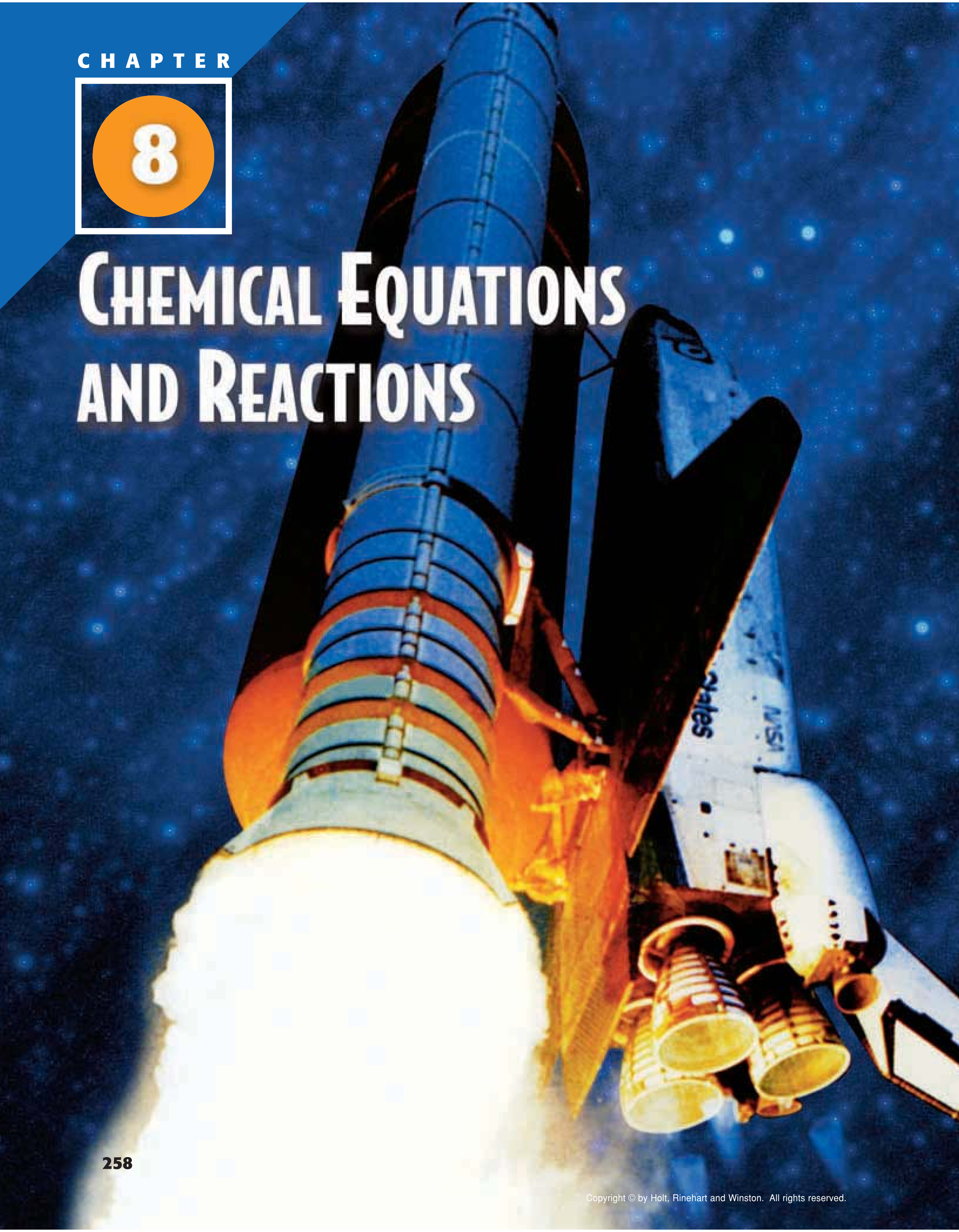
CHAPTER 8

Chemical Equations and Reactions



With an eruption of flames and hot gases, a space shuttle leaves the ground on its way into orbit. The brightness and warmth of the flame clearly indicates that a change is occurring. From the jets of the shuttle itself, blue flames emerge. These flames are the result of a reaction between hydrogen and oxygen. The sight is awesome and beautiful. In this chapter, you will learn about chemical reactions, such as the ones that send a space shuttle into space.

START-UP ACTIVITY

SAFETY PRECAUTIONS

Observing a Chemical Reaction

PROCEDURE

1. Place about 5 g (1 tsp) of **baking soda** into a **sealable plastic bag.**
2. Place about 5 mL (1 tsp) of **vinegar** into a **plastic film canister.** Secure the lid.
3. Place the canister into the bag. Squeeze the air out of the bag, and tightly seal the bag.
4. Use a **balance** to determine the total mass of the bag and the bag's contents. Make a note of this value.
5. Open the canister without opening the bag, and allow the vinegar and baking soda to mix.
6. When the reaction has stopped, measure and record the total mass of the bag and the bag's contents.

ANALYSIS

1. What evidence shows that a chemical reaction has taken place?
2. Compare the masses of the bag and its contents before and after the reaction. What does this result demonstrate about chemical reactions?

Pre-Reading Questions

1. **What are some signs that a chemical change may be taking place?**
2. **What are the reactants of a reaction? What are the products of a reaction?**
3. **Describe the law of conservation of mass.**
4. **Define the terms *synthesis* and *decomposition,* and describe what you would expect to happen in each of these types of reactions.**

CONTENTS 8

SECTION

1 Describing Chemical Reactions

KEY TERMS

- **chemical reaction**
- **chemical equation**

OBJECTIVES

1. **List** evidence that suggests that a chemical reaction has occurred and evidence that proves that a chemical reaction has occurred.
2. **Describe** a chemical reaction by using a word equation and a formula equation.
3. **Interpret** notations in formula equations, such as those relating to states of matter or reaction conditions.

Chemical Change

You witness chemical changes taking place in iron that rusts, in milk that turns sour, and in a car engine that burns gasoline. The processes of digestion and respiration in your body are the result of chemical changes.

A **chemical reaction** is the process by which one or more substances change into one or more new substances whose chemical and physical properties differ from those of the original substances. In any chemical reaction, the original substances, which can be elements or compounds, are known as *reactants*. The substances created are called *products*. A common example of a chemical reaction is shown in **Figure 1.**

chemical reaction

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

Figure 1
Chemical changes occur as wood burns. Two products formed are carbon dioxide and water.

Evidence of a Chemical Reaction

It's not always easy to tell that a chemical change is happening, but there are some signs to look for, which are summarized in **Table 1.** For example, certain signs indicate that wood burning in a campfire is undergoing a chemical change. Smoke rises from the wood, and a hissing sound is made. Energy that lights up the campsite and warms the air around the fire is released. The surface of the wood changes color as the wood burns. Eventually, all that remains of the firewood is a grey, powdery ash.

In **Figure 2,** you can see copper reacting with nitric acid. Again, several clues suggest that a chemical reaction is taking place. The color of the solution changes from colorless to blue. The solution bubbles and fizzes as a gas forms. The copper seems to be used up as the reaction continues.

Sometimes, the evidence for a chemical change is indirect. When you place a new battery in a flashlight, you don't see any changes in the battery. However, when you turn the flashlight on, electrical energy causes the filament in the bulb to heat up and emit light. This release of electrical energy is a clue that a chemical reaction is taking place in the battery. Although these signs suggest a change may be chemical, they do not prove that the change is chemical.

Table 1 Evidence of Chemical Change

Changes in energy	Formation of new substances
release of energy as heat	formation of a gas
release of energy as light	formation of a precipitate (an insoluble solid)
production of sound	change in color
reduction or increase of temperature	change in odor
absorption or release of electrical energy	

Chemical Reaction Versus Physical Change

For proof of a chemical change, you need a chemical analysis to show that at least one new substance forms. The properties of the new substance—such as density, melting point, or boiling point—must differ from those of the original substances.

Even when evidence suggests a chemical change, you can't be sure immediately. For example, when paints mix, the color of the resulting paint differs from the color of the original paints. But the change is physical—the substances making up the paints have not changed. When you boil water, the water absorbs energy and a gas forms. But the gas still consists of water molecules, so a new substance has not formed. Even though they demonstrate some of the signs of a chemical change, all changes of state, including evaporation, condensation, melting, and freezing, are physical changes.

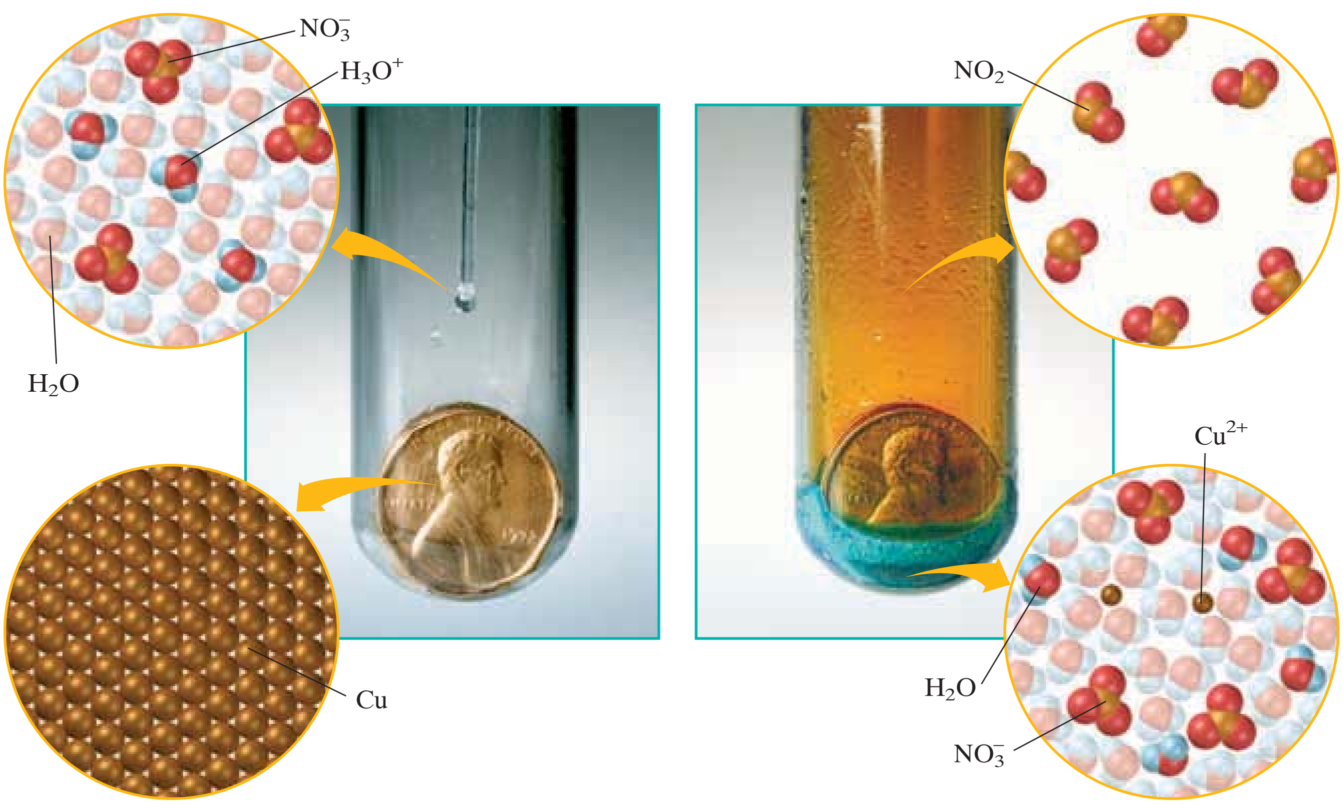


Figure 2
When copper reacts with nitric acid, several signs of a reaction are seen. A toxic, brown gas is produced, and the color of the solution changes.

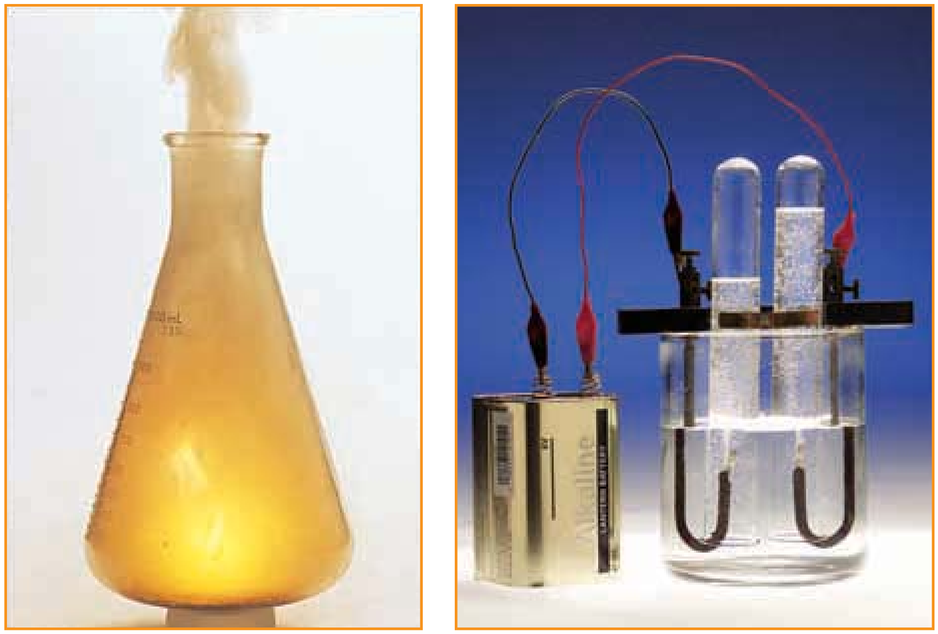


Figure 3
Energy is released as the elements sodium and chlorine react to form the compound sodium chloride. Breaking down water into hydrogen and oxygen requires the input of electrical energy.

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Reactions and Energy Changes

Chemical reactions either release energy or absorb energy as they happen, as shown in **Figure 3.** A burning campfire and burning natural gas are examples of reactions that release energy. Natural gas, which is mainly methane, undergoes the following reaction:

$$\text{methane} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water} + \text{energy}$$

Notice that when energy is released, it can be considered a product of the reaction.

