2S$

c. $H_2SO_4 + KOH \longrightarrow$ ______

Group E

a. $CH_4 + O_2 \longrightarrow CO_2 + H_2O$

b. $CO + O_2 \longrightarrow CO_2$

c. $C_3H_8 + O_2 \longrightarrow$ ______

Materials

- large and small
  at least four diff
- toothpicks

SECTION REVIEW

1. List five types of chemical reactions.

2. Classify each of the following reactions as a synthesis, decomposition, single-displacement, double-displacement, or combustion reaction:

a. $N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$

b. $2Li(s) + 2H_2O(l) \longrightarrow 2LiOH(aq) + H_2(g)$

c. $2NaNO_3(s) \longrightarrow 2NaNO_2(s) + O_2(g)$

d. $2C_6H_{14}(l) + 19O_2(g) \longrightarrow 12CO_2(g) + 14H_2O(l)$

3. For each of the following reactions, identify the missing reactant(s) or products(s) and then balance the resulting equation. Note that each empty slot may require one or more substances.

a. synthesis: ______ $\longrightarrow Li_2O$

b. decomposition: $Mg(ClO_3)_2 \longrightarrow$ ______

c. double displacement: $HNO_3 + Ca(OH)_2 \longrightarrow$ ______

d. combustion: $C_5H_{12} + O_2 \longrightarrow$ ______

4. For each of the following reactions, write the missing product(s) and then balance the resulting equation. Identify each reaction by type.

a. $Br_2 + KI \longrightarrow$ ______

b. $NaClO_3 \longrightarrow$ ______

c. $C_7H_{14} + O_2 \longrightarrow$ ______

d. $CuCl_2 + Na_2S \longrightarrow$ ______

Critical Thinking

5. INFERRING RELATIONSHIPS In an experiment, an iron sample is oxidized to iron(III) oxide by oxygen, which is generated in the thermal decomposition of potassium chlorate. Write the two chemical reactions in the correct sequence.

17. For each of the following synthesis reactions, identify the missing reactant(s) or product(s), and then balance the resulting equation.
    a. $Mg + \_\_\_\_ \longrightarrow MgO$
    b. $\_\_\_\_ + O_2 \longrightarrow Fe_2O_3$
    c. $Li + Cl_2 \longrightarrow \_\_\_\_$
    d. $Ca + \_\_\_\_ \longrightarrow CaI_2$

Types of Chemical Reactions

SECTION 2 REVIEW

18. Define and give general equations for the five basic types of chemical reactions introduced in Chapter 8.
19. How are most decomposition reactions initiated?
20. A substance is decomposed by an electric current. What is the name of this type of reaction?
21. a. In what environment do many single-displacement reactions commonly occur?
    b. In general, how do single-displacement reactions compare with synthesis and decomposition reactions in terms of the amount of energy involved?

PRACTICE PROBLEMS

22. Complete each of the following synthesis reactions by writing both a word equation and a chemical equation.
    a. sodium + oxygen ⟶ ____
    b. magnesium + fluorine ⟶ ____
23. Complete and balance the equations for the following decomposition reactions:
    a. $HgO \xrightarrow{\Delta}$
    b. $H_2O(l) \xrightarrow{\text{electricity}}$
    c. $Ag_2O \xrightarrow{\Delta}$
    d. $CuCl_2 \xrightarrow{\text{electricity}}$
24. Complete and balance the equations for the following single-displacement reactions:
    a. $Zn + Pb(NO_3)_2 \longrightarrow \_\_\_\_$
    b. $Al + Hg(CH_3COO)_2 \longrightarrow \_\_\_\_$
    c. $Al + NiSO_4 \longrightarrow \_\_\_\_$
    d. $Na + H_2O \longrightarrow \_\_\_\_$
25. Complete and balance the equations for the following double-displacement reactions:
    a. $AgNO_3(aq) + NaCl(aq) \longrightarrow \_\_\_\_$
    b. $Mg(NO_3)_2(aq) + KOH(aq) \longrightarrow \_\_\_\_$
    c. $LiOH(aq) + Fe(NO_3)_3(aq) \longrightarrow \_\_\_\_$
26. Complete and balance the equations for the following combustion reactions:
    a. $CH_4 + O_2 \longrightarrow \_\_\_\_$
    b. $C_3H_6 + O_2 \longrightarrow \_\_\_\_$
    c. $C_5H_{12} + O_2 \longrightarrow \_\_\_\_$
27. Write and balance each of the following equations, and then identify each by type.
    a. hydrogen + iodine ⟶ hydrogen iodide
    b. lithium + hydrochloric acid ⟶ lithium chloride + hydrogen
    c. sodium carbonate ⟶ sodium oxide + carbon dioxide
    d. mercury(II) oxide ⟶ mercury + oxygen
    e. magnesium hydroxide ⟶ magnesium oxide + water
28. Identify the compound that could undergo decomposition to produce the following products, and then balance the final equation.
    a. magnesium oxide and water
    b. lead(II) oxide and water
    c. lithium chloride and oxygen
    d. barium chloride and oxygen
    e. nickel chloride and oxygen
29. In each of the following combustion reactions, identify the missing reactant(s), product(s), or both, and then balance the resulting equation.
    a. $C_3H_8 + \_\_\_\_ \longrightarrow \_\_\_\_ + H_2O$
    b. $\_\_\_\_ + 8O_2 \longrightarrow 5CO_2 + 6H_2O$
    c. $C_2H_5OH + \_\_\_\_ \longrightarrow \_\_\_\_ + \_\_\_\_$
30. Complete and balance the equations for the following reactions, and then identify each by type.
    a. zinc + sulfur ⟶ ____
    b. silver nitrate + potassium iodide ⟶ ____
    c. toluene, C_7H_8 + oxygen ⟶ ____
    d. nonane, C_9H_{20} + oxygen ⟶ ____

