11.1 Describing Chemical Reactions

Connecting to Your World On May 6, 1937, the huge airship Hindenburg was heading for its landing site in Lakehurst, New Jersey, after an uneventful trans-Atlantic crossing. Suddenly, to the horror of observers on the ground, the airship erupted into a fireball. Within a short time, 210,000 cubic meters of the airship's lifting gas, hydrogen, had burned and the airship was destroyed. The chemical reaction that occurred can be described as "hydrogen combines with oxygen to produce water." In this section, you will learn to represent this chemical reaction by a chemical equation.

Guide for Reading

Key Concepts

- How do you write a word equation?
- How do you write a skeleton equation?
- What are the steps in writing a balanced chemical equation?

Vocabulary

chemical equation
skeleton equation
catalyst
coefficients
balanced equation

Reading Strategy

Relating Text and Visuals As you read this section, look at the illustrations of equations. In your notebook, explain how the illustrations demonstrate the difference between a balanced and unbalanced chemical equation.

Writing Chemical Equations

Every minute of the day chemical reactions take place—both inside you and around you. Not all are as dramatic as the explosion of the Hindenburg, but many are more complex. After a meal, a series of chemical reactions take place as your body digests food. Similarly, plants use sunlight to drive the photosynthetic processes needed to produce plant growth. Although the chemical reactions involved in photosynthesis and digestion are different, both chemical reactions are necessary to sustain life.

In a chemical reaction, one or more reactants change into one or more products. Figure 11.1a shows the ingredients for making leavened bread—flour, salt, yeast, and water. Chemical reactions take place when the ingredients are mixed together and heated in the oven. Figure 11.1b shows the product—a loaf of bread. Chemists use a chemical equation—a quick, shorthand notation—to convey as much information as possible about what happens in a chemical reaction.

Figure 11.1 Chemical changes occur when bread dough is mixed and baked. a Flour, salt, yeast, and water are the ingredients for making leavened bread. b Reactants in the ingredients undergo chemical changes to form the product (baked bread). **Observing** ***What evidence shows that chemical changes have occurred?***

Section Resources

Print

- **Guided Reading and Study Workbook,** Section 11.1
- **Core Teaching Resources,** Section 11.1 Review
- **Small-Scale Chemistry Laboratory Manual,** Lab 14
- **Transparencies,** T113–T117

Technology

- **Interactive Textbook with ChemASAP,** Animation 12; Simulation 11; Problem-Solving 11.2, 11.4, 11.6; Assessment 11.1
- **Go Online,** Section 11.1

11.1

1 FOCUS

Objectives

11.1.1 Describe how to write a word equation.
11.1.2 Describe how to write a skeleton equation
11.1.3 Describe the steps for writing a balanced chemical equation.

Guide for Reading

Build Vocabulary L2

Paraphrase Write the following chemical equation on the board and have students provide synonymous words or phrases for each of the vocabulary words as they describe the equation:

$$2H_2O_2 \xrightarrow{MnO_2} 2H_2O + O_2$$

Reading Strategy L2

Sequence As students read this section, have them write in their own words the sequence of steps that need to be taken to write and balance a chemical equation.

2 INSTRUCT

Connecting to Your World

Have students study the photograph and read the text. Explain that airships during the 1930s often contained hydrogen because it is the lightest element. However, when hydrogen is ignited in air, a vigorous reaction occurs. Have students describe the results as shown in the photograph. Write the word equation for the reaction of hydrogen with oxygen to produce water. Ask, **Do you think there is a simpler way to write chemical equations?** *(Yes, describe the reaction using chemical symbols of the elements and chemical formulas of compounds.)*

Answers to...

Figure 11.1 The separate ingredients of the bread are now combined into one product—the loaf of bread.

Writing Chemical Equations

Discuss L2

To assess students' prior knowledge about chemical compounds, ask, **What are the differences between molecular compounds and ionic compounds?** *(Molecular compounds are composed of nonmetallic elements. Ionic compounds are composed of a metal cation and an anion.)* **How are chemical compounds represented?** *(By chemical formulas that show the kinds and numbers of atoms in each molecule or formula unit.)* **What is the difference between a monatomic ion and a polyatomic ion?** *(A monatomic ion is formed when an atom gains or loses one or more electrons. A polyatomic ion is a tightly bound group of atoms that behaves as a unit and carries a charge.)*

Use Visuals L1

Figure 11.1 Have students study the photographs. Ask, **What are some indications that a chemical reaction has taken place?** *(increase in volume and change in color)* Explain that bakers use yeast to make bread dough rise. Yeasts are unicellular organisms that are able to extract energy from sugar in the absence of oxygen, a process known as fermentation. Point out that yeasts produce proteins that catalyze or facilitate the breakdown of carbohydrates in the dough, producing CO_2 and ethanol. The bubbles of trapped CO_2 cause the dough to rise. As the dough bakes, the ethanol evaporates.