If the energy required is not too great, some other reactions that absorb energy will occur because they take energy from their surroundings. An example is the decomposition of dinitrogen tetroxide, which occurs at room temperature.

$$\text{dinitrogen tetroxide} + \text{energy} \longrightarrow \text{nitrogen dioxide}$$

Notice that when energy is absorbed, it can be considered a reactant of the reaction.

Reactants Must Come Together

You cannot kick a soccer ball unless your shoe contacts the ball. Chemical reactions are similar. Molecules and atoms of the reactants must come into contact with each other for a reaction to take place. Think about what happens when a safety match is lighted, as shown in **Figure 4.** One reactant, potassium chlorate ($KClO_3$) is on the match head. The other reactant, phosphorus, P_4, is on the striking surface of the matchbox. The reaction begins when the two substances come together by rubbing the match head across the striking surface. If the reactants are kept apart, the reaction will not happen. Under most conditions, safety matches do not ignite by themselves.

Figure 4
The reactants $KClO_3$ (on the match head) and P_4 (on the striking surface) must be brought together for a safety match to ignite.

Constructing a Chemical Equation

You know that symbols represent elements, and formulas represent compounds. In the same way, equations are used to represent chemical reactions. A correctly written **chemical equation** shows the chemical formulas and relative amounts of all reactants and products. Constructing a chemical equation usually begins with writing a word equation. This word equation contains the names of the reactants and of the products separated by an arrow. The arrow means "forms" or "produces." Then, the chemical formulas are substituted for the names. Finally, the equation is balanced so that it obeys the law of conservation of mass. The numbers of atoms of each element must be the same on both sides of the arrow.

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

Writing a Word Equation or a Formula Equation

The first step in writing a chemical equation is to write a word equation. To write the word equation for a reaction, you must write down the names of the reactants and separate the names with plus signs. An arrow is used to separate the reactants from the products. Then, the names of the products are written to the right of the arrow and are separated by plus signs. The word equation for the reaction of methane with oxygen to form carbon dioxide and water is written as follows:

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

To convert this word equation into a formula equation, use the formulas for the reactants and for the products. The formulas for methane, oxygen, carbon dioxide, and water replace the words in the word equation to make a formula equation. The word *methane* carries no quantitative meaning, but the formula CH_4 means a molecule of methane. This change gives the unbalanced formula equation below. The question marks indicate that we do not yet know the number of molecules of each substance.

$$?CH_4 + ?O_2 \longrightarrow ?CO_2 + ?H_2O$$

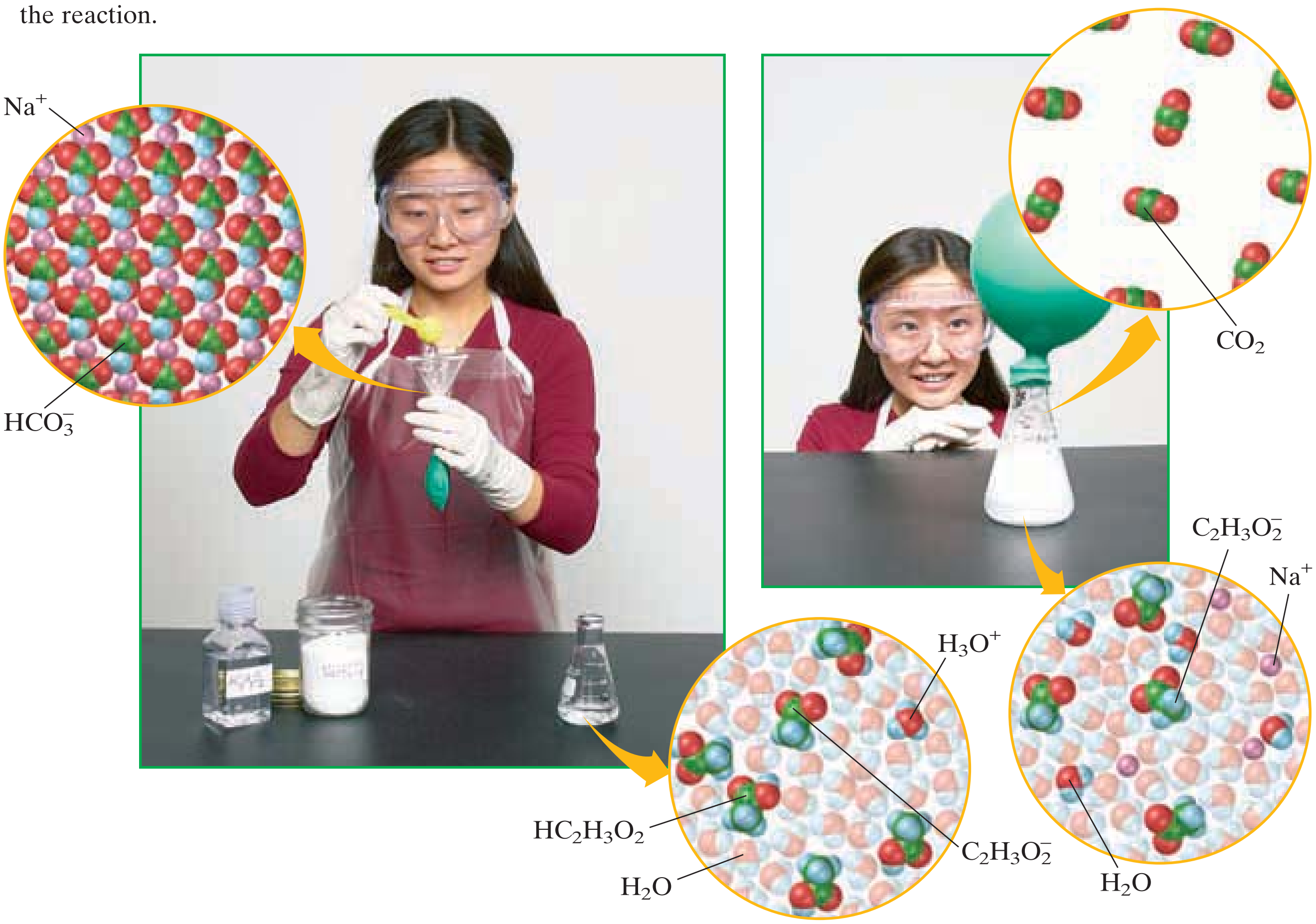
Equations and Reaction Information

A chemical equation indicates the amount of each substance in the reaction. But it can also provide other valuable information about the substances or conditions, such as temperature or pressure, that are needed for the reaction.

Equations Are Like Recipes

Imagine that you need to bake brownies for a party. Of course, you would want to follow a recipe closely to be sure that your brownies turn out right. You must know which ingredients to use and how much of each ingredient to use. Special instructions, such as whether the ingredients should be chilled or at room temperature when you mix them, are also provided in the recipe.

Chemical equations have much in common with a recipe. Like a recipe, any instructions shown in an equation can help you or a chemist be sure the reaction turns out the way it should, as shown in **Figure 5.** A balanced equation indicates the relative amounts of reactants and products in the reaction. As discussed below, even more information can be shown by an equation.



$$NaHCO_3(s) + HC_2H_3O_2(aq) \longrightarrow NaC_2H_3O_2(aq) + CO_2(g) + H_2O(l)$$

Figure 5
The equation for the reaction between baking soda and vinegar provides a lot of information about the reaction.

Equations Can Show Physical States and Reaction Conditions

The recipe for brownies will specify whether each ingredient should be used in a solid or liquid form. The recipe also may state that the batter should bake at 400°F for 20 min. Additional instructions tell what to do if you are baking at high elevation. Chemical equations are similar. Equations for chemical reactions often list the physical state of each reactant and the conditions under which the reaction takes place.

Look closely at the equation that represents the reaction of baking soda with vinegar.

$$NaHCO_3(s) + HC_2H_3O_2(aq) \longrightarrow NaC_2H_3O_2(aq) + CO_2(g) + H_2O(l)$$

Baking soda, sodium hydrogen carbonate, is a solid, so the formula is followed by the symbol (s). Vinegar, the other reactant, is acetic acid dissolved in water—an aqueous solution. Sodium acetate, one of the products, remains in aqueous solution. So, the formulas for vinegar and sodium acetate are followed by the symbol (aq). Another product, carbon dioxide, is a gas and is marked with the symbol (g). Finally, water is produced in the liquid state, so its formula is followed by the symbol (l).

When information about the conditions of the reaction is desired, the arrow is a good place to show it. Several symbols are used to show the conditions under which a reaction happens. Consider the preparation of ammonia in a commercial plant.

$$N_2(g) + 3H_2(g) \underset{\text{catalyst}}{\overset{350°\text{C}, 25\,000 \text{ kPa}}{\rightleftarrows}} 2NH_3(g)$$

The double arrow indicates that reactions occur in both the forward and reverse directions and that the final result is a mixture of all three substances. The temperature at which the reaction occurs is 350°C. The pressure at which the reaction occurs, 25 000 kPa, is also shown above the arrow. A catalyst is used to speed the reaction, so the catalyst is mentioned, too. Other symbols used in equations are shown in **Table 2.**

Table 2 State Symbols and Reaction Conditions

Symbol	Meaning
(s), (l), (g)	substance in the solid, liquid, or gaseous state
(aq)	substance in aqueous solution (dissolved in water)
$\longrightarrow$	"produces" or "yields," indicating result of reaction
$\rightleftarrows$	reversible reaction in which products can reform into reactants; final result is a mixture of products and reactants
$\xrightarrow{\Delta}$ or $\xrightarrow{heat}$	reactants are heated; temperature is not specified
$\xrightarrow{Pd}$	name or chemical formula of a catalyst, added to speed a reaction

Refer to Appendix A to see more symbols used in equations.

When to Use the Symbols

Although chemical equations can be packed with information, most of the ones you will work with will show only the formulas of reactants and products. However, sometimes you need to know the states of the substances. Recognizing and knowing the symbols used will help you understand these equations better. And learning these symbols now will make learning new information that depends on these symbols easier.

1 Section Review

UNDERSTANDING KEY IDEAS

1. What is a chemical reaction?
2. What is the only way to prove that a chemical reaction has occurred?
3. When water boils on the stove, does a chemical change or a physical change take place?
4. Give four examples of evidence that suggests that a chemical change probably is occurring.
5. When propane gas, C_3H_8, is burned with oxygen, the products are carbon dioxide and water. Write an unbalanced formula equation for the reaction.
6. Assume that liquid water forms in item 5. Write a formula equation for the reaction that shows the physical states of all compounds.
7. What does "Mn" above the arrow in a formula equation mean?
8. What symbol is used in a chemical equation to indicate the phrase "reacts with"?
9. Solid silicon and solid magnesium chloride form when silicon tetrachloride gas reacts with magnesium metal. Write a word equation and an unbalanced formula equation. Include all of the appropriate notations.
10. Magnesium oxide forms from magnesium metal and oxygen gas. Write a word equation and an unbalanced formula equation. Include all of the appropriate notations.

CRITICAL THINKING

11. Describe evidence that burning gasoline in an engine is a chemical reaction.
12. Describe evidence that chemical reactions take place during a fireworks display.
13. The directions on a package of an epoxy glue say to mix small amounts of liquid from two separate tubes. Either liquid alone does not work as a glue. Should the liquids be considered reactants? Explain your answer.
14. When sulfur is heated until it melts and then is allowed to cool, beautiful yellow crystals form. How can you prove that this change is physical?
15. Besides the reactant, what is needed for the electrolysis experiment that breaks down water?
16. Write the word equation for the electrolysis of water, and indicate the physical states and condition(s) of the reaction.
17. For each of the following equations, write a sentence that describes the reaction, including the physical states and reaction conditions.

    a. $Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$

    b. $CaCl_2(aq) + Na_2CO_3(aq) \longrightarrow CaCO_3(s) + 2NaCl(aq)$

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

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

SECTION

2 Balancing Chemical Equations

KEY TERMS

- **coefficient**

OBJECTIVES

1. **Relate** the conservation of mass to the rearrangement of atoms in a chemical reaction.
2. **Write** and interpret a balanced chemical equation for a reaction, and relate conservation of mass to the balanced equation.

Reactions Conserve Mass

A basic law of science is the law of conservation of mass. This law states that in ordinary chemical or physical changes, mass is neither created nor destroyed. If you add baking soda to vinegar, they react to release carbon dioxide gas, which escapes into the air. But if you collect all of the products of the reaction, you find that their total mass is the same as the total mass of the reactants.

Topic Link

Refer to the "The Science of Chemistry" chapter for more information about the law of conservation of mass.

Reactions Rearrange Atoms

This law is based on the fact that the products and the reactants of a reaction are made up of the same number and kinds of atoms. The atoms are just rearranged and connected differently. Look at the formula equation for the reaction of sodium with water.

$$?Na + ?H_2O \longrightarrow ?NaOH + ?H_2$$

The same types of atoms appear in both the reactants and products. However, **Table 3** shows that the number of each type of atom is not the same on both sides of the equation. To show that a reaction satisfies the law of conservation of mass, its equation must be *balanced*.

Table 3 Counting Atoms in an Equation

	Reactants	Products	Balanced?
Unbalanced formula equation	$Na + H_2O$	$NaOH + H_2$	
Sodium atoms	1	1	yes
Hydrogen atoms	2	3	no
Oxygen atoms	1	1	yes

Balancing Equations

To balance an equation, you need to make the number of atoms for each element the same on the reactants' side and on the products' side. But there is a catch. You cannot change the formulas of any of the substances. For example, you could not change CO_2 to CO_3. You can only place numbers called *coefficients* in front of the formulas. A **coefficient** multiplies the number of atoms of each element in the formula that follows. For example, the formula H_2O represents 2 atoms of hydrogen and 1 atom of oxygen. But $2H_2O$ represents 2 molecules of water, for a total of 4 atoms of hydrogen and 2 atoms of oxygen. The formula $3Ca(NO_3)_2$ represents 3 calcium atoms, 6 nitrogen atoms, and 18 oxygen atoms. Look at **Skills Toolkit 1** as you balance equations.

coefficient

a small whole number that appears as a factor in front of a formula in a chemical equation

1 SKILLS Toolkit

Balancing Chemical Equations

1. Identify reactants and products.
- If no equation is provided, identify the reactants and products and write an unbalanced equation for the reaction. (You may find it helpful to write a word equation first.)
- If not all chemicals are described in the problem, try to predict the missing chemicals based on the type of reaction.

