Section 11.1

Describing Chemical Reactions

113 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.

Section 11.1-Describing Chemical Reactions

- 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.
  - Iron + oxygen → iron(III) oxide

Section 11.1-Describing Chemical Reactions

Chemical Equations

- a representation of a chemical reaction;
  - reactants (on the left)
  - connected by an arrow
  - products (on the right).
    - Here is a chemical equation for rusting:

$$Fe + O_2 \rightarrow Fe_2O_3$$

Section 11.1-Describing Chemical Reactions

- **Skeleton equation**
  - is a chemical equation that does not indicate the relative amounts of the reactants and products.
    - $Fe + O_2 \rightarrow Fe_2O_3$

- The first step in writing a complete chemical equation is to write the skeleton equation.

Section 11.1-Describing Chemical Reactions

- To add more information to the equation,
  - 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).
  - $Fe(s) + O_2(g) \rightarrow Fe_2O_3(s)$

Section 11.1-Describing Chemical Reactions

- A **catalyst** is a substance that speeds up the reaction but <u>is not used up</u> in the reaction.
  - <u>neither</u> a reactant <u>nor</u> a product,
  - written <u>above</u> the arrow in a chemical equation.
    - H_2O_2 (l) $\xrightarrow{MnO_2}$ H_2O(l) + O_2(g)

115 Table 11.1 Symbols Used in Chemical Equations

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
$\xrightarrow{\Delta}$ $\xrightarrow{\text{heat}}$	Indicates that heat is supplied to the reaction
$\xrightarrow{\text{Pt}}$	A formula written above or below the yield sign indicates its use as a catalyst (in this example, platinum).

Section 11.1-Describing Chemical Reactions

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.

Section 11.1-Describing Chemical Reactions

- **Balancing Chemical Equations**

  Bicycle

  - Frame, wheels, handle bars, pedals
  - $F + W + H + P \rightarrow FW_2HP_2$ (skeleton/unbalanced)
  - $F + 2W + H + 2P \rightarrow FW_2HP_2$ (balanced)

- **Coefficients**—small whole numbers that are placed in front of the formulas in an equation in order to balance it.

- **Balanced equation** in which each side of the equation has the same number of atoms of each element and mass is conserved.
  - 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

Section 11.1-Describing Chemical 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

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.

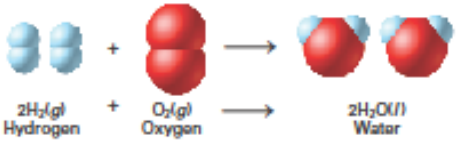
2 **Solve** ***Apply concepts to this situation.***
Write correct formulas to give the skeleton equation.

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

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.



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

117 Conceptual Problem 11.3

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

Section 11.2

Types of Chemical Reactions

11.2 Types of Chemical Reactions

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

Section 11.2-Types of Chemical Reactions

- 5 Types of Chemical Reactions:
  - Combustion
  - Combination
  - Decomposition
  - Single replacement
  - Double replacement

Section 11.2-Types of Chemical Reactions

- Combustion Reactions
  - A chemical change in which an element or compound reacts with oxygen, often producing energy in the form of heat and light.

  - $2C_8H_{18}(l) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(l)$
  - $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$
  - $S(s) + O_2(g) \rightarrow SO_2(g)$

CONCEPTUAL PROBLEM 11.8

Writing Equations for Combustion Reactions

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

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

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

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

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

Practice Problems

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

a. formic acid (HCOOH)

b. heptane (C_7H_{16})

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

Section 11.2-Types of Chemical Reactions

- Combination Reactions
  - A chemical change in which two or more substances react to form a single new substance.
  - Examples
    - $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$
    - $2K(s) + Cl_2(g) \rightarrow 2KCl(s)$
  - 2 nonmetals -more than one product is often possible.
    - $S(s) + O_2(g) \rightarrow SO_2(g)$ sulfur dioxide
    - $2S(s) + 3O_2(g) \rightarrow 2SO_3(g)$ sulfur trioxide
  - transition metal and a nonmetal may = more than 1 product
    - $Fe(s) + S(s) \rightarrow FeS(s)$ iron(II) sulfide
    - $2Fe(s) + 3S(s) \rightarrow Fe_2S_3(s)$ iron(III) sulfide

CONCEPTUAL PROBLEM 11.4

Writing Equations for Combination Reactions

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

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

Practice Problems

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

$Be + O_2 \longrightarrow$

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

Section 11.2-Types of Chemical Reactions

- **Decomposition Reaction**
  - A chemical change in which a single compound breaks down into 2 or more simpler products.
    - Example

