Chapter Three Learning Objectives

• write, balance, and classify chemical equations
• understand the meaning and uses of the mole
• calculate the percent composition of a compound and derive empirical formulas from experimental data
• perform stoichiometry calculations
• understand the concept of a limiting reactant and percent yield

Balancing Chemical Equations

• A chemical equation is a shorthand expression in which symbols and formulas are used to represent a chemical reaction.

• A chemical reaction produces new arrangements of atoms without a gain or loss in the number or type of atoms:

\[ 2 \text{H}_2 + \text{O}_2 \rightarrow 2 \text{H}_2\text{O} \]
Key Concept

• It is important to understand the difference between a coefficient in front of a formula and a subscript within a formula:

Add these coefficients to balance the equation

$$ 2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} $$

NOT ALLOWED! When this subscript is added, we get a completely different reaction.

$$ \text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O}_2 $$

• How many atoms of Mg, N, and O are represented by 3 Mg(NO₃)₂?

Review Exercise

Balance the following chemical equations:

(a) Al₂(SO₄)₃ + Na₃PO₄ \(\Rightarrow\) AlPO₄ + Na₂SO₄

(b) CaO + P₄O₁₀ \(\Rightarrow\) Ca₃(PO₄)₂

(c) Na₂O₂ + H₂O \(\Rightarrow\) NaOH + O₂

(d) KClO₃ + C₁₂H₂₂O₁₁ \(\Rightarrow\) KCl + CO₂ + H₂O

Screaming Gummy Bear
Classifying Chemical Equations

The key to predicting the products of a reaction is to recognize general patterns of chemical reactivity:

TABLE 3.1 Combination and Decomposition Reactions

<table>
<thead>
<tr>
<th>Combination Reactions</th>
<th>Decomposition Reactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A + B → C</td>
<td>C → A + B</td>
</tr>
<tr>
<td>C(s) + O₂(g) → CO₂(g)</td>
<td>2KClO₃(s) → 2KCl(s) + 3O₂(g)</td>
</tr>
<tr>
<td>N₂(g) + 3H₂(g) → 2NH₃(g)</td>
<td>PbCO₃(s) → PbO(s) + CO₂(g)</td>
</tr>
<tr>
<td>CaO(s) + H₂O(l) → Ca(OH)₂(s)</td>
<td>Cu(OH)₂(s) → CuO(s) + H₂O(l)</td>
</tr>
</tbody>
</table>

Two reactants combine to form a single product. Many elements react with one another in this fashion to form compounds. *Combination Reactions with Oxygen*

A single reactant breaks apart to form two or more substances. Many compounds react this way when heated.

Recognizing Combustion Reactions

- A *combustion reaction* is characterized by the burning of a carbon-containing compound in the presence of oxygen to form carbon dioxide and water.

- Typically, H₂O (g) is the product at high temperatures and in an open container.
Review Exercise

Write a balanced chemical equation, including phase symbols, for each of the following reactions:

(a) The combination reaction of lithium metal with chlorine gas.

(b) The combustion reaction of liquid C$_6$H$_{10}$O$_2$.

(c) The decomposition reaction of mercury (II) nitrate upon heating into mercury (II) oxide, nitrogen dioxide gas, and oxygen.

Counting Atoms, Ions, and Molecules

- A **mole** (mol) counts $6.022 \times 10^{23}$ or *Avogadro’s number* of items just as a dozen counts 12 items.
- What is **molar mass**? Which amount would have more mass: a mole of K atoms or a mole of Au atoms? Which amount contains more atoms?
- The molecular formula of aspartame, otherwise known as NutraSweet®, is C$_{14}$H$_{18}$N$_2$O$_5$. How many molecules of aspartame are present in a 1.00 mg sample of aspartame? How many H atoms are present in the 1.00 mg sample?
Determining Empirical and Molecular Formulas

• What is the mass percent composition of acetylene, $\text{C}_2\text{H}_2$? of benzene, $\text{C}_6\text{H}_6$?