2. Count atoms.
- Count the number of atoms of each element in the reactants and in the products, and record the results in a table.
- Identify elements that appear in only one reactant and in only one product, and balance the atoms of those elements first. Delay the balancing of atoms (often hydrogen and oxygen) that appear in more than one reactant or product.
- If a polyatomic ion appears on both sides of the equation, treat it as a single unit in your counts.

3. Insert coefficients.
- Balance atoms one element at a time by inserting coefficients.
- Count atoms of each element frequently as you try different coefficients. Watch for elements whose atoms become unbalanced as a result of your work.
- Try the odd-even technique (explained later in this section) if you see an even number of a particular atom on one side of an equation and an odd number of that atom on the other side.

4. Verify your results.
- Double-check to be sure that the numbers of atoms of each element are equal on both sides of the equation.

SAMPLE PROBLEM A

Balancing an Equation

Balance the equation for the reaction of iron(III) oxide with hydrogen to form iron and water.

1 Identify reactants and products.

Iron(III) oxide and hydrogen are the reactants. Iron and water are the products. The unbalanced formula equation is

$$Fe_2O_3 + H_2 \longrightarrow Fe + H_2O$$

2 Count atoms.

	Reactants	Products	Balanced?
Unbalanced formula equation	$Fe_2O_3 + H_2$	$Fe + H_2O$	
Iron atoms	2	1	no
Oxygen atoms	3	1	no
Hydrogen atoms	2	2	yes

3 Insert coefficients.

Add a coefficient of 2 in front of Fe to balance the iron atoms.

$$Fe_2O_3 + H_2 \longrightarrow 2Fe + H_2O$$

Add a coefficient of 3 in front of H_2O to balance the oxygen atoms.

$$Fe_2O_3 + H_2 \longrightarrow 2Fe + 3H_2O$$

Now there are two hydrogen atoms in the reactants and six in the products. Add a coefficient of 3 in front of H_2.

$$Fe_2O_3 + 3H_2 \longrightarrow 2Fe + 3H_2O$$

4 Verify your results.

There are two iron atoms, three oxygen atoms, and six hydrogen atoms on both sides of the equation, so it is balanced.

PRACTICE HINT

One way to know what coefficient to use is to find a lowest common multiple. In this example, there were six hydrogen atoms in the products and two in the reactants. The lowest common multiple of 6 and 2 is 6, so a coefficient of 3 in the reactants balances the atoms.

PRACTICE

Write a balanced equation for each of the following.

1. $P_4 + O_2 \longrightarrow P_2O_5$
2. $C_3H_8 + O_2 \longrightarrow CO_2 + H_2O$
3. $Ca_2Si + Cl_2 \longrightarrow CaCl_2 + SiCl_4$
4. Silicon reacts with carbon dioxide to form silicon carbide, SiC, and silicon dioxide.

PROBLEM SOLVING SKILL

Balanced Equations Show Mass Conservation

The balanced equation for the reaction of sodium with water is

$$2Na + 2H_2O \longrightarrow 2NaOH + H_2$$

Each side of the equation has two atoms of sodium, four atoms of hydrogen, and two atoms of oxygen. The reactants and the products are made up of the same atoms so they must have equal masses. So a balanced equation shows the conservation of mass.

Never Change Subscripts to Balance an Equation

If you needed to write a balanced equation for the reaction of H_2 with O_2 to form H_2O, you might start with this formula equation:

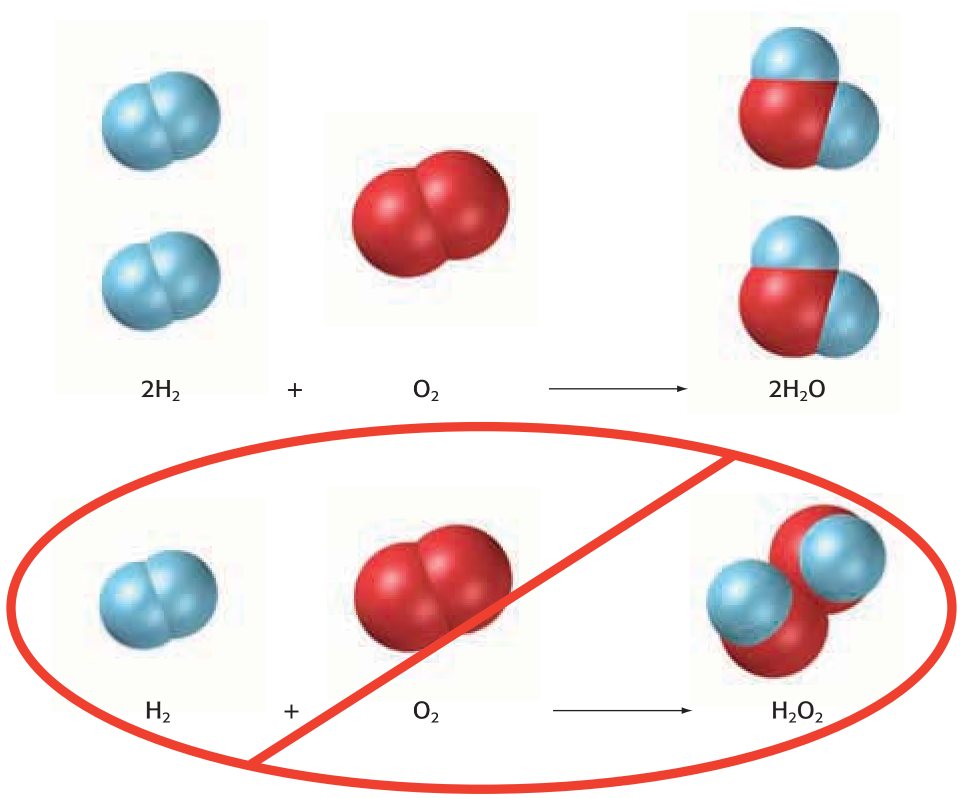
$$H_2 + O_2 \longrightarrow H_2O$$

To balance this equation, some people may want to change the formula of the product to H_2O_2.

$$H_2 + O_2 \longrightarrow H_2O_2$$

Although the equation is balanced, the product is no longer water, but hydrogen peroxide. Look at the models and equations in **Figure 6** to understand the problem. The first equation was balanced correctly by adding coefficients. As expected, the model shows the correct composition of the water molecules formed by the reaction. The second equation was incorrectly balanced by changing a subscript. The model shows that the change of a subscript changes the composition of the substance. As a result, the second equation no longer shows the formation of water, but that of hydrogen peroxide. When balancing equations, never change subscripts. Keep this in mind as you learn about the odd-even technique for balancing equations.

Figure 6
Use coefficients to balance an equation. Never change subscripts.



SAMPLE PROBLEM B

The Odd-Even Technique

The reaction of ammonia with oxygen produces nitrogen monoxide and water vapor. Write a balanced equation for this reaction.

1 Identify reactants and products.

The unbalanced formula equation is

$$NH_3 + O_2 \longrightarrow NO + H_2O$$

2 Count atoms.

	Reactants	Products	Balanced?
Unbalanced formula equation	$NH_3 + O_2$	$NO + H_2O$	
Nitrogen atoms	1	1	yes
Hydrogen atoms	3	2	no
Oxygen atoms	2	2	yes

The odd-even technique uses the fact that multiplying an odd number by 2 always results in an even number.

3 Insert coefficients.

A 2 in front of NH_3 gives an even number of H atoms. Add coefficients to NO and H_2O to balance the H atoms and N atoms.

$$2NH_3 + O_2 \longrightarrow 2NO + 3H_2O$$

For oxygen, double *all* coefficients to have an even number of O atoms on both sides and keep the other atoms balanced.

$$4NH_3 + 2O_2 \longrightarrow 4NO + 6H_2O$$

Change the coefficient for O_2 to 5 to balance the oxygen atoms.

$$4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O$$

4 Verify your results.

There are four nitrogen atoms, twelve hydrogen atoms, and ten oxygen atoms on both sides of the equation, so it is balanced.

PRACTICE HINT

Watch for cases in which all atoms in an equation are balanced except one, which has an odd number on one side of the equation and an even number on the other side. Multiplying all coefficients by 2 will result in an even number of atoms for the unbalanced atoms while keeping the rest balanced.

PRACTICE

Write a balanced chemical equation for each of the following.

1. $C_2H_2 + O_2 \longrightarrow CO_2 + H_2O$
2. $Fe(OH)_2 + H_2O_2 \longrightarrow Fe(OH)_3$
3. $FeS_2 + Cl_2 \longrightarrow FeCl_3 + S_2Cl_2$

PROBLEM SOLVING SKILL

Polyatomic Ions Can Be Balanced as a Unit

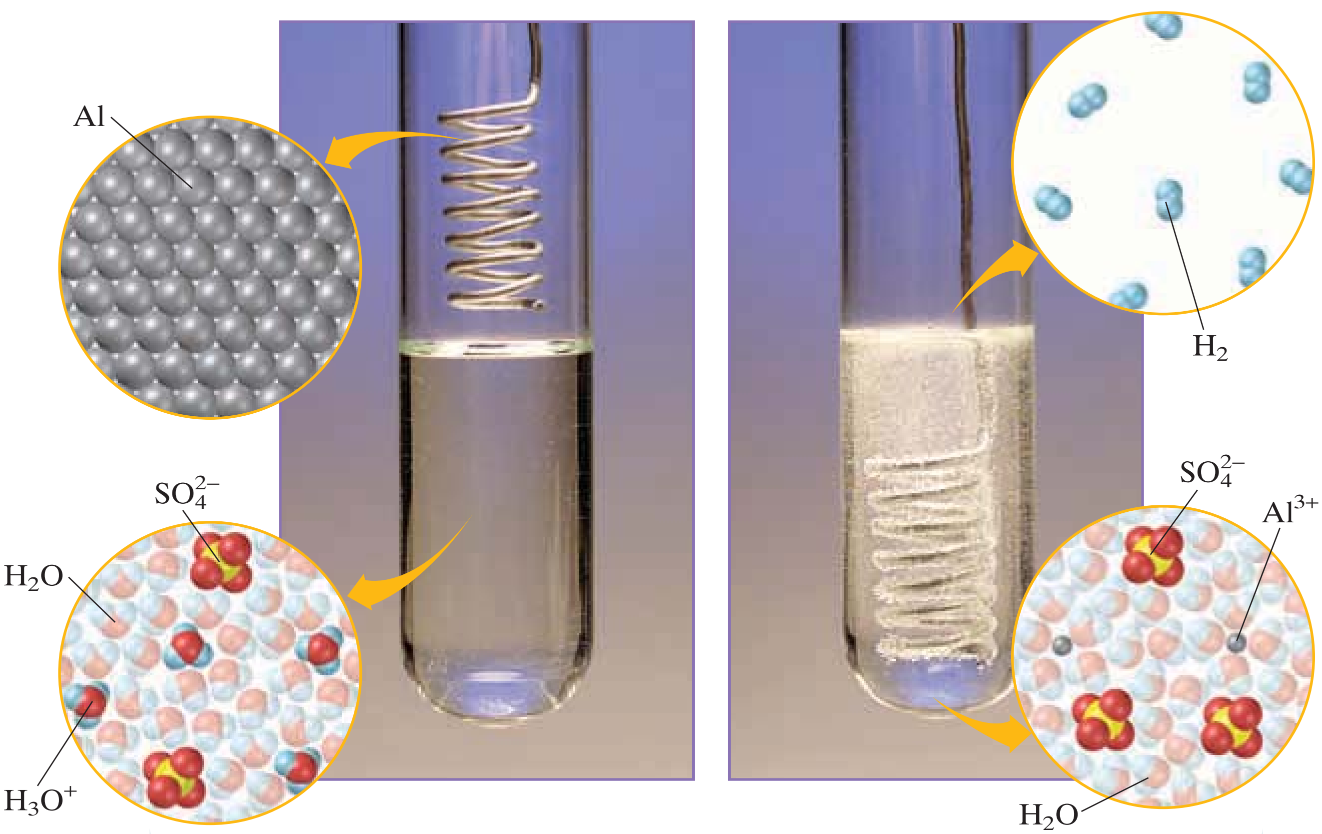
So far, you've balanced equations by balancing individual atoms one at a time. However, balancing some equations is made easier because groups of atoms can be balanced together. This is especially true in the case of polyatomic ions, such as NO_3^-. Often a polyatomic ion appears in both the reactants and the products without changing. The atoms within such ions are not rearranged during the reaction. The polyatomic ion can be counted as a single unit that appears on both sides of the equation. Of course, when you think that you have finished balancing an equation, checking each atom by itself is still helpful.

Look at **Figure 7.** The sulfate ion appears in both the reactant sulfuric acid and in the product aluminum sulfate. You could look at the sulfate ion as a single unit to make balancing the equation easier. Looking at the balanced equation, you can see that there are three sulfate ions on the reactants' side and three on the products' side.

In balancing the equation for the reaction between sodium phosphate and calcium nitrate, you can consider the nitrate ion and the phosphate ion each to be a unit. The resulting balanced equation is

$$2Na_3PO_4 + 3Ca(NO_3)_2 \longrightarrow 6NaNO_3 + Ca_3(PO_4)_2$$

Count the atoms of each element to make sure that the equation is balanced.



$$2Al(s) + 3H_2SO_4(aq) \longrightarrow Al_2(SO_4)_3(aq) + 3H_2(g)$$

Figure 7
In the reaction of aluminum with sulfuric acid, sulfate ions are part of both the reactants and the products.

SAMPLE PROBLEM C

Polyatomic Ions as a Group

Aluminum reacts with arsenic acid, $HAsO_3$, to form H_2 and aluminum arsenate. Write a balanced equation for this reaction.

1 Identify reactants and products.

The unbalanced formula equation is

$$Al + HAsO_3 \longrightarrow H_2 + Al(AsO_3)_3$$

2 Count atoms.

	Reactants	Products	Balanced?
Unbalanced formula equation	$Al + HAsO_3$	$H_2 + Al(AsO_3)_3$	
Aluminum atoms	1	1	yes
Hydrogen atoms	1	2	no
Arsenate ions	1	3	no

Because the arsenate ion appears on both sides of the equation, consider it a single unit while balancing.