Go Online NSTA SciLinks

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

Figure 11.2 Three common chemical reactions are shown. a When methane gas burns, it combines with oxygen to form carbon dioxide and water. b Iron turns to red-brown rust (iron(III) oxide) in the presence of oxygen in the air. c Hydrogen peroxide decomposes to water and oxygen when used as an antiseptic.

Word Equations

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

Reactants ⟶ products

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

Iron + oxygen ⟶ iron(III) oxide

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

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

Hydrogen peroxide ⟶ water + oxygen

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

Methane + oxygen ⟶ carbon dioxide + water

Checkpoint ***What does the arrow (⟶) in a word equation mean?***

Go Online NSTA SciLinks
For: Links on Chemical Equations
Visit: www.SciLinks.org
Web Code: cdn-1111

Differentiated Instruction

English Learners L1

As they read through the chapter, Spanish-speaking students with limited English proficiency may find it helpful to consult the chapter summary and key terms in the Spanish supplement in the Teacher's Resource Package.

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

$$Fe + O_2 \longrightarrow Fe_2O_3$$

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

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

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

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

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

Many of the symbols commonly used in writing chemical equations are listed in Table 11.1.

Table 11.1

Symbols Used in Chemical Equations

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

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

Interactive Textbook

Animation 12 Relate chemical symbols and formulas to the information they communicate.

with ChemASAP

Use Visuals L1

Table 11.1 Use an overhead projector to display Table 11.1. Make sure students understand the meaning and role of each symbol. Point out that the phase symbols provide important clues about reactions. Note that the items placed above the yield arrow represent conditions that must be met before the reaction can take place at a reasonable pace.

Use Visuals L1

Figure 11.3 Point out that although hydrogen peroxide contains the same kinds of elements as water, it has very different properties. Hydrogen peroxide is much less stable than water. Have students write the balanced chemical equation for the reaction described in the caption. Students should indicate the MnO_2 catalyst above the reaction arrow. Write the equation on the board and explain that this is an example of a decomposition reaction—a single compound is broken down into two or more products. Explain that although hydrogen peroxide is an unstable compound that readily decomposes to produce water and oxygen, it does so slowly at room temperature. Therefore, hydrogen peroxide must come in contact with a catalyst in order for the decomposition to proceed rapidly, as shown in **b**.

Relate L2

Tell students that frequently in nature the products of one reaction become the reactants of a subsequent reaction. An example is the combustion of octane (C_8H_{18}), the primary ingredient of gasoline, which produces carbon dioxide and water vapor. The carbon dioxide can combine with atmospheric water vapor to produce carbonic acid (H_2CO_3), which is a component of acid rain. Ask students if they can think of other such processes.

Facts and Figures

Hydrogen Peroxide

Challenge students to propose a hypothesis about why our bodies produce an enzyme that helps catalyze the decomposition of hydrogen peroxide. *(to prevent the accumulation in the body of hydrogen peroxide, a toxic by-product of reactions involving oxygen.)* Students may be interested to learn that hydrogen peroxide is sometimes used to restore the clarity of old paintings. Lead-based paints darken with time (PbS). Hydrogen peroxide converts PbS to $PbSO_4$.

Answers to...

Checkpoint The arrow means yields, gives, or reacts to produce.

CONCEPTUAL PROBLEM 11.1

Answers

1. When solid sodium is dropped in water, hydrogen gas and aqueous sodium hydroxide are produced.
2. $S(s) + O_2(g) \rightarrow SO_2(g)$

Balancing Chemical Equations

Discuss L2

Review with students the law of conservation of mass. Emphasize that mass, or matter, cannot be created or destroyed. Explain that it is because of this law that a chemical equation is not complete until it is balanced.