• The mass percent composition of a compound is readily obtained by experiment but only provides an empirical formula: the smallest whole-number ratio of atoms in the compound.

• What must be known to determine the molecular formula of the compound?

Review Exercises

• A foul smelling substance produced by the action of bacteria on meat, cadaverine, is 58.55% C, 13.81% H, and 27.40% N by mass. What is the empirical formula of cadaverine?

• The empirical formula of glucose is $\text{CH}_2\text{O}$. If the molar mass of glucose is 180.2 g/mol, then what is the molecular formula of this compound?
Determining Empirical Formulas by Combustion Analysis

- The empirical formula of a compound containing principally C and H can be determined by mass analysis of the products following the complete combustion of the compound.

- Which combustion product traps all of the C in the compound? Which combustion product traps all of the H?

Practice Exercise

The complete combustion of 1.125 g of a liquid hydrocarbon, C\textsubscript{x}H\textsubscript{y}, produces 3.447 g of CO\textsubscript{2} and 1.647 g of H\textsubscript{2}O.

(a) What is the empirical formula of the unknown hydrocarbon?

(b) If the molar mass of the unknown hydrocarbon was found to be 86.17 g/mol in a separate experiment, then what is its molecular formula?
Performing Stoichiometry Calculations Using Balanced Chemical Equations

• The coefficients in a balanced equation provide mole relationships, not mass relationships:

\[ 3 \text{H}_2 + 1 \text{N}_2 \rightarrow 2 \text{NH}_3 \]

• How many grams of NH\(_3\) are produced from the complete reaction of 1.4 g of N\(_2\)? How many grams of H\(_2\) are consumed in the process?

Integrative Exercise

The primary cause of rising and disastrous CO\(_2\) levels in the atmosphere is the combustion of fossil fuels such as octane, C\(_8\)H\(_{18}\), the main component of gasoline. If a car with a gas mileage rating of 20.5 mi/gal travels 225 mi, then how many grams of CO\(_2\) are consequently released into the atmosphere, assuming the gasoline is completely combusted and composed entirely of C\(_8\)H\(_{18}\), whose density is 0.69 g/mL?
Determining the Limiting Reactant

• The reactant that determines, or limits, the amount of product formed in a chemical reaction is called the *limiting reactant*.

• A complete tool set contains 4 screwdrivers, 2 pliers, and 6 wrenches. If a manufacturer has in stock 2000 screwdrivers, 900 pliers, and 3600 wrenches, then how many tool sets can be completed by the manufacturer?

Review Exercise

Solid aluminum chloride, AlCl₃, is made by treating scrap aluminum metal with chlorine gas:

\[
2 \text{Al} \,(s) + 3 \text{Cl}_2 \,(g) \Rightarrow 2 \text{AlCl}_3 \,(s)
\]

(a) How many moles of AlCl₃ can be formed from 2.50 mol of Al and 4.00 mol of Cl₂?

(b) How many moles of the excess reactant remain at the end of the reaction?
Calculating Percent Yield

- How is the theoretical yield of a reaction different from the actual yield?

\[
\text{percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%
\]

- If the reaction \(4 \text{ K (s)} + \text{O}_2 (g) \rightarrow 2 \text{ K}_2\text{O (s)}\) has a 82.6% yield, then how many moles of K are required to produce an actual yield of 8.00 mol of \(\text{K}_2\text{O}\)?

Review Exercise

The following (unbalanced) equation is one of the steps in the commercial process for converting ammonia to nitric acid:

\[
\text{NH}_3 (g) + \text{O}_2 (g) \rightarrow \text{NO (g)} + \text{H}_2\text{O (g)}
\]

If 7.15 g of each reactant undergoes a reaction with a 69.0% yield, then what is the actual yield of NO (in moles) produced from the reaction?