3 Insert coefficients.

Change the coefficient of $HAsO_3$ to 3 to balance the arsenate ions.

$$Al + 3HAsO_3 \longrightarrow H_2 + Al(AsO_3)_3$$

Double all coefficients to keep the other atoms balanced and to get an even number of hydrogen atoms on each side.

$$2Al + 6HAsO_3 \longrightarrow 2H_2 + 2Al(AsO_3)_3$$

Change the coefficient of H_2 to 3 to balance the hydrogen atoms.

$$2Al + 6HAsO_3 \longrightarrow 3H_2 + 2Al(AsO_3)_3$$

4 Verify your results.

There are 2 aluminum atoms, 6 hydrogen atoms, 6 arsenic atoms, and 18 oxygen atoms on both sides of the equation, so it is balanced.

PRACTICE HINT

If you consider polyatomic ions as single units, be sure to count the atoms of each element when you double-check your work.

PRACTICE

Write a balanced equation for each of the following.

1. $HgCl_2 + AgNO_3 \longrightarrow Hg(NO_3)_2 + AgCl$
2. $Al + Hg(CH_3COO)_2 \longrightarrow Al(CH_3COO)_3 + Hg$
3. Calcium phosphate and water are produced when calcium hydroxide reacts with phosphoric acid.

PROBLEM SOLVING SKILL

Practice Makes Perfect

You have learned a few techniques that you can use to help you approach balancing equations logically. But don't think that you are done. The more you practice balancing equations, the faster and better you will become. The best way to discover more tips to help you balance equations is to practice a lot! As you learn about the types of reactions in the next section, be aware that these types can provide tips that make balancing equations even easier.

2 Section Review

UNDERSTANDING KEY IDEAS

1. What fundamental law is demonstrated in balancing equations?

2. What is meant by a balanced equation?

3. When balancing an equation, should you adjust the subscripts or the coefficients?

PRACTICE PROBLEMS

4. Write each of the following reactions as a word equation, an unbalanced formula equation, and finally as a balanced equation.

a. When heated, potassium chlorate decomposes into potassium chloride and oxygen.

b. Silver sulfide forms when silver and sulfur, S_8, react.

c. Sodium hydrogen carbonate breaks down to form sodium carbonate, carbon dioxide, and water vapor.

5. Balance the following equations.

a. $ZnS + O_2 \longrightarrow ZnO + SO_2$

b. $Fe_2O_3 + CO \longrightarrow Fe + CO_2$

c. $AgNO_3 + AlCl_3 \longrightarrow AgCl + Al(NO_3)_3$

d. $Ni(ClO_3)_2 \longrightarrow NiCl_2 + O_2$

6. Balance the following equations.

a. $(NH_4)_2Cr_2O_7 \longrightarrow Cr_2O_3 + N_2 + H_2O$

b. $NH_3 + CuO \longrightarrow N_2 + Cu + H_2O$

c. $Na_2SiF_6 + Na \longrightarrow Si + NaF$

d. $C_4H_{10} + O_2 \longrightarrow CO_2 + H_2O$

CRITICAL THINKING

7. Use diagrams of particles to explain why four atoms of phosphorus can produce only two molecules of diphosphorus trioxide, even when there is an excess of oxygen atoms.

8. Which numbers in the reactants and products in the following equation are coefficients, and which are subscripts?

$$2Al + 3H_2SO_4 \longrightarrow Al_2(SO_4)_3 + 3H_2$$

9. Write a balanced equation for the formation of water from hydrogen and oxygen. Use the atomic mass of each element to determine the mass of each molecule in the equation. Use these masses to show that the equation demonstrates the law of conservation of mass.

10. A student writes the equation below as the balanced equation for the reaction of iron with chlorine. Is this equation correct? Explain.

$$Fe(s) + Cl_3(g) \longrightarrow FeCl_3(s)$$

SECTION

3 Classifying Chemical Reactions

KEY TERMS

- **combustion reaction**
- **synthesis reaction**
- **decomposition reaction**
- **activity series**
- **double-displacement reaction**

OBJECTIVES

1. **Identify** combustion reactions, and write chemical equations that predict the products.
2. **Identify** synthesis reactions, and write chemical equations that predict the products.
3. **Identify** decomposition reactions, and write chemical equations that predict the products.
4. **Identify** displacement reactions, and use the activity series to write chemical equations that predict the products.
5. **Identify** double-displacement reactions, and write chemical equations that predict the products.

Reaction Types

So far in this book, you have learned about a lot of chemical reactions. But they are just a few of the many that take place. To make learning about reations simpler, it is helpful to classify them and to start with a few basic types. Consider a grocery store as an example of how classification makes things simpler. A store may have thousands of items. Even if you have never been to a particular store before, you should be able to find everything you need. Because similar items are grouped together, you know what to expect when you start down an aisle.

Look at the reaction shown in **Figure 8.** The balanced equation for this reaction is

$$2Al + Fe_2O_3 \longrightarrow 2Fe + Al_2O_3$$

By classifying chemical reactions into several types, you can more easily predict what products are likely to form. You will also find that reactions in each type follow certain patterns, which should help you balance the equations more easily.

The five reaction types that you will learn about in this section are not the only ones. Additional types are discussed in other chapters, and there are others beyond the scope of this book. In addition, reactions can belong to more than one type. There are even reactions that do not fit into any type. The value in dividing reactions into categories is not to force each reaction to fit into a single type but to help you see patterns and similarities in reactions.

Figure 8
Knowing which type of reaction occurs between aluminum and iron(III) oxide could help you predict that iron is produced.

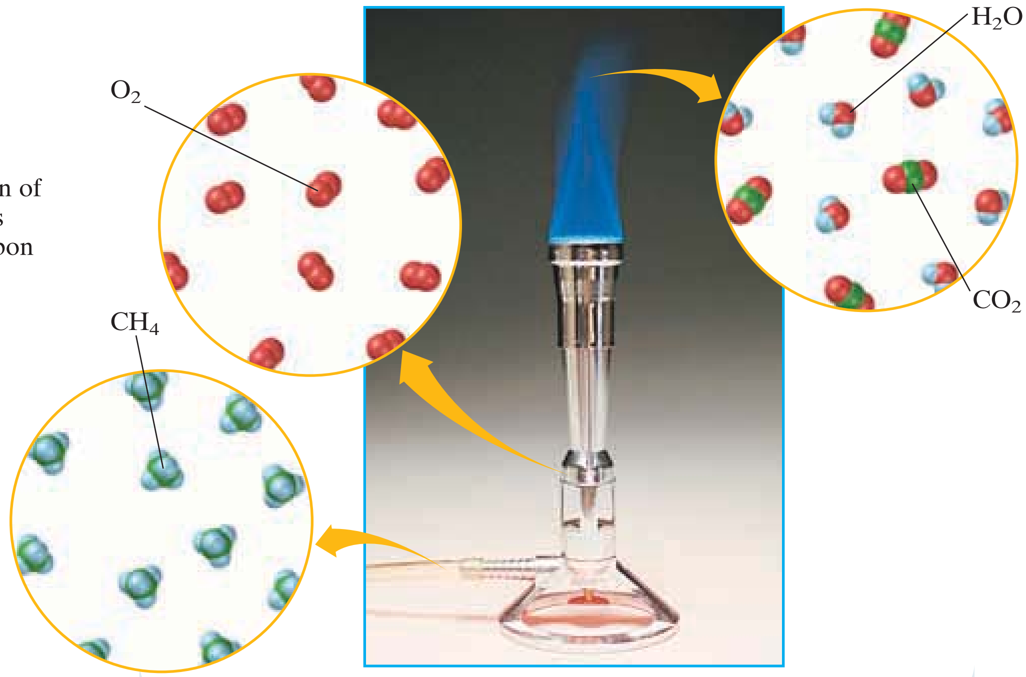


Figure 9
The complete combustion of any hydrocarbon, such as methane, yields only carbon dioxide and water.

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

Combustion Reactions

Combustion reactions are often used to generate energy. Much of our electrical energy is generated in power plants that work because of the combustion of coal. Combustion of hydrocarbons (as in gasoline) provides energy used in transportation—on the land, in the sea, and in the air. For our purposes, a **combustion reaction** is the reaction of a carbon-based compound with oxygen. The products are carbon dioxide and water vapor. An example of a combustion reaction is shown in **Figure 9.**

combustion reaction
the oxidation reaction of an organic compound, in which heat is released

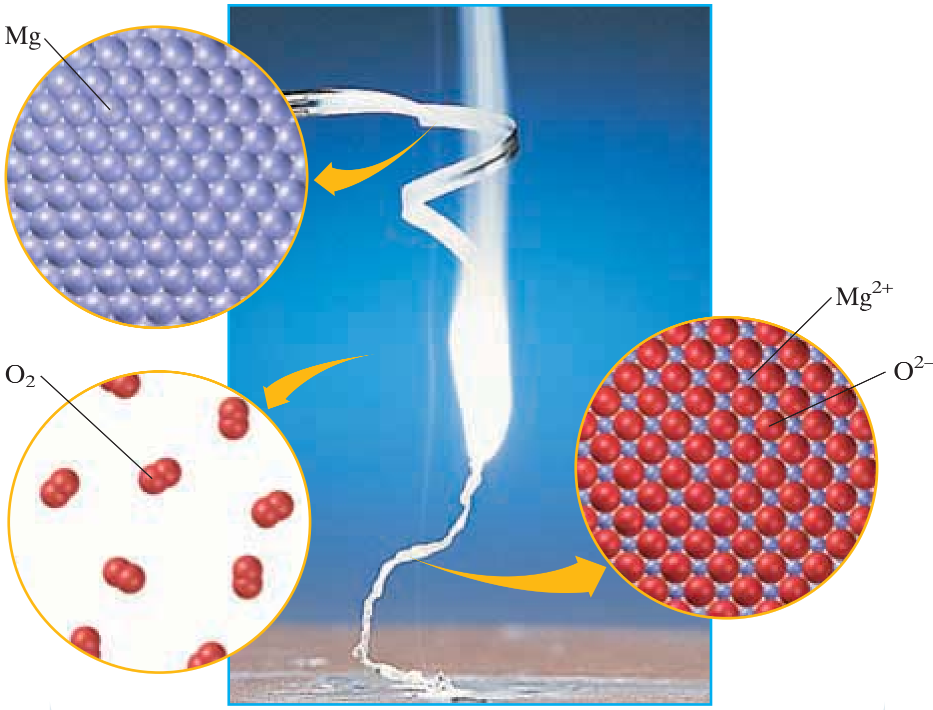
Many of the compounds in combustion reactions are called *hydrocarbons* because they are made of only carbon and hydrogen. Propane is a hydrocarbon that is often used as a convenient portable fuel for lanterns and stoves. The balanced equation for the combustion of propane is shown below.

$$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$$

Some compounds, such as alcohols, are made of carbon, hydrogen, and oxygen. In the combustion of these compounds, carbon dioxide and water are still made. For example, the fuel known as gasohol is a mixture of gasoline and ethanol, an alcohol. The balanced chemical equation for the combustion of ethanol is shown below.

$$CH_3CH_2OH + 3O_2 \longrightarrow 2CO_2 + 3H_2O$$

When enough oxygen is not available, the combustion reaction is incomplete. Carbon monoxide and unburned carbon (soot), as well as carbon dioxide and water vapor are made.



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

Figure 10
When the elements magnesium and oxygen react, they combine to form the binary compound magnesium oxide.

Synthesis Reactions

The word *synthesis* comes from a Greek word that means "to put together." In the case of a **synthesis reaction,** a single compound forms from two or more reactants. If you see a chemical equation that has only one product, the reaction is a synthesis reaction. The reactants in many of these reactions are two elements or two small compounds.

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

Two Elements Form a Binary Compound

If the reactants in an equation are two elements, the only way in which they can react is to form a binary compound, which is composed of two elements. Often, when a metal reacts with a nonmetal, electrons are transferred and an ionic compound is formed. You can use the charges of the ions to predict the formula of the compound formed. Metals in Groups 1 and 2 lose one electron and two electrons, respectively. Nonmetals in Groups 16 and 17 gain two electrons and one electron, respectively. Using the charges on the ions, you can predict the formula of the product of a synthesis reaction, such as the one in **Figure 10.**

Nonmetals on the far right of the periodic table can react with one another to form binary compounds. Often, more than one compound could form, however, so predicting the product of these reactions is not always easy. For example, carbon and oxygen can combine to form carbon dioxide or carbon monoxide, as shown below.

$$C + O_2 \longrightarrow CO_2 \qquad\qquad 2C + O_2 \longrightarrow 2CO$$

STUDY TIP

WORKING WITH A PARTNER

If you can explain difficult concepts to a study partner, then you know that you understand them yourself.

- Make flashcards that contain examples of chemical reactions. Quiz each other on reaction types by using the flashcards. Explain how you identified each type.

Refer to Appendix B for other studying strategies.

Two Compounds Form a Ternary Compound

Two compounds can combine to form a ternary compound, a compound composed of three elements. One example is the reaction of water and a Group 1 or Group 2 metal oxide to form a metal hydroxide. An example is the formation of "slaked lime," or calcium hydroxide.

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

Some oxides of nonmetals can combine with water to produce acids. Carbon dioxide combines with water to form carbonic acid.