Address Misconceptions

Students often think that they can balance an equation by changing the subscripts in one or more of the formulas. Use the following example to show why this approach is incorrect. $H_2(g) + O_2(g) \rightarrow H_2O(l)$ could be balanced by changing the formula of the product to H_2O_2. But H_2O_2 (hydrogen peroxide) is not the same substance as water. Therefore, the equation would describe a different reaction. To help students overcome this misconception, have them draw a box around the formulas for the reactants and products before they start to balance the equation. Tell them that the boxes are "off-limits" or "out of bounds." They cannot change any number that appears inside a box.

Relate L2

Glass is often etched to provide a design. Glass contains calcium silicate, $CaSiO_3$. When hydrofluoric acid, HF, is placed on the glass, it reacts with the calcium silicate, etching the glass by producing aqueous calcium fluoride, silicon tetrafluoride, and water. Have students write a balanced chemical equation for this reaction. *($CaSiO_3 + 6HF \rightarrow CaF_2 + SiF_4 + 3H_2O$)*

CONCEPTUAL PROBLEM 11.1

Writing a Skeleton Equation

Hydrochloric acid and solid sodium hydrogen carbonate are shown before being placed in the beaker to react. The products formed are aqueous sodium chloride, water, and carbon dioxide gas. Write a skeleton equation for this chemical reaction.

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

Write the correct formula for each substance in the reaction. Separate the reactants from the products by means of an arrow. Indicate the state of each substance.

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

solid sodium hydrogen carbonate: $NaHCO_3(s)$
hydrochloric acid: $HCl(aq)$
aqueous sodium chloride: $NaCl(aq)$
water: $H_2O(l)$
carbon dioxide gas: $CO_2(g)$

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

Practice Problems

1. Write a sentence that describes this chemical reaction.
   $Na(s) + H_2O(l) \longrightarrow NaOH(aq) + H_2(g)$
2. Sulfur burns in oxygen to form sulfur dioxide. Write a skeleton equation for this chemical reaction. Include appropriate symbols from Table 11.1.

Interactive Textbook
Problem-Solving 11.2
Solve Problem 2 with the help of an interactive guided tutorial.
with ChemASAP

Balancing Chemical Equations

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

$$\underset{\text{(reactants)}}{\text{Frame + wheel + handlebar + pedal}} \longrightarrow \underset{\text{(product)}}{\text{bicycle}}$$

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

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

$$F + W + H + P \longrightarrow FW_2HP_2$$

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

Differentiated Instruction

Special Needs L1

Have students, working in pairs, take turns writing equations for each other to balance. Two pairs of students may enjoy getting together for a "doubles match" in which each pair works as a team to balance equations that the opposing team creates.

F + 2W + H + 2P ⟶ FW_2HP_2

This is a balanced equation for making a bicycle. It tells you that one frame, two wheels, one handlebar, and two pedals produce one bicycle. To balance the equation, the number 2 was placed before wheels and pedals. The number 1 is understood to be in front of frame, handlebar, and bicycle. These numbers are called **coefficients**—small whole numbers that are placed in front of the formulas in an equation in order to balance it. In this balanced equation, the number of each bicycle part on the reactant side is the same as the number of those parts on the product side. A chemical reaction is also described by a **balanced equation** in which each side of the equation has the same number of atoms of each element and mass is conserved. Real bicycles are being assembled in Figure 11.4.

Recall that John Dalton's atomic theory states that as reactants are converted to products, the bonds holding the atoms together are broken and new bonds are formed. The atoms themselves are neither created nor destroyed; they are merely rearranged. This part of Dalton's theory explains the law of conservation of mass: In any chemical change, mass is conserved. The atoms in the products are the same atoms that were in the reactants—they are just rearranged.

Representing a chemical reaction by a balanced chemical equation is a two-step process. **To write a balanced chemical equation, first write the skeleton equation. Then use coefficients to balance the equation so that it obeys the law of conservation of mass.** In every balanced equation, each side of the equation has the same number of atoms of each element.