CONCEPTUAL PROBLEM 11.5

Writing the Equation for a Decomposition Reaction

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

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

Practice Problems

15. Complete and balance this decomposition reaction.

$$HI \longrightarrow$$

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

Interactive Textbook

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

with ChemASAP

Section 11.2-Types of Chemical Reactions

- Single Replacement Reaction
  - A chemical change in which one element replaces a second element in a compound
    - Examples
      - $2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$
      - $Zn(s) + Cu(NO_3)_2(aq) \rightarrow Cu(s) + Zn(NO_3)_2(aq)$
- Activity Series
  - Lists metals in order of decreasing activity
  - Metals will displace any metal listed below it in the activity series

Table 11.2

Activity Series of Metals

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

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

CONCEPTUAL PROBLEM 11.6

Writing Equations for Single-Replacement Reactions

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

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

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

Practice Problem

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

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

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

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

Section 11.2-Types of Chemical Reactions

- Double Replacement Reactions
  - A chemical change involving a change of positive ions between 2 compounds
    - Examples
      - $Na_2S(aq) + Cd(NO_3)_2(aq) \rightarrow CdS(s) + 2NaNO_3(aq)$
      - $2NaCN(aq) + H_2SO_4(aq) \rightarrow 2HCN(g) + Na_2SO_4(aq)$
      - $Ca(OH)_2(aq) + 2HCl(aq) \rightarrow CaCl_2(aq) + 2H_2O(l)$

CONCEPTUAL PROBLEM 11.7

Writing Equations for Double-Replacement Reactions

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

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

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

Practice Problems

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

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

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

19. Write a balanced equation for each reaction.

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

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

Section 11.2-Types of Chemical Reactions

- **Predicting the Products of a Chemical Reaction**

Matching chemical reactions

summary 5 types of reactions

Technology and Society-Battling Combustion

SECTION 11.3

Reactions in Aqueous Solutions

121 11.3 Reactions in Aqueous Solutions

Connecting to Your World The beauty of a limestone cavern is the result of chemical reactions involving water. Limestone caverns form as calcium carbonate reacts with carbon dioxide dissolved in water and forms soluble calcium hydrogen carbonate. Additional carbon dioxide then converts the calcium hydrogen carbonate back into calcium carbonate. The calcium carbonate precipitates and forms dramatic stalactites and stalagmites. In this section, you will learn to predict the formation of precipitates and write equations to describe the reactions that produce them.

11.3 Reactions in Aqueous Solutions

- Reactions that take place in water
  - $AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$
- **Complete ionic equation-**
  - equation that shows dissolved ionic compounds as dissociated free ions.
- $Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Cl^-(aq) \rightarrow$

  $AgCl(s) + Na^+(aq) + NO_3^-(aq)$

11.3 Reactions in Aqueous Solutions

- **Spectator Ion-**
  - An ion that appears on both sides of the equation and is not directly involved in the reaction
  - Must be in same physical state on both sides.

- **Net Ionic Equation-**
  - An equation for a reaction in solution that shows only those particles directly involved in the chemical change.
  - Must be balanced in respect to mass and charge

11.3 Reactions in Aqueous Solutions

- Lead reacts with silver nitrate to form Lead (II) Nitrate and solid silver

- Skeleton equation:
  - $Pb(s) + AgNO_3(aq) \rightarrow Ag(s) + Pb(NO_3)_2(aq)$

- The nitrate ion is the spectator ion in this reaction.
  - NO_3^{-1}

- Net ionic equation:
  - $Pb(s) + Ag^{+}(aq) \rightarrow Ag(s) + Pb^{2+}(aq)$ (unbalanced)

  - $Pb(s) + 2Ag^{+}(aq) \rightarrow 2Ag(s) + Pb^{2+}(aq)$ (balanced)

11.3 Reactions in Aqueous Solutions

Conceptual Problem 11.9

11.3 Reactions in Aqueous Solutions

- Predicting the Formation of a Precipitate
  - Precipitate -the formation of an insoluble salt in solution.
    - A solid product
  - Use table 11.3 to predict the formation of a precipitate
    - Table 11.3 Solubility Rules for Ionic Compounds
- $2Na^+(aq) + CO_3^{2-}(aq) + Ba^{2+}(aq) + 2NO_3^-(aq) \rightarrow ?$

11.3 Reactions in Aqueous Solutions

- Practice Problems:

- 11.3 Assessment