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

Decomposition Reactions

decomposition reaction

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

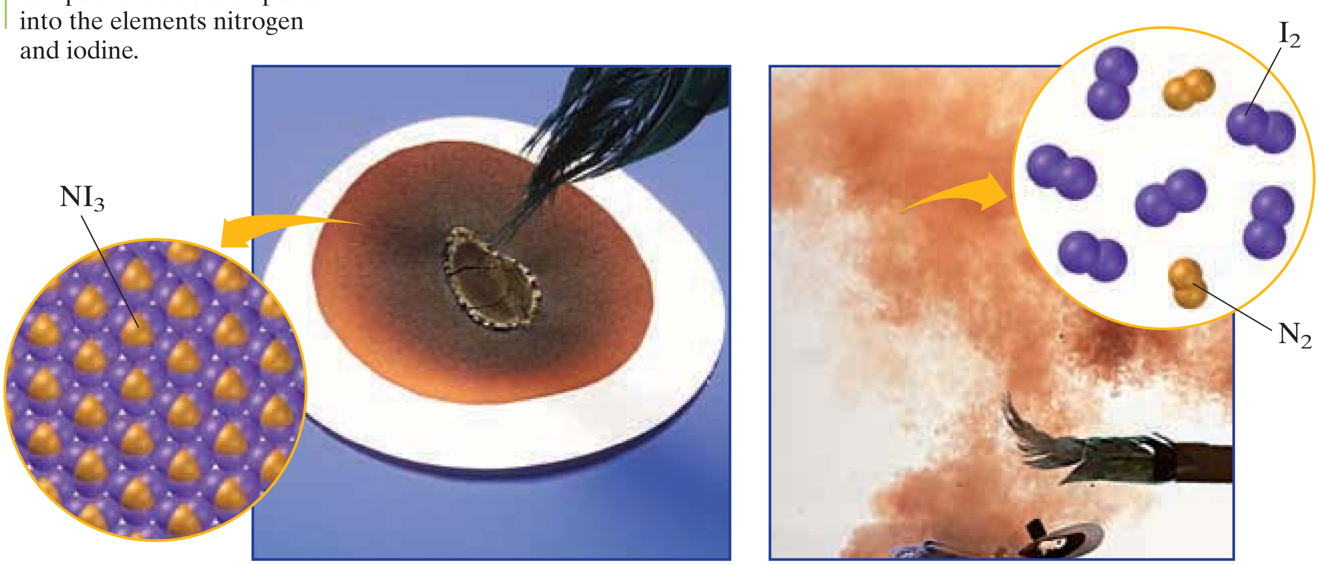
Decomposition reactions are the opposite of synthesis reactions—they have only one reactant. In a **decomposition reaction,** a single compound breaks down, often with the input of energy, into two or more elements or simpler compounds.

If your reactant is a binary compound, then the products will most likely be the two elements that make the compound up, as shown in **Figure 11.** In another example, water can be decomposed into the elements hydrogen and oxygen through the use of electrical energy.

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

The gases produced are very pure and are used for special purposes, such as in hospitals. But these gases are very expensive because of the energy needed to make them. Experiments are underway to make special solar cells in which sunlight is used to decompose water.

Figure 11
Nitrogen triiodide is a binary compound that decomposes into the elements nitrogen and iodine.



$$2NI_3(s) \longrightarrow N_2(g) + 3I_2(g)$$

Compounds made up of three or more elements usually do not decompose into those elements. Instead, each compound that consists of a given polyatomic ion will break down in the same way. For example, a metal carbonate, such as $CaCO_3$ in limestone, decomposes to form a metal oxide and carbon dioxide.

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

Many of the synthesis reactions that form metal hydroxides and acids can be reversed to become decomposition reactions.

SAMPLE PROBLEM D

Predicting Products

Predict the product(s) and write a balanced equation for the reaction of potassium with chlorine.

1 Gather information.

Because the reactants are two elements, the reaction is most likely a synthesis. The product will be a binary compound.

2 Plan your work.

Potassium, a Group 1 metal, will lose one electron to become a 1+ ion. Chlorine, a Group 17 nonmetal, gains one electron to form a 1– ion. The formula for the product will be KCl. The unbalanced formula equation is

$$K + Cl_2 \longrightarrow KCl$$

3 Calculate.

Place a coefficient of 2 in front of KCl and also K.

$$2K + Cl_2 \longrightarrow 2KCl$$

4 Verify your results.

The final equation has two atoms of each element on each side, so it is balanced.

PRACTICE HINT

Look for hints about the type of reaction. If the reactants are two elements or simple compounds, the reaction is probably a synthesis reaction. The reaction of oxygen with a hydrocarbon is a combustion reaction. If there is only one reactant, it is a decomposition reaction.

PRACTICE

Predict the product(s) and write a balanced equation for each of the following reactions.

1. the reaction of butane, C_4H_{10}, with oxygen
2. the reaction of water with calcium oxide
3. the reaction of lithium with oxygen
4. the decomposition of carbonic acid

PROBLEM SOLVING SKILL

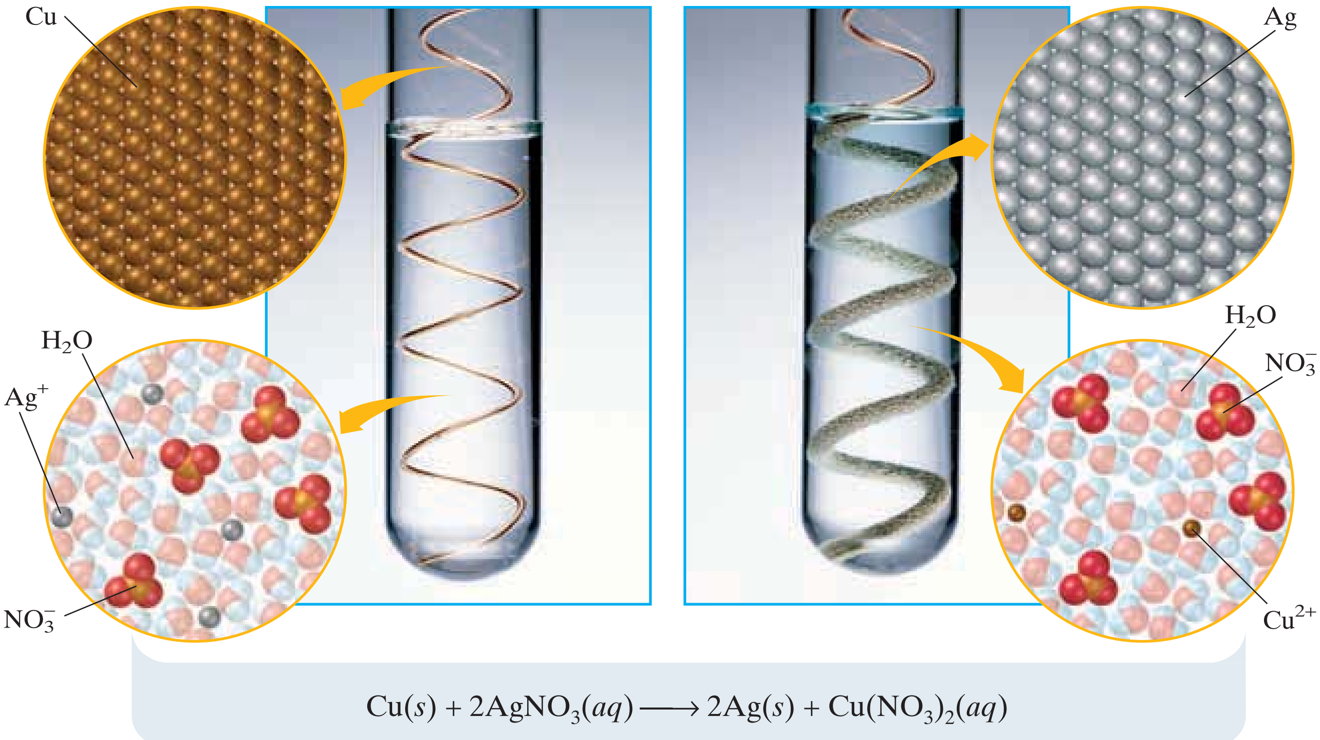


Figure 12
Copper is the more active metal and displaces silver from the silver nitrate solution. So copper is higher on the activity series than silver is. The Cu^{2+} formed gives the solution a blue color.

Displacement Reactions

When aluminum foil is dipped into a solution of copper(II) chloride, reddish copper metal forms on the aluminum and the solution loses its blue color. It is as if aluminum atoms and copper ions have switched places to form aluminum ions and copper atoms.

$$2Al(s) + 3CuCl_2(aq) \longrightarrow 2AlCl_3(aq) + 3Cu(s)$$

In this *displacement reaction,* a single element reacts with a compound and displaces another element from the compound. The products are a different element and a different compound than the reactants are. In general, a metal may displace another metal (or hydrogen), while a nonmetal may displace only another nonmetal.

The Activity Series Ranks Reactivity

activity series
a series of elements that have similar properties and that are arranged in descending order of chemical activity

Results of experiments, such as the one in **Figure 12,** in which displacement reactions take place are summarized in the **activity series,** a portion of which is shown in **Table 4.** In the activity series, elements are arranged in order of activity with the most active one at the top. In general, an element can displace those listed below it from compounds in solution, but not those listed above it. Thus, you can use the activity series to make predictions about displacement reactions. You could also predict that no reaction would happen, such as when silver is put into a copper(II) nitrate solution.

When a metal is placed in water, the reactivity information in the activity series helps you tell if hydrogen is displaced. If the metal is active enough for this to happen, a metal hydroxide and hydrogen gas form.

Table 4 Activity Series

Element	Reactivity
K Ca Na	react with cold water and acids to replace hydrogen; react with oxygen to form oxides
Mg Al Zn Fe	react with steam (but not with cold water) and acids to replace hydrogen; react with oxygen to form oxides
Ni Pb	do not react with water; react with acids to replace hydrogen; react with oxygen to form oxides
H_2 Cu	react with oxygen to form oxides
Ag Au	fairly unreactive; form oxides only indirectly

Refer to Appendix A for a more complete activity series of metals and of halogens.

SKILLS Toolkit 2

Using the Activity Series

1. Identify the reactants.
- Determine whether the single element is a metal or a halogen.
- Determine the element that might be displaced from the compound if a displacement reaction occurs.

2. Check the activity series.
- Determine whether the single element or the element that might be displaced from the compound is more active. The more active element is higher on the activity series.
- For a metal reacting with water, determine whether the metal can replace hydrogen from water in that state.

3. Write the products, and balance the equation.
- If the more active element is already part of the compound, then no reaction will occur.
- Otherwise, the more active element will displace the less active element.

4. Verify your results.
- Double-check to be sure that the equation is balanced.

SAMPLE PROBLEM E

Determining Products by Using the Activity Series

Magnesium is added to a solution of lead(II) nitrate. Will a reaction happen? If so, write the equation and balance it.

1 Identify the reactants.

Magnesium will attempt to displace lead from lead(II) nitrate.

2 Check the activity series.

Magnesium is more active than lead and displaces it.

3 Write the products, and balance the equation.

A reaction will occur. Lead is displaced by magnesium.

$$Mg + Pb(NO_3)_2 \longrightarrow Pb + Mg(NO_3)_2$$

4 Verify your results.

The equation is balanced.

PRACTICE HINT

You can sometimes use your knowledge of the periodic table to verify how you apply the activity series. In general, Group 1 metals are rarely in atomic form at the end of most reactions. Group 2 metals are less likely than Group 1 metals but more likely than transition metals to be in atomic form after a reaction.

PRACTICE

PROBLEM SOLVING SKILL

For the following situations, write a balanced equation if a reaction happens. Otherwise write "no reaction."

1. Aluminum is dipped into a zinc nitrate solution.
2. Sodium is placed in cold water.
3. Gold is added to a solution of calcium chloride.

Quick LAB

Balancing Equations by Using Models

SAFETY PRECAUTIONS

PROCEDURE

1. Use **toothpicks** and **gumdrops of at least four different colors** (representing atoms of different elements) to make models of the substances in each equation below.
2. For each reaction below, use your models to determine the products, if needed, and then balance the equation.

ANALYSIS

Use your models to classify each reaction by type.

a. $H_2 + Cl_2 \longrightarrow HCl$

b. $Mg + O_2 \longrightarrow MgO$

c. $C_2H_6 + O_2 \longrightarrow CO_2 + H_2O$

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

e. $H_2CO_3 \longrightarrow CO_2 + H_2O$

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

g. $KClO_3 \longrightarrow KCl + O_2$

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

i. $Zn + HCl \longrightarrow$ ______

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

k. $C_3H_8 + O_2 \longrightarrow$ ______

l. $BaO + H_2O \longrightarrow$ ______

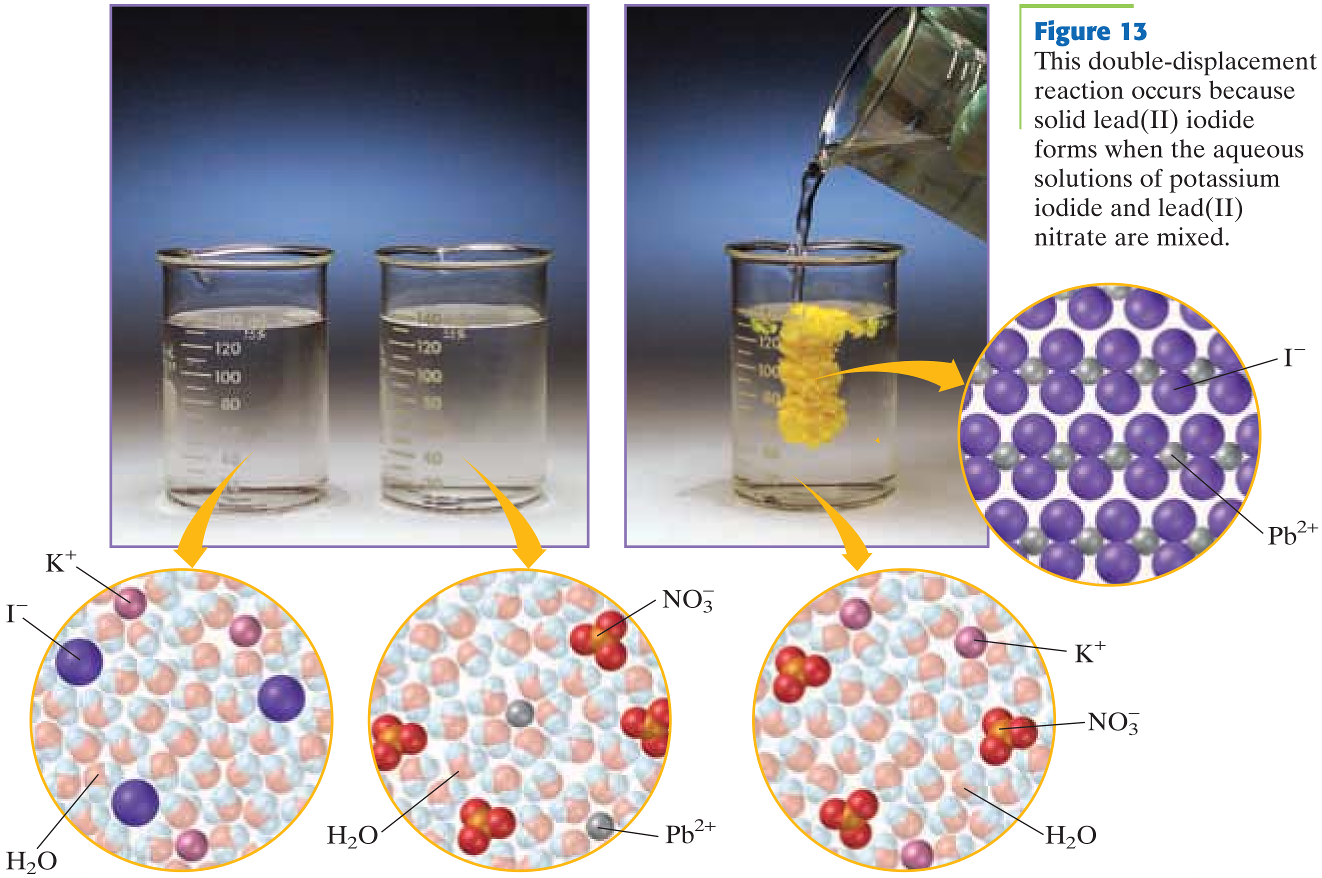


Figure 13 This double-displacement reaction occurs because solid lead(II) iodide forms when the aqueous solutions of potassium iodide and lead(II) nitrate are mixed.