Activity Series of the Elements

SECTION 3 REVIEW

31. a. What is meant by the *activity* of an element?
    b. How does this description differ for metals and nonmetals?

32. a. What is an activity series of elements?
b. What is the basis for the ordering of the elements in the activity series?

33. a. What chemical principle is the basis for the activity series of metals?
b. What is the significance of the distance between two metals in the activity series?

PRACTICE PROBLEMS

34. Based on the activity series of metals and halogens, which element within each pair is more likely to replace the other in a compound?
a. K and Na
b. Al and Ni
c. Bi and Cr
d. Cl and F
e. Au and Ag
f. Cl and I
g. Fe and Sr
h. I and F

35. Using the activity series in **Table 3** on page 286, predict whether each of the possible reactions listed below will occur. For the reactions that will occur, write the products and balance the equation.
a. $Ni(s) + CuCl_2(aq) \longrightarrow$ ______
b. $Zn(s) + Pb(NO_3)_2(aq) \longrightarrow$ ______
c. $Cl_2(g) + KI(aq) \longrightarrow$ ______
d. $Cu(s) + FeSO_4(aq) \longrightarrow$ ______
e. $Ba(s) + H_2O(l) \longrightarrow$ ______

36. Use the activity series to predict whether each of the following synthesis reactions will occur, and write the chemical equations for those predicted to occur.
a. $Ca(s) + O_2(g) \longrightarrow$ ______
b. $Ni(s) + O_2(g) \longrightarrow$ ______
c. $Au(s) + O_2(g) \longrightarrow$ ______

MIXED REVIEW

37. Ammonia reacts with oxygen to yield nitrogen and water.
$$4NH_3(g) + 3O_2(g) \longrightarrow 2N_2(g) + 6H_2O(l)$$
Given this chemical equation, as well as the number of moles of the reactant or product indicated below, determine the number of moles of all remaining reactants and products.
a. 3.0 mol O_2
b. 8.0 mol NH_3
c. 1.0 mol N_2
d. 0.40 mol H_2O

38. Complete the following synthesis reactions by writing both the word and chemical equation for each:
a. potassium + chlorine $\longrightarrow$ ______
b. hydrogen + iodine $\longrightarrow$ ______
c. magnesium + oxygen $\longrightarrow$ ______

39. Use the activity series to predict which metal—Sn, Mn, or Pt—would be the best choice as a container for an acid.

40. Aqueous sodium hydroxide is produced commercially by the electrolysis of aqueous sodium chloride. Hydrogen and chlorine gases are also produced. Write the balanced chemical equation for the production of sodium hydroxide. Include the physical states of the reactants and products.

41. Balance each of the following:
a. $Ca(OH)_2 + (NH_4)_2SO_4 \longrightarrow CaSO_4 + NH_3 + H_2O$
b. $C_2H_6 + O_2 \longrightarrow CO_2 + H_2O$
c. $Cu_2S + O_2 \longrightarrow Cu_2O + SO_2$
d. $Al + H_2SO_4 \longrightarrow Al_2(SO_4)_3 + H_2$

42. Use the activity series to predict whether each of the following reactions will occur, and write the balanced chemical equations for those predicted to occur.
a. $Al(s) + O_2(g) \longrightarrow$ ______
b. $Pb(s) + ZnCl_2(s) \longrightarrow$ ______

43. Complete and balance the equations for the following reactions, and identify the type of reaction that each equation represents.
a. $(NH_4)_2S(aq) + ZnCl_2(aq) \longrightarrow$ ______ $+ ZnS(s)$
b. $Al(s) + Pb(NO_3)_2(aq) \longrightarrow$ ______
c. $Ba(s) + H_2O(l) \longrightarrow$ ______
d. $Cl_2(g) + KBr(aq) \longrightarrow$ ______
e. $NH_3(g) + O_2(g) \xrightarrow{Pt} NO(g) + H_2O(l)$
f. $H_2O(l) \longrightarrow H_2(g) + O_2(g)$

44. Write and balance each of the following equations, and then identify each by type.
a. copper + chlorine $\longrightarrow$ copper(II) chloride
b. calcium chlorate $\longrightarrow$ calcium chloride + oxygen
c. lithium + water $\longrightarrow$ lithium hydroxide + hydrogen
d. lead(II) carbonate $\longrightarrow$ lead(II) oxide + carbon dioxide