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

C(*s*) + O_2(*g*) ⟶ CO_2(*g*)

Reactants
1 carbon atom, 2 oxygen atoms

Product
1 carbon atom, 2 oxygen atoms

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

Checkpoint ***What is the law of conservation of mass?***

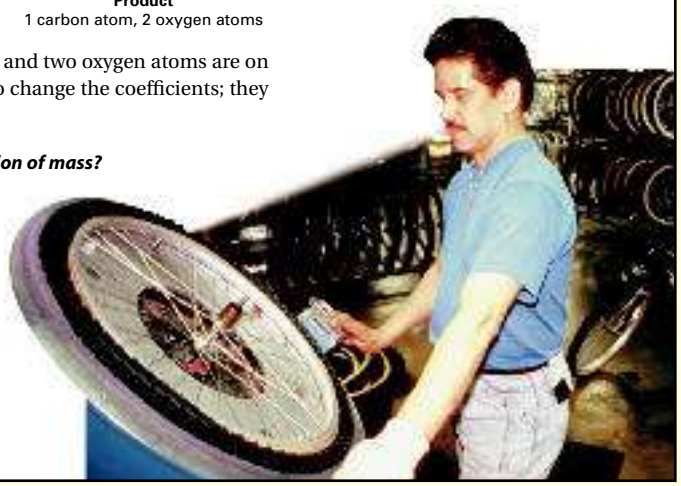


Figure 11.4 If a bicycle factory runs out of any part needed for a bicycle, production must stop.

Differentiated Instruction

Gifted and Talented L3

Point out to students that not all chemical equations are easily balanced. Methods other than those they currently use must be used to balance some equations, such as those they will encounter in Chapter 21.

Challenge students to balance the following equation.

$HCl + HNO_3 \rightarrow HOCl + NO + H_2O$

($3HCl + 2HNO_3 \rightarrow 3HOCl + 2NO + H_2O$)

TEACHER Demo

An Example of Chemical Change L2

Purpose Students observe a dramatic example of chemical change.

Materials 150-mL Pyrex beaker, table sugar, hood, concentrated sulfuric acid

Procedure Fill a 150-mL Pyrex beaker to the 30-mL mark with table sugar. Place the beaker in a hood, and add 30 mL of concentrated sulfuric acid, which will dehydrate the sugar.

Safety and Disposal The hood will remove any sulfur dioxide and carbon monoxide, which are possible by-products of the reaction. Wear goggles, a face shield, a lab apron, and protective gloves. Use a plexiglas shield to separate the students from the reaction. As a further precaution, have them wear goggles. While wearing protective gear, place the beaker and contents into a 500-mL beaker half full of water. Swirl the small beaker in the water and then neutralize using a base with a molarity of less than 1*M*. Decant the liquid and fill the large beaker halfway with water once again. Let stand overnight in a protected location, test for pH, and neutralize. Repeat if necessary. Wrap the carbon in newspaper before placing in a wastebasket.

Expected Outcome The carbon left behind will expand to form a porous, foam cylinder as the water vapor escapes.

Discuss L2

Tell students that it is not necessary for coefficients to be the same on both sides of the equation in order for the number of atoms of each type to balance. Use the diagram of the formation of CO_2 on the student page to illustrate this concept. The atoms balance, but the coefficients total 2 on the left side of the equation and 1 on the right side. If the sums of the coefficients on both sides of a balanced chemical equation are the same number, it is coincidental.

Answers to...

Checkpoint In any physical or chemical change, mass is conserved.

Quick LAB

Removing Silver Tarnish L2

Objective After completing this activity, students will be able to:

- describe and write a balanced chemical equation for a single-replacement reaction.

Skills Focus Observing, Inferring, Communicating Results

Prep Time 10 minutes
Class Time 20 minutes

Expected Outcome Aluminum replaces the silver in the tarnish on the fork or spoon.

Analyze and Conclude

1. After the reaction, the fork looks silvery, and the tarnish is gone.
2. The aluminum becomes darkened.
3. Al_2S_3
4. $3Ag_2S(s) + 2Al(s) \rightarrow 6Ag(s) + Al_2S_3(s)$

For Enrichment L3

Have students repeat the Quick Lab using a piece of magnesium instead of aluminum foil. Have them compare the results and the speed of the reaction. Students will find that the reaction occurs more quickly with magnesium. After students learn about single-replacement reactions on page 333, have them explain why the reaction proceeded more rapidly with magnesium. *(Magnesium is more active than aluminum.)*

Relate L2

Tell students that one way of purifying air in space vehicles is to react lithium peroxide with carbon dioxide, producing lithium carbonate and oxygen. Ask, **What is the balanced chemical equation for this reaction?** *($2Li_2O_2 + 2CO_2 \rightarrow 2Li_2CO_3 + O_2$)*

Quick LAB

Removing Silver Tarnish

Materials

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

Procedure

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

Analyze and Conclude

1. Compare the silver fork with your observations before placing the fork in the water. What changes do you observe?
2. Did a chemical reaction occur? How do you know?