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

Double-Displacement Reactions

Figure 13 shows the result of the reaction between KI and $Pb(NO_3)_2$. The products are a yellow precipitate of PbI_2 and a colorless solution of KNO_3. From the equation, it appears as though the parts of the compounds just change places. Early chemists called this a **double-displacement reaction.** It occurs when two compounds in aqueous solution appear to exchange ions and form two new compounds. For this to happen, one of the products must be a solid precipitate, a gas, or a molecular compound, such as water. Water is often written as HOH in these equations.

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

For example, when dilute hydrochloric acid and sodium hydroxide are mixed, little change appears to happen. However, by looking at the equation for the reaction, you can see that liquid water, a molecular compound, forms.

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

Although this type of formula equation is not the best description, the term *double-displacement reaction* is still in use. A better way to represent these reactions is to use a net ionic equation, which will be covered in the next section.

3 SKILLS Toolkit

Identifying Reactions and Predicting Products

1. Is there only one reactant?

If the answer is no, go to step 2.
If the answer is yes, you have a decomposition reaction.

- A binary compound generally breaks into its elements.
- A ternary compound breaks according to the guidelines given earlier in this section.

2. Are the reactants two elements or two simple compounds?

If the answer is no, go to step 3.
If the answer is yes, you probably have a synthesis reaction.

- If both reactants are elements, the product is a binary compound. For a metal reacting with a nonmetal, use the expected charges to predict the formula of the compound.
- If the reactants are compounds, the product will be a single ternary compound according to the guidelines given earlier in this section.

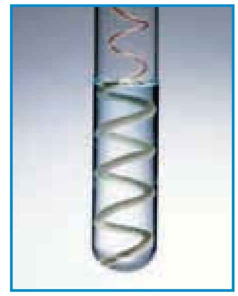
3. Are the reactants oxygen and a hydrocarbon?

If the answer is no, go to step 4.
If the answer is yes, you have a combustion reaction.

- The products of a combustion reaction are carbon dioxide and water.

4. Are the reactants an element and a compound other than a hydrocarbon?

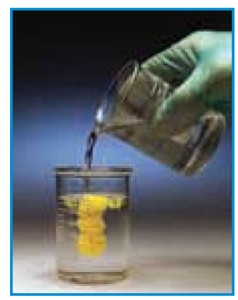
If the answer is no, go to step 5.
If the answer is yes, you probably have a displacement reaction.



- Use the activity series to determine the activities of the elements.
- If the more active element is already part of the compound, no reaction will occur. Otherwise, the more active element will displace the less active element from the compound.

5. Are the reactants two compounds composed of ions?

If the answer is no, go back to step 1 because you might have missed the proper category.
If the answer is yes, you probably have a double-displacement reaction.



- Write formulas for the possible products by forming two new compounds from the ions available.
- Determine if one of the possible products is a solid precipitate, a gas, or a molecular compound, such as water. If neither product qualifies in the above categories, no reaction occurs. Use the rules below to determine whether a substance will be an insoluble solid.

All compounds of Group 1 and NH_4^+ are soluble.

All nitrates are soluble.

All halides, except those of Ag^+ and Pb^{2+}, are soluble.

All sulfates, except Ca^{2+}, Sr^{2+}, Ba^{2+}, Hg_2^{2+}, and Pb^{2+}, are soluble.

All carbonates, except those of Group 1 and NH_4^+, are insoluble.

More Types to Come

This section has been a short introduction to the classification of chemical reactions. Even so, you now have the tools, summarized in **Skills Toolkit 3,** to predict the products of hundreds of reactions. Keep the reaction types in mind as you continue your study of chemistry. And as you learn about other reaction types, think about how they relate to the five types described here.

internet connect
www.scilinks.org
Topic: Reaction Types
SciLinks code: HW4163
SciLinks Maintained by the National Science Teachers Association

3 Section Review

UNDERSTANDING KEY IDEAS

1. Why is the formation of a ternary compound also a synthesis reaction?
2. When a binary compound is the only reactant, what are the products most likely to be?
3. Explain how synthesis and decomposition reactions can be the reverse of one another.
4. What two compounds form when hydrocarbons burn completely?
5. Explain how to use the activity series to predict chemical behavior.
6. In which part of the periodic table are the elements at the top of the activity series?
7. What must be produced for a double-displacement reaction to occur?

PRACTICE PROBLEMS

8. Balance each of the equations below, and indicate the type of reaction for each equation.
   - **a.** $Cl_2(g) + NaBr(aq) \longrightarrow NaCl(aq) + Br_2(l)$
   - **b.** $CaO(s) + H_2O(l) \longrightarrow Ca(OH)_2(aq)$
   - **c.** $Ca(ClO_3)_2(s) \longrightarrow CaCl_2(s) + O_2(g)$
   - **d.** $AgNO_3(aq) + K_2SO_4(aq) \longrightarrow Ag_2SO_4(s) + KNO_3(aq)$
   - **e.** $Zn(s) + CuBr_2(aq) \longrightarrow ZnBr_2(aq) + Cu(s)$
   - **f.** $C_8H_{18}(l) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$
9. Predict whether a reaction would occur when the materials indicated are brought together. For each reaction that would occur, complete and balance the equation.
   - **a.** $Ag(s) + H_2O(l)$
   - **b.** $Mg(s) + Cu(NO_3)_2(aq)$
   - **c.** $Al(s) + O_2(g)$
   - **d.** $H_2SO_4(aq) + KOH(aq)$
10. Predict the products, write a balanced equation, and identify the type of reaction for each of the following reactions.
    - **a.** $HgO \longrightarrow$
    - **b.** $C_3H_7OH + O_2 \longrightarrow$
    - **c.** $Zn + CuSO_4 \longrightarrow$
    - **d.** $BaCl_2 + Na_2SO_4 \longrightarrow$
    - **e.** $Zn + F_2 \longrightarrow$
    - **f.** $C_5H_{10} + O_2 \longrightarrow$

CRITICAL THINKING

11. When will a displacement reaction *not* occur?
12. Explain why the terms *synthesis* and *decomposition* are appropriate names for their respective reaction types.
13. Platinum is used for jewelry because it does not corrode. Where would you expect to find platinum on the activity series?
14. Will a reaction occur when copper metal is dipped into a solution of silver nitrate? Explain.

SECTION

4 Writing Net Ionic Equations

KEY TERMS

- **spectator ions**

OBJECTIVES

1. **Write** total ionic equations for reactions in aqueous solutions.
2. **Identify** spectator ions and write net ionic equations for reactions in aqueous solutions.

Ionic Equations

When ionic compounds dissolve in water, the ions separate from each other and spread throughout the solution. Thus, the formulas $KI(aq)$ and $Pb(NO_3)_2(aq)$ are actually aqueous ions, as shown below.

$$KI(aq) = K^+(aq) + I^-(aq)$$

$$Pb(NO_3)_2(aq) = Pb^{2+}(aq) + 2NO_3^-(aq)$$

Notice that when lead(II) nitrate dissolves, there are two nitrate ions for every lead ion, so a coefficient of 2 is used for NO_3^-. The reaction between KI and $Pb(NO_3)_2$ can be described by the chemical equation below.

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

However, it is more correct to describe the reaction by using a *total ionic equation* as shown below. When you write a total ionic equation, make sure that both the mass and the electric charge are conserved.

$$2K^+(aq) + 2I^-(aq) + Pb^{2+}(aq) + 2NO_3^-(aq) \longrightarrow PbI_2(s) + 2K^+(aq) + 2NO_3^-(aq)$$

But even this equation is not the best way to view the reaction.

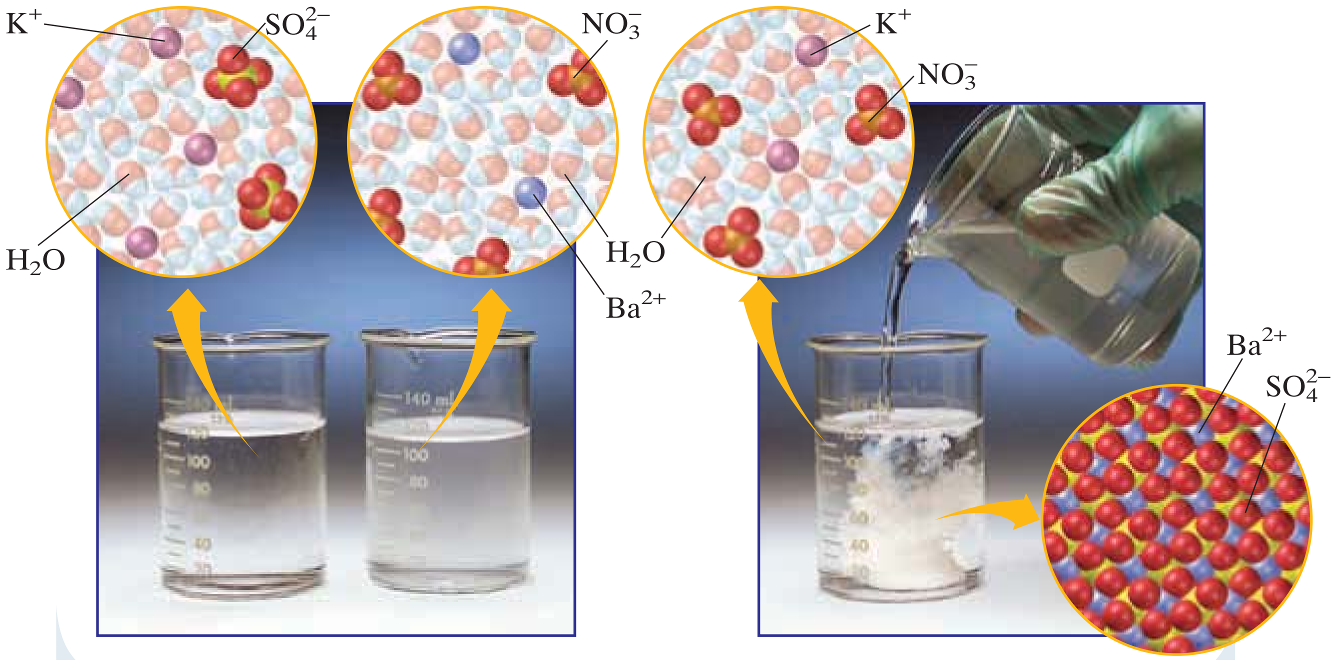
Identifying Spectator Ions

When two solutions are mixed, all of the ions are present in the combined solution. In many cases, some of the ions will react with each other. However, some ions do not react. These **spectator ions** remain unchanged in the solution as aqueous ions. In the equation above, the K^+ and NO_3^- ions appear as aqueous ions both on the reactants' side and on the products' side. Because K^+ and NO_3^- ions are spectator ions in the above reaction, they can be removed from the total ionic equation. What remains are the substances that do change during the reaction.

spectator ions

ions that are present in a solution in which a reaction is taking place but that do not participate in the reaction

$$\cancel{2K^+(aq)} + 2I^-(aq) + Pb^{2+}(aq) + \cancel{2NO_3^-(aq)} \longrightarrow PbI_2(s) + \cancel{2K^+(aq)} + \cancel{2NO_3^-(aq)}$$



Chemical equation:

$$K_2SO_4(aq) + Ba(NO_3)_2(aq) \longrightarrow 2KNO_3(aq) + BaSO_4(s)$$

Total ionic equation:

$$\cancel{2K^+(aq)} + SO_4^{2-}(aq) + Ba^{2+}(aq) + \cancel{2NO_3^-(aq)} \longrightarrow \cancel{2K^+(aq)} + \cancel{2NO_3^-(aq)} + BaSO_4(s)$$

Net ionic equation:

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

Figure 14
For the reaction of potassium sulfate with barium nitrate, the net ionic equation shows that aqueous barium and sulfate ions join to form solid, insoluble barium sulfate.

Writing Net Ionic Equations

The substances that remain once the spectator ions are removed from the chemical equation make an equation that shows only the net change. This is called a *net ionic equation*. The one for the reaction of KI with $Pb(NO_3)_2$ is shown below.

$$2I^-(aq) + Pb^{2+}(aq) \longrightarrow PbI_2(s)$$

Figure 14 shows the process of determining the net ionic equation for another reaction.

The net ionic equation above is the same as the one for the reaction between NaI and $Pb(ClO_3)_2$. Both compounds are soluble, and their aqueous solutions contain iodide and lead(II) ions, which would form lead(II) iodide. So, the net change is the same.

Net ionic equations can also be used to describe displacement reactions. For example, Zn reacts with a solution of $CuSO_4$ and displaces the copper ion, Cu^{2+}, as shown in the total ionic equation

$$Zn(s) + Cu^{2+}(aq) + \cancel{SO_4^{2-}(aq)} \longrightarrow Cu(s) + Zn^{2+}(aq) + \cancel{SO_4^{2-}(aq)}$$

Only the sulfate ion remains unchanged and is a spectator ion. Thus, the net ionic equation is as follows:

$$Zn(s) + Cu^{2+}(aq) \longrightarrow Cu(s) + Zn^{2+}(aq)$$

4 SKILLS Toolkit

Writing Net Ionic Equations

1. List what you know.
- Identify each chemical described as a reactant or product.
- Identify the type of reaction taking place.

2. Write a balanced equation.
- Use the type of reaction to predict products, if necessary.
- Write a formula equation, and balance it. Include the physical state for each substance. Use the rules below with double-displacement reactions to determine whether a substance is an insoluble solid.

All compounds of Group 1 and NH_4^+ are soluble.
All nitrates are soluble.
All halides, except those of Ag^+ and Pb^{2+}, are soluble.
All sulfates, except Ca^{2+}, Sr^{2+}, Ba^{2+}, Hg_2^{2+}, and Pb^{2+}, are soluble.
All carbonates, except those of Group 1 and NH_4^+, are insoluble.

3. Write the total ionic equation.
- Write separated aqueous ions for each aqueous ionic substance in the chemical equation.
- Do not split up any substance that is a solid, liquid, or gas.

4. Find the net ionic equation.
- Cancel out spectator ions, and write whatever remains as the net ionic equation.
- Double-check that the equation is balanced with respect to atoms and electric charge.

Check Atoms and Charge

Balanced net ionic equations are no different than other equations in that the numbers and kinds of atoms must be the same on each side of the equation. However, you also need to check that the sum of the charges for the reactants equals the sum of the charges for the products. As an example, recall the net ionic equation from **Figure 14.**

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

One barium atom is on both sides of the equation, and one sulfate ion is on both sides of the equation. The sum of the charges is zero both in the reactants and in the products. Each side of a net ionic equation can have a net charge that is not zero. For example, the net ionic equation below has a net charge of 2+ on each side and is balanced.

$$Zn(s) + Cu^{2+}(aq) \longrightarrow Zn^{2+}(aq) + Cu(s)$$

4 Section Review

UNDERSTANDING KEY IDEAS

1. Explain why the term *spectator ions* is used.

2. What chemicals are present in a net ionic equation?

3. Is the following a correct net ionic equation? Explain.

$$Na^+(aq) + Cl^-(aq) \longrightarrow NaCl(aq)$$

4. Identify the spectator ion(s) in the following reaction:

$$MgSO_4(aq) + 2AgNO_3(aq) \longrightarrow Ag_2SO_4(s) + Mg(NO_3)_2(aq)$$

5. Use the rules from **Skills Toolkit 4** to explain how to determine the physical states of the products in item 4.

PRACTICE PROBLEMS

6. Write a total ionic equation for each of the following unbalanced formula equations:

a. $Br_2(l) + NaI(aq) \longrightarrow NaBr(aq) + I_2(s)$

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

c. $Mg(s) + AgNO_3(aq) \longrightarrow Ag(s) + Mg(NO_3)_2(aq)$

d. $AgNO_3(aq) + KBr(aq) \longrightarrow AgBr(s) + KNO_3(aq)$

e. $Ni(s) + Pb(NO_3)_2(aq) \longrightarrow Ni(NO_3)_2(aq) + Pb(s)$

f. $Ca(s) + H_2O(l) \longrightarrow Ca(OH)_2(aq) + H_2(g)$

7. Identify the spectator ions, and write a net ionic equation for each reaction in item 6.

8. Predict the products for each of the following reactions. If no reaction happens, write "no reaction." Write a total ionic equation for each reaction that does happen.

a. $AuCl_3(aq) + Ag(s) \longrightarrow$

b. $AgNO_3(aq) + CaCl_2(aq) \longrightarrow$

c. $Al(s) + NiSO_4(aq) \longrightarrow$

d. $Na(s) + H_2O(l) \longrightarrow$

e. $AgNO_3(aq) + NaCl(aq) \longrightarrow$

9. Identify the spectator ions, and write a net ionic equation for each reaction that happens in item 8.

10. Write a total ionic equation for each of the following reactions:

a. silver nitrate + sodium sulfate

b. aluminum + nickel(II) iodide

c. potassium sulfate + calcium chloride

d. magnesium + copper(II) bromide

e. lead(II) nitrate + sodium chloride

11. Identify the spectator ions, and write a net ionic equation for each reaction in item 10.

CRITICAL THINKING

12. Why is K^+ always a spectator ion?

13. Do net ionic equations always obey the rule of conservation of charge? Explain.

14. Suppose a drinking-water supply contains Ba^{2+}. Using solubility rules, write a net ionic equation for a double-displacement reaction that indicates how Ba^{2+} might be removed.

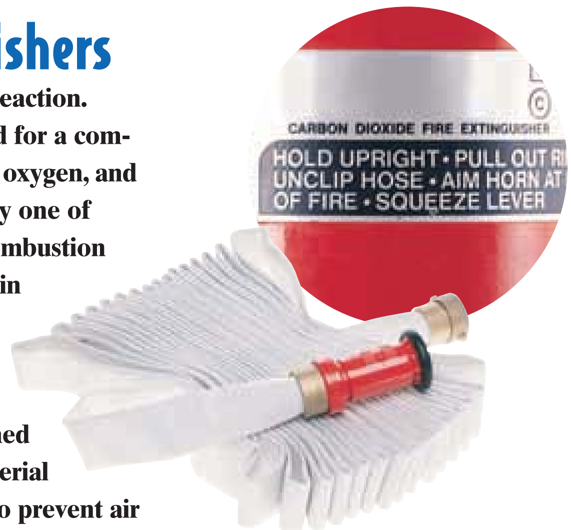
15. Explain why no reaction occurs if a double-displacement reaction has four spectator ions.

16. Explain why more than one reaction can have the same net ionic equation. Provide at least two reactions that have the same net ionic equation.

CONSUMER FOCUS

Fire Extinguishers

A fire is a combustion reaction. Three things are needed for a combustion reaction: a fuel, oxygen, and an ignition source. If any one of these three is absent, combustion cannot occur. One goal in fighting a fire is to remove one or more of these parts. Many extinguishers are designed to cool the burning material (to hinder ignition) or to prevent air and oxygen from reaching it.



Types of Fires

Each type of fire requires different firefighting methods. Class A fires involve solid fuels, such as wood. Class B fires involve a liquid or a gas, such as gasoline or natural gas. Class C fires involve the presence of a "live" electric circuit. Class D fires involve burning metals.

The type of extinguisher is keyed to the type of fire. Extinguishers for Class A fires often use water. The water cools the fuel so that it does not react as readily. The steam that is produced helps displace the oxygen-containing air around the fire. Carbon dioxide extinguishers can also be used. Because carbon dioxide is denser than air, it forms a layer underneath the air and cuts off the O_2 supply. Water cannot be used on Class B fires. Because water is usually denser than the fuel, it sinks below the fuel. Carbon dioxide is preferred for Class B fires.

Dry Chemical Extinguishers

Class C fires involving a "live" electric circuit can also be extinguished by CO_2. Water cannot be used because of the danger of electric shock. Some Class C fire extinguishers contain a dry chemical that smothers the fire by interrupting the chain reaction that is occurring. For example, a competing reaction may take place with the contents of the fire extinguisher and the intermediates of the reaction. Class C fire extinguishers usually contain compounds such as ammonium dihydrogen phosphate, $NH_4H_2PO_4$, or sodium hydrogen carbonate, $NaHCO_3$.

Finally, Class D fires involve burning metals. These fires cannot be extinguished with CO_2 or water because these compounds may react with some hot metals. For these fires, nonreactive dry powders are used to cover the metal and to keep it separate from oxygen. One kind of powder contains finely ground sodium chloride crystals mixed with a special polymer that allows the crystals to adhere to any surface, even a vertical one.

Questions

1. Identify the type of fire extinguisher available in your laboratory. On what classes of fires should it be used? Record the steps needed to use the fire extinguisher.
2. Explain why a person whose clothing has caught fire is likely to make the situation worse by running. Explain why wrapping a person in a fire blanket can help extinguish the flames.

internet connect

www.scilinks.org
Topic: Fire Extinguishers
SciLinks code: HW4059
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CHAPTER HIGHLIGHTS 8

KEY TERMS / KEY IDEAS

SECTION ONE Describing Chemical Reactions

Key terms: **chemical reaction**, **chemical equation**

- In a chemical reaction, atoms rearrange to form new substances.
- A chemical analysis is the only way to prove that a reaction has occurred.
- Symbols are used in chemical equations to identify the physical states of substances and the physical conditions during a chemical reaction.

SECTION TWO Balancing Chemical Equations

Key terms: **coefficient**

- A word equation is translated into a formula equation to describe the change of reactants into products.
- The masses, numbers, and types of atoms are the same on both sides of a balanced equation.
- Coefficients in front of the formulas of reactants and products are used to balance an equation. Subscripts cannot be changed.

SECTION THREE Classifying Chemical Reactions

Key terms: **combustion reaction**, **synthesis reaction**, **decomposition reaction**, **activity series**, **double-displacement reaction**

- In a combustion reaction, a carbon-based compound reacts with oxygen to form carbon dioxide and water.
- In a synthesis reaction, two reactants form a single product.
- In a decomposition reaction, a single reactant forms two or more products.
- In a displacement reaction, an element displaces an element from a compound. The activity series is used to determine if a reaction will happen.
- In a double-displacement reaction, the ions of two compounds switch places such that two new compounds form. One of the products must be a solid, a gas, or a molecular compound, such as water, for a reaction to occur.

SECTION FOUR Writing Net Ionic Equations

Key terms: **spectator ions**

- A total ionic equation shows all aqueous ions for a reaction.
- Spectator ions do not change during a reaction and can be removed from the total ionic equation.
- Net ionic equations show only the net change of a reaction and are the best way to describe displacement and double-displacement reactions.

KEY SKILLS

Balancing an Equation
Skills Toolkit 1 p. 268
Sample Problem A p. 269

The Odd-Even Technique
Sample Problem B p. 271

Polyatomic Ions as a Group
Sample Problem C p. 273

Predicting Products
Sample Problem D p. 279
Skills Toolkit 3 p. 284

Determining Products by Using the Activity Series
Skills Toolkit 2 p. 281
Sample Problem E p. 282

Writing Net Ionic Equations
Skills Toolkit 4 p. 288

8

Physical Setting/Chemistry
REGENTS EXAM PRACTICE

PART A

For each item, write on a separate piece of paper the number of the word, expression, or statement that best answers the item.

1. Which is evidence of a chemical change, but not of a physical change?
(1) Energy is absorbed.
(2) Energy is released.
(3) Reactants change state.
(4) New substances are formed.

2. In a chemical reaction, the original substances are known as
(1) solutions. **(3)** products.
(2) reactants. **(4)** catalysts.

3. How can the term *energy* be used in the equation for a chemical reaction?
(1) It must be written as a product and shown on the right side of the equation.
(2) It must be written as a reactant and shown on the left side of the equation.
(3) It is never included in a chemical equation.
(4) It may be written as either a reactant or a product.

4. In a chemical equation, the symbol *(aq)* indicates that the substance is
(1) water.
(2) an acid.
(3) dissolved in water.
(4) insoluble.

5. The use of a double arrow in a chemical reaction indicates that the reaction
(1) is reversible.
(2) requires energy as heat.
(3) is written backward.
(4) has not been confirmed in the laboratory.

6. In a word equation for a chemical reaction, the plus sign, +, represents the word
(1) *and.* **(3)** *produce.*
(2) *heat.* **(4)** *yield.*

7. According to the law of conservation of mass, the total mass of the reacting substances is
(1) always more than the total mass of the products.
(2) always less than the total mass of the products.
(3) sometimes more and sometimes less than the total mass of the products.
(4) always equal to the total mass of the products.

8. Which terms can be adjusted in order to balance a chemical equation?
(1) coefficients
(2) subscripts
(3) formulas of the products
(4) number of products formed

9. What is the number of hydrogen atoms represented in this equation?

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

(1) 1 **(3)** 10
(2) 6 **(4)** 12

Regents Test-Taking Tip

Focus on one question at a time unless you are asked to refer to previous answers.

10. Which quantity is represented by the coefficients in a chemical equation?
   (1) the number of grams of each substance that reacts
   (2) the number of molecules of each substance that reacts
   (3) the molar masses of each reactant and product
   (4) the number of valence electrons for each atom of reactant and product

11. What is the ratio of moles of nitrogen to moles of ammonia in the reaction below?

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

(1) 1:2 **(3)** 3:2
(2) 2:4 **(4)** 4:2

12. What is the coefficient for sodium nitrate when the equation below is correctly balanced using smallest whole number ratios?

$$Na_3PO_4 + Ca(NO_3)_2 \longrightarrow NaNO_3 + Ca_3(PO_4)_2$$

(1) 2 **(3)** 5
(2) 3 **(4)** 6

13. Which category includes the reaction shown below?

$$4Fe + 3O_2 \longrightarrow 2Fe_2O_3$$

(1) decomposition
(2) synthesis
(3) single replacement
(4) double replacement

14. Which category represents a reaction in which two compounds appear to exchange atoms or ions with one another?
(1) synthesis reaction
(2) decomposition reaction
(3) combustion reaction
(4) double replacement reaction

15. Which type of reaction involves only one reactant?
(1) decomposition
(2) single replacement
(3) synthesis
(4) combustion

16. The products of complete combustion of a hydrocarbon are
(1) carbon and hydrogen.
(2) carbon and water.
(3) carbon monoxide and water.
(4) carbon dioxide and water.

17. The number of products formed in a synthesis reaction is
(1) 1. **(3)** 3.
(2) 2. **(4)** 4.

18. Elements in an activity series are arranged in order of
(1) increasing ionization energy.
(2) increasing electronegativity.
(3) increasing atomic number.
(4) experimentally determined reactivity.

19. Ions which remain unchanged during a reaction are referred to as
(1) reactants. **(3)** separated ions.
(2) spectator ions. **(4)** products.

PART B–1

For each item, write on a separate piece of paper the number of the word, expression, or statement that best answers the item.

20. Which is an example of a chemical change?
(1) evaporating alcohol
(2) melting sodium
(3) burning propane
(4) freezing bromine

21. When magnesium strips are added to a test tube containing a dilute solution of hydrochloric acid, the magnesium dissolves and bubbles of hydrogen gas form. The test tube is hot to the touch. Which most likely provides evidence that a chemical reaction occurred?

(1) The magnesium dissolves.
(2) Hydrogen gas forms.
(3) The test tube gets warm.
(4) Bubbles come out of solution.