3. The tarnish on the silver fork is silver sulfide (Ag_2S). Silver becomes tarnished when it is exposed to air, egg yolk, or rubber bands. Each of these substances contains sulfur. Look carefully for a pale yellow precipitate of aluminum sulfide on the bottom of the beaker. Write the formula for aluminum sulfide.
4. The unbalanced equation for the reaction is

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

Balance the equation.

What about the equation for the reaction of hydrogen gas and oxygen gas? This is the reaction that occurred in the Hindenburg disaster, which you read about in *Connecting to Your World*. When hydrogen and oxygen are mixed, a spark will initiate a rapid reaction. The product of the reaction is water. This is the equation for the burning of hydrogen:

$H_2(g)$ Hydrogen + $O_2(g)$ Oxygen ⟶ $H_2O(l)$ Water

Reactants
2 hydrogen atoms
2 oxygen atoms

Product
2 hydrogen atoms
1 oxygen atom

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

Interactive Textbook
Simulation 11 Sharpen your skills by balancing chemical equations.
with ChemASAP

Differentiated Instruction

Special Needs L1

Polystyrene models can help students understand the meaning of subscripts and coefficients when balancing chemical reactions. They can also help illustrate how atoms are rearranged during a chemical reaction. Use a knife or razor blade to cut polystyrene balls of various sizes in half. Paint the hemispheres different colors to stand for various elements. Glue a small, flat magnet to the flat side of each of the hemispheres. Using the spheres, show on a metal board how formulas of reactants become formulas of products in various types of reactions.

Rules for Writing and Balancing Equations

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

CONCEPTUAL PROBLEM 11.2

Writing a Balanced Chemical Equation

Hydrogen and oxygen react to form water. The reaction releases enough energy to launch a rocket. Write a balanced equation for the reaction.

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

Apply the rules for balancing equations to the skeleton equation describing the reaction.

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

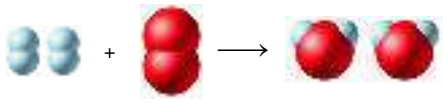
Write correct formulas to give the skeleton equation.

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

Count the number of each kind of atom. Hydrogen is balanced but oxygen is not. If you put the coefficient 2 in front of H_2O, the oxygen will be balanced.

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

Now twice as many hydrogen atoms are in the product as are in the reactants. To correct this, put the coefficient 2 in front of H_2. Four hydrogen atoms and two oxygen atoms are on each side of the chemical equation. The equation is now balanced.



$2H_2(g)$ Hydrogen + $O_2(g)$ Oxygen ⟶ $2H_2O(l)$ Water

Reactants
4 hydrogen atoms
2 oxygen atoms

Products
4 hydrogen atoms
2 oxygen atoms

Practice Problems

3. Balance each equation.
   a. $AgNO_3 + H_2S \longrightarrow Ag_2S + HNO_3$
   b. $Zn(OH)_2 + H_3PO_4 \longrightarrow Zn_3(PO_4)_2 + H_2O$
4. Rewrite these word equations as balanced chemical equations.
   a. hydrogen + sulfur ⟶ hydrogen sulfide
   b. iron(III) chloride + calcium hydroxide ⟶ iron(III) hydroxide + calcium chloride

Interactive Textbook
Problem-Solving 11.4 Solve Problem 4 with the help of an interactive guided tutorial.
with ChemASAP

Differentiated Instruction

English Learners L1

Have students name different elements in their native languages and in English. Some periodic table Internet sites list the names of elements in several languages other than English. Then have them list the symbols for several elements in their native languages.

Point out that the names might differ, but chemical symbols are the same in any language. Balancing equations uses only universal symbols and numbers and is not language dependent.