22. When an ionic solid is dissolved in water, its phase is best represented by the symbol

(1) (l). **(3)** (aq).
(2) (s). **(4)** (g).

23. In a balanced chemical equation which of the following must be equal?

(1) the number of molecules of reactants and products
(2) the number of moles of reactants and products
(3) the number of ions as reactants and as products
(4) the number of atoms of each element as reactants and as products

24. Why is it important not to change the subscripts when balancing chemical equations?

(1) The subscripts for each element are always the same.
(2) Changing the subscripts will change the chemical formula of a substance.
(3) The sum of the subscripts must be equal in a balanced equation.
(4) The subscripts represent the mole ratios of reactants and products.

25. How does a balanced equation represent conservation of mass?

(1) The number of molecules always remains the same.
(2) The sum of the coefficients is the same on each side of the equation.
(3) For each element, the reactants contain the same number of atoms as the products.
(4) The number of moles of reactants equals the number of moles of products.

26. Examine the following unbalanced equation.

$$C_2H_4(g) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$$

When this equation is balanced using smallest whole number ratios, the coefficient of $O_2(g)$ is

(1) 1. **(3)** 3.
(2) 2. **(4)** 4.

27. When water is decomposed according to the equation $2H_2O \longrightarrow 2H_2 + O_2$, the number of hydrogen molecules formed from the decomposition of one molecule of water is

(1) one. **(3)** five.
(2) two. **(4)** four.

28. Which equation illustrates conservation of mass?

(1) $H_2 + Cl_2 \longrightarrow 2HCl$
(2) $H_2 + Cl_2 \longrightarrow HCl$
(3) $H_2 + O_2 \longrightarrow H_2O$
(4) $H_2 + O_2 \longrightarrow 2H_2O$

29. When the equation $H_2 + N_2 \longrightarrow NH_3$ is balanced using smallest whole number ratios, the sum of the coefficients is

(1) five. **(3)** three.
(2) six. **(4)** four.

30. When aqueous solutions of sodium chloride and silver nitrate are mixed, a cloudy white precipitate forms. Which category most likely includes this chemical reaction?

(1) synthesis
(2) decomposition
(3) single replacement
(4) double replacement

31. When a solid piece of zinc is placed in a solution of copper(II) sulfate, a reddish brown solid forms and the solution loses its original blue color. Which category most likely includes this chemical reaction?

(1) synthesis
(2) decomposition
(3) single replacement
(4) double replacement

32. What are the two products formed if a hydrocarbon does not completely combust because of a lack of oxygen?
(1) carbon monoxide and water
(2) carbon dioxide and water
(3) carbon and water
(4) carbon and hydrogen

33. The products of a single replacement reaction between zinc and a solution of copper(II) chloride are
(1) chlorine and zinc.
(2) chlorine and copper.
(3) copper and zinc chloride.
(4) chlorine and zinc chloride.

34. What are the products of the decomposition of calcium carbonate, $CaCO_3$?
(1) CaO and CO_2
(2) Ca, C, and O_2
(3) CaC and O_2
(4) Ca and CO_3

35. Which symbols represent an aqueous solution of sodium chloride in a net ionic equation?
(1) $NaCl(l)$
(2) $NaCl(aq)$
(3) $Na^+(aq) + Cl^-(aq)$
(4) $Na^+(l) + Cl^-(l)$

36. Which are the spectator ions in the equation shown below?

$$AgNO_3(aq) + Br(aq) \longrightarrow AgBr(s) + KNO_3(aq)$$

(1) K^+ and Br^-
(2) Ag^+ and NO_3^-
(3) Ag^+ and Br^-
(4) K^+ and NO_3^-

37. Which is the spectator ion in the equation shown below?

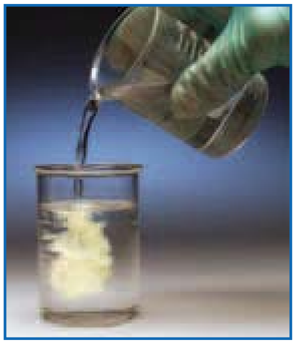
$$Zn(s) + HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$$

(1) Zn^{2+}
(2) H^+
(3) Cl^-
(4) H_2

PART B–2

Answer the following items.

38. Examine the photograph shown below.



a. Identify evidence that a chemical reaction has taken place.
b. What type of reaction is shown in this photograph? Explain your answer.

39. Aluminum metal reacts with fluorine gas to produce aluminum fluoride.
a. Write a balanced equation using the smallest whole number ratios.
b. What type of reaction does this balanced equation represent?

40. Rewrite each of the following chemical equations as a word equation.
a. $CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + H_2O(g)$
b. $NaCl(aq) + AgNO_3(aq) \longrightarrow NaNO_3(aq) + AgCl(s)$
c. $Mg(s) + HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g)$

Items 41 to 44 are based on the following information.

Calcium oxide, CaO, is an ingredient in cement mixes. When water is added to CaO, the mixture warms up and calcium hydroxide $Ca(OH)_2$ is formed.

41. State two kinds of observations that indicate that a chemical reaction has occurred.

42. Write a balanced chemical equation that represents the reaction between CaO and H_2O.

43. Add the term *energy* to the correct side of the equation for item 42.

44. What type of reaction is represented by the equation for item 42?

---

45. Write a balanced equation, including the state of matter symbols, that represents the reaction of steam with solid carbon to form carbon monoxide and hydrogen.

46. For each of the following word equations, write a balanced chemical reaction:
a. Copper(II) sulfate plus ammonium sulfide yields copper(II) sulfide plus ammonium sulfate.
b. Nitric acid plus barium hydroxide produces barium nitrate plus water.
c. Barium chloride plus phosphoric acid yields barium phosphate plus hydrochloric acid.

47. What type of reaction is represented by all the balanced equations in item 46? Explain your answer.

48. When solutions of lead(II) nitrate and potassium iodide are mixed, a yellow precipitate of lead(II) iodide is formed. Write a balanced chemical equation to illustrate this reaction. Include the state symbols.

Items 49–51 refer to the following unbalanced combustion reaction.

$$C_3H_8(g) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$$

49. When properly balanced, what is the coefficient for oxygen?

50. When properly balanced, what is the coefficient for carbon dioxide?

51. When properly balanced, how many hydrogen atoms are present on each side of the equation?

---

52. Based on the activity series in **Appendix A**, determine which of the following reactions would occur. Explain your answer.
a. Na and $MgCl_2$
b. Zn and $MgCl_2$
c. Pb and $MgCl_2$
d. Ag and $MgCl_2$
e. K and $MgCl_2$

53. Write the net ionic equation for each of the following reactions.
a. $Mg(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g)$
b. $CaCl_2(aq) + Na_2CO_3(aq) \longrightarrow 2NaCl(aq) + CaCO_3(s)$
c. $Mg(s) + Zn(NO_3)_2(aq) \longrightarrow Zn(s) + Mg(NO_3)_2(aq)$

PART C

Answer the following items.

54. Iron(III) chloride is a chemical compound used in photography. It can be produced by reacting iron and chlorine. Identify the correct chemical equation for this reaction from the choices below. Explain why the other choices are incorrect.

a. $Fe(s) + Cl_2(g) \longrightarrow FeCl_2(s)$

b. $2Fe(s) + 3Cl_2(g) \longrightarrow 2FeCl_3(s)$

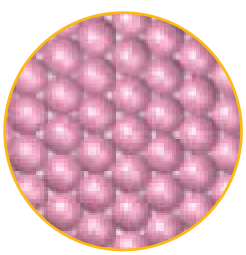
c. $4Fe(s) + 3Cl_2(g) \longrightarrow 2Fe_2Cl_3(s)$

55. When wood burns, the ash that remains weighs much less than the original wood. Explain why this observation does not violate the law of conservation of mass.

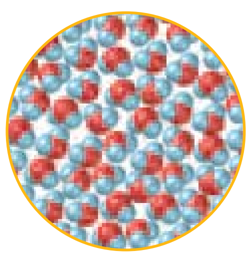
56. Methanol, CH_3OH, is a clean-burning fuel. It has been investigated as a possible alternative fuel for automobiles and other combustion engines. Write a balanced chemical equation for the synthesis of methanol from carbon monoxide and hydrogen gas.

57. Aluminate sulfate and calcium hydroxide are used in a water-purification process. When added to water, these two solids dissolve and react to produce two precipitates, aluminum hydroxide and calcium sulfate. These products purify the water as they settle out, taking suspended solid particles with them. Write the balanced chemical equation for this water-purification reaction.

58. The images below represent the reactants of a chemical reaction that releases energy as heat. Study the images and answer the following questions.



sodium



water

a. Write a balanced chemical equation that shows the reactants, products, and states of matter of all substances in the reaction.

b. Add the term *energy* to the proper side of the equation.

c. What type of reaction does this represent?

59. Sodium bicarbonate, commonly known as baking soda can be used to neutralize stomach acid, HCl, producing sodium chloride, water, and carbon dioxide. Calcium carbonate is found in many over-the counter antacid products and will neutralize stomach acid, producing water, calcium chloride, and carbon dioxide. Write balanced chemical equations for the reaction of each antacid with HCl.

60. Create an activity series for the hypothetical elements, A, J, Q, and Z, by using the reaction information provided below.

$A + ZX \longrightarrow Ax + Z$

$J + ZX \longrightarrow$ no reaction

$Q + AX \longrightarrow QX + A$

Items 61–66 are based on the following passage.

The Contact Process

The product produced by the chemical industry in the United States in the largest quantity by mass is sulfuric acid. One of the methods of its production is the contact process, which essentially uses three steps to produce pure sulfuric acid. In the first step, sulfur is burned in the presence of oxygen gas to yield sulfur dioxide gas. It may also be obtained by burning hydrogen sulfide gas to produce water and sulfur dioxide.

The second step further oxidizes the sulfur dioxide by adding more oxygen to yield sulfur trioxide gas. The second step is a slow process that is speeded up by the use of a vanadium pentoxide catalyst. It is also a slightly exothermic process. In the third and final step, the sulfur trioxide is then mixed with 98% sulfuric acid. The sulfur trioxide mixes with the remaining 2% water to form pure liquid sulfuric acid.

Concentrated sulfuric acid is then used in the manufacture of other products, including agricultural fertilizers. Sulfuric acid has a great affinity for water and is widely used as a drying agent to remove water from chemical compounds during the manufacturing process. It is even used to prepare dried fruits! It will dehydrate table sugar ($C_{12}H_{22}O_{11}$) leaving a solid black residue and releasing a great deal of steam and energy as heat. When concentrated sulfuric acid is added to water, the reaction is so highly exothermic that enough energy as heat may be released to boil the mixture. For this reason, concentrated sulfuric acid must be added to water slowly and carefully.

61. What are the reactants in the first step of the contact process?

62. Write the balanced chemical equation for the first step of the contact process in which sulfur is burned to produce sulfur dioxide.

63. Write the chemical formula for the product of the second step of the contact process. Be sure to include the catalyst in the proper location in the equation.

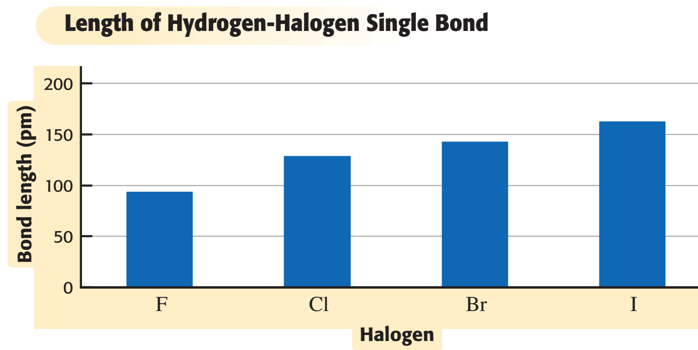
64. Write a balanced chemical equation, including notation of states of matter for the third and final step of the contact process.

65. When writing a chemical equation to represent the dissolving of concentrated sulfuric acid in water, on what side of the equation should the term *energy* be written?

66. Which component of table sugar is most likely to be left behind as a black residue after the reaction with concentrated sulfuric acid?

FOCUS ON GRAPHING

Study the graph below, and answer the questions that follow.
For help in interpreting graphs, see Appendix B, "Study Skills for Chemistry."



67. Which halogen has the shortest single bond with hydrogen?

68. What is the difference in length between an H—Br bond and an H—I bond?

69. Describe the trend in bond length as you move down the elements in Group 17 on the periodic table.

70. Based on this graph, what conclusion can be drawn about the relative sizes of halogen atoms? Could you draw the same conclusion if an atom of an element other than hydrogen was bonded to an atom of each halogen?

TECHNOLOGY AND LEARNING

71. Graphing Calculator

Least Common Multiples When writing chemical formulas or balancing a chemical equation, being able to identify the least common multiple of a set of numbers can often help. Your graphing calculator has a least common multiple function that can compare two numbers. On a TI-83 Plus or similar graphing calculator, press MATH ➢ 8. The screen should read "lcm(." Next, enter one number and then a comma followed by the other number and a closing parenthesis. Press ENTER, and the calculator will show the least common multiple of the pair you entered.

Use this function as needed to find the answers to the following questions.

a. Tin(IV) sulfate contains Sn^{4+} and SO_4^{2-} ions. Use the least common multiple of 2 and 4 to determine the empirical formula for this compound.

b. Aluminum ferrocyanide contains Al^{3+} ions and $Fe(CN)_6^{4-}$ ions. Use the least common multiple of 3 and 4 to determine the empirical formula for this compound.

c. Balance the following **unbalanced** equation.

$$\_\_P_4O_{10}(s) + \_\_H_2O(g) \longrightarrow \_\_H_3PO_4(aq)$$

d. Balance the following **unbalanced** equation.

$$\_\_KMnO_4(aq) + \_\_MnCl_2(aq) + 2H_2O(l) \longrightarrow \_\_MnO_2(s) + 4HCl(aq) + 2KCl(aq)$$

e. The combustion of octane, C_8H_{18}, and oxygen, O_2, is one of many reactions that occur in a car's engine. The products are CO_2 and H_2O. Balance the equation for the combustion reaction. (Hint: Balance oxygen last, and use the least common multiple of the number of oxygen atoms on the products' side and on the reactants' side to help balance the equation.)