CONCEPTUAL PROBLEM 11.2

Answers

3. **a.** $2AgNO_3 + H_2S \rightarrow Ag_2S + 2HNO_3$
   b. $3Zn(OH)_2 + 2H_3PO_4 \rightarrow Zn_3(PO_4)_2 + 6H_2O$
4. **a.** $H_2 + S \rightarrow H_2S$
   b. $2FeCl_3 + 3Ca(OH)_2 \rightarrow 2Fe(OH)_3 + 3CaCl_2$

Practice Problems Plus L2

1. Rewrite the following word equation as a balanced chemical equation: aluminum sulfate + calcium hydroxide → aluminum hydroxide + calcium sulfate. *($Al_2(SO_4)_3 + 3Ca(OH)_2 \rightarrow 2Al(OH)_3 + 3CaSO_4$)*

2. Rewrite the following word equation as a balanced chemical equation: phosphoric acid + sodium hydroxide → sodium phosphate + water. *($H_3PO_4 + 3NaOH \rightarrow Na_3PO_4 + 3H_2O$)*

TEACHER Demo

Balance a Chemical Equation L2

Purpose Students observe a chemical reaction and write skeleton and balanced chemical equations for the reaction.

Materials 100-mL graduated cylinder, 0.1*M* copper(II) chloride solution, 400-mL beaker, metric ruler, scissors, aluminum foil

Safety $CuCl_2$ is an irritant.

Procedure Add 200 mL of 0.1*M* copper(II) chloride solution to a 400-mL beaker. Cut a 5-cm square piece of aluminum foil. Crumple the piece of aluminum foil into a loose ball and place it in the copper solution. Ask students to note any evidence of chemical change. Write a sentence on the board that describes the chemical reaction. Have students write a skeleton equation for the reaction in their notebooks. Then have students balance the equation. Decant the liquid and flush down the drain with excess water. Dry the copper residue and use it again.

Expected Outcome The solution will begin to produce gas and a red-brown precipitate of copper will fall to the bottom of the beaker. The skeleton equation is $CuCl_2(aq) + Al(s) \rightarrow AlCl_3(aq) + Cu(s)$. The balanced chemical equation is $3CuCl_2(aq) + 2Al(s) \rightarrow 2AlCl_3(aq) + 3Cu(s)$.

CONCEPTUAL PROBLEM 11.3

Answers

5. a. $FeCl_3 + 3NaOH \rightarrow Fe(OH)_3 + 3NaCl$

b. $CS_2 + 3Cl_2 \rightarrow CCl_4 + S_2Cl_2$

6. $Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4 + 2H_2O$

Discuss

L2

Emphasize to students that in order to write a correct balanced chemical equation, the formulas for all reactants and products must be written correctly. Write an unbalanced chemical equation on the board, with all the formulas written correctly. Rewrite the equation with one formula written incorrectly. Identify the incorrect formula so that students consistently recognize that it is not correct. Have students balance the two equations and note the differences. Often an equation with an incorrect formula cannot be balanced.

Relate

L2

Point out that balanced chemical equations can help manufacturers who use chemical processes to know how much of each reactant should be purchased and how much of each product will be made. For example, a welder might use oxygen and acetylene (C_2H_2) in a torch. Have students write a balanced chemical equation for the reaction that occurs in the torch. Water and carbon dioxide are produced. *($2C_2H_2 + 5O_2 \rightarrow 4CO_2 + 2H_2O$)* Ask, **From this balanced equation, what would be an effective acetylene: oxygen ratio in the torch?** *(2:5)*

Have students research chemistry-related careers in the library or on the Internet. Students can then construct a table that describes the nature of the work, educational and training requirements, employment outlook, working conditions, and other necessary information.

The reaction of copper metal with an aqueous solution of silver nitrate is described by this skeleton equation. How can it be balanced?

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

The nitrate ion appears unchanged on both sides of the equation, so this ion can be balanced as a unit. Do this by placing a 2 in front of $AgNO_3$.

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

But now the atoms of silver are not balanced. You must add a 2 in front of Ag on the product side to balance the atoms of silver.

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

The equation is now balanced because the same number of each kind of atom are on both sides of the equation.

CONCEPTUAL PROBLEM 11.3

Balancing a Chemical Equation

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

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

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

Apply the rules for balancing equations.

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

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

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

How can the odd number of oxygen atoms in the product (right side) balance the even number of oxygen atoms on the left? Any whole-number coefficient placed in front of the O_2 will give an even number of oxygen atoms on the left. This is because the coefficient is always being multiplied by the subscript 2. The solution is to multiply the formula with the odd number of oxygen atoms by 2.

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

Now six oxygen atoms are on the right. Balance the oxygens on the left by placing a 3 in front of O_2. Then rebalance the aluminum by changing the coefficient of Al(*s*) from 2 to 4.

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

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

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

Because this equation obeys the law of conservation of mass, it is correct. However, equations are normally written with coefficients in their lowest possible ratio. Each of the coefficients can be divided by 2 to give the previous equation, which has the lowest whole-number ratio of coefficients.

Practice Problems

5. Balance each equation.

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

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

6. Write and balance this equation.

calcium hydroxide + sulfuric acid $\longrightarrow$ calcium sulfate + water

Problem-Solving 11.6
Solve Problem 6 with the help of an interactive guided tutorial.

with ChemASAP

Differentiated Instruction

Special Needs

L1

Provide students with molecular model kits or Styrofoam balls of different sizes and colors. Using the balls to represent different types of atoms, have students model balancing a simple equation. Provide students with several additional unbalanced chemical equations, and have them balance the equations using the models. Caution students to keep "atoms" in compounds together so that they use multiples of the entire unit and not multiples of just one atom in the unit.

Hazardous Materials Specialist

Hazardous materials specialists do the vital work of keeping the environment safe from harmful substances. Backed by regulations devised primarily by the Environmental Protection Agency (EPA), these specialists are responsible for the safe handling, treatment, storage, and transportation of hazardous materials. They work at all levels of government and are employed by industries and universities where dangerous materials are generated or used. Part of their jobs may be to educate those who need to know, including the public, about the rules and regulations applied to hazardous materials.

Hazardous materials specialists often work in the field inspecting, testing, overseeing cleanup work, and determining whether storage facilities are in compliance with regulations. First on the scene when a chemical spill occurs, these specialists must be able to identify the spilled chemical substance and know how to take emergency action to neutralize its effect and thus protect the public. Then they must devise a cleanup procedure and oversee its implementation.

Entry into the field usually requires a degree from a four-year college with a major in chemistry or other physical science. Other areas of concentration might be industrial hygiene, environmental health, or engineering.

Go Online PHSchool.com
For: Careers in Chemistry
Visit: PHSchool.com
Web Code: cdb-1111

11.1 Section Assessment

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

Writing Activity

Paragraph Some products are marketed as biodegradable. What does *biodegradable* mean? Identify three biodegradable products. How do these products benefit the environment?

Interactive Textbook
Assessment 11.1 Test yourself on the concepts in Section 11.1.
with ChemASAP

Section 11.1 Assessment

7. Write the names of the reactants separated by a plus sign followed by an arrow followed by the names of the products separated by a plus sign.
8. Write the formulas of the reactants to the left of the yields sign and the formulas of the products to the right.
9. Write the skeleton equation with the correct formulas of the reactants on the left and the correct formulas of the products on the right. Then balance the equation using coefficients so that it obeys the law of conservation of mass.
10. **a.** $CuS + O_2 \xrightarrow{\text{heat}} Cu + SO_2$
    b. $NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$
11. **a.** $2Fe(s) + 3Cl_2(g) \rightarrow 2FeCl_3(s)$
    b. $Al_2(CO_3)_3(s) \rightarrow Al_2O_3(s) + 3CO_2(g)$
    c. $Mg(s) + 2AgNO_3(aq) \rightarrow 2Ag(s) + Mg(NO_3)_2(aq)$
12. **a.** $2SO_2 + O_2 \rightarrow 2SO_3$ **b.** $Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$ **c.** $4P + 5O_2 \rightarrow P_4O_{10}$
    d. $2Al + N_2 \rightarrow 2AlN$

Careers in Chemistry

Hazardous Materials Specialist

Materials are classified as hazardous when the chemical reactions they undergo are potentially dangerous to humans or the environment. Being a hazardous materials specialist is an ever-changing career because the list of materials that are considered hazardous is constantly changing.

3 ASSESS

Evaluate Understanding L2

To evaluate students' understanding of how to write and interpret chemical equations, write some word equations on the board and have students produce skeleton equations. Write some unbalanced chemical equations on the board; have students balance them and describe them in words. Write some equations on the board and begin to balance them by changing subscripts. When students object, ask why this approach is incorrect.

Reteach L1

Review with students the key steps in writing balanced equations. Have them make a flow chart to describe the best way to subdivide the task.

Writing Activity

Student answers will vary but should reflect an understanding of the term *biodegradable* as applied to materials that can and will decompose through natural organic processes.

Interactive Textbook

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 11.1.

with ChemASAP