Learning Objectives

- Write balanced chemical reactions with chemical formulas and with molecular models
- Interpret balanced chemical equations to calculate the moles of reactants and products involved in each of the reactions
- Interpret balanced equations to calculate the masses of reactants and products involved in each of the reactions
- Determine which reactant is the limiting reactant in reactions
- Use the limiting reactant concept on calculations recording chemical equations
- Work with sequential reactions

Learning Objectives

- Compare the amount of substance formed in a reaction (actual yield) with the predicted amount (theoretical yield), and determine the percent yield
- Learn and use the terminology of solutions - solute, solvent, and concentration - and recognize the molecular significance
- Calculate the concentration of solutions
- Carry out calculations related to the use of solutions in chemical reactions

Chemical Equations

- Chemical equations give a description of a chemical reaction.
- There are parts to any equation:
  - Reactants (written to the left of the arrow) and
  - Products (written to the right of the arrow):
- Relative amounts of each using stoichiometric coefficients

\[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \]

Reactants \hspace{2cm} Products
Chemical Equations

• Attempt to show on paper what is happening at the laboratory and molecular levels.

Chemical Equations

• A chemical equation is a shorthand notation to describe a chemical reaction.
• Just like a chemical formula, a chemical equation expresses quantitative relations.
• All substances must be written with chemical formulas that describe them as they exist.
• Subscripts in formulas must not be changed.

Chemical Equations

• Depict the reactants and products and their relative amounts in a reaction.
  \[2\text{Mg}(s) + \text{O}_2(g) \rightarrow 2\text{MgO}(s)\]
• The numbers in the front are called stoichiometric coefficients.
• The letters (s), (g) and (l) are the physical states of the compounds.
• This equation can be read as...
  • 2 Mg atoms + 1 O₂ molecule gives 2 molecules of MgO
  • 2 Mg moles + 1 O₂ mole gives 2 moles of MgO

Chemical Equations

• Law of Conservation of Matter
• There is no detectable change in quantity of matter in an ordinary chemical reaction.
• Balanced chemical equations must always include the same number of each kind of atom on both sides of the equation.
• This law was determined by Antoine Lavoisier.
• Propane, \(\text{C}_3\text{H}_8\), burns in oxygen to give carbon dioxide and water.
  \[\text{C}_3\text{H}_8 + 5\text{O}_2 \rightarrow 3\text{CO}_2 + 4\text{H}_2\text{O}\]

5

6

7

8
1. Write the correct formula for each substance
   \[ \text{H}_2 + \text{Cl}_2 \rightarrow \text{HCl} \]
2. Add coefficients so the number of atoms of each element are the same on both sides of the equation
   \[ \text{H}_2 + \text{Cl}_2 \rightarrow 2\text{HCl} \]
   
   \begin{align*}
   \text{H} & \quad 2 \text{ atoms} \quad 2 \text{ atoms} \\
   \text{Cl} & \quad 2 \text{ atoms} \quad 2 \text{ atoms}
   \end{align*}

• Balance
   \[ \text{Al} + \text{Cl}_2 \rightarrow \text{AlCl}_3 \]
   \[ \text{Al} + 3 \text{Cl}_2 \rightarrow 2 \text{AlCl}_3 \]
   \[ 2 \text{Al} + 3 \text{Cl}_2 \rightarrow 2 \text{AlCl}_3 \]

• Assume one molecule of the most complicated substance
  \[ \text{C}_5\text{H}_{12} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]

• Adjust the coefficient of \( \text{CO}_2 \) to balance C
  \[ \text{C}_5\text{H}_{12} + \text{O}_2 \rightarrow 5\text{CO}_2 + \text{H}_2\text{O} \]

• Adjust the coefficient of \( \text{H}_2\text{O} \) to balance H
  \[ \text{C}_5\text{H}_{12} + \text{O}_2 \rightarrow 5\text{CO}_2 + 6\text{H}_2\text{O} \]

• Adjust the coefficient of \( \text{O}_2 \) to balance O
  \[ \text{C}_5\text{H}_{12} + 8\text{O}_2 \rightarrow 5\text{CO}_2 + 6\text{H}_2\text{O} \]

平衡化学方程式

• Balance the equation
  \[ \text{C}_4\text{H}_{10}\text{O} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]
Balancing Chemical Equations

• Sometimes fractional coefficients are obtained
  \[ \text{C}_3\text{H}_10 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]
  \[ \text{C}_3\text{H}_10 + \text{O}_2 \rightarrow 5\text{CO}_2 + \text{H}_2\text{O} \]
  \[ \text{C}_3\text{H}_10 + \text{O}_2 \rightarrow 5\text{CO}_2 + 5\text{H}_2\text{O} \]
  \[ \text{C}_3\text{H}_10 + \frac{15}{2}\text{O}_2 \rightarrow 5\text{CO}_2 + 5\text{H}_2\text{O} \]
  • Multiply all coefficients by the denominator
  \[ 2\text{C}_3\text{H}_10 + 15\text{O}_2 \rightarrow 10\text{CO}_2 + 10\text{H}_2\text{O} \]

Guidelines for Reaction Stoichiometry

• Write the balanced equation.
• Calculate the number of moles of the species for which the mass is given.
• Use the coefficients in the equation to convert the moles of the given substance into moles of the substance desired.
• Calculate the mass of the desired species.

Reaction Stoichiometry

• How many CO molecules are required to react with 25 formula units of Fe$_2$O$_3$?

\[ \text{Fe}_2\text{O}_3 + 3 \text{CO} \xrightarrow{\Delta} 2 \text{Fe} + 3 \text{CO}_2 \]

? CO molecules = 25 formula units Fe$_2$O$_3$

Reaction Stoichiometry

• How many iron atoms can be produced by the reaction of 2.50 \times 10^5 formula units of iron(III) oxide with excess carbon monoxide?

\[ \text{Fe}_2\text{O}_3 + 3 \text{CO} \xrightarrow{\Delta} 2 \text{Fe} + 3 \text{CO}_2 \]

? Fe atoms = 2.50 \times 10^5 formula units Fe$_2$O$_3$
Reaction Stoichiometry

• What mass of CO is required to react with 146 g of iron(III) oxide?

\[ \text{Fe}_2\text{O}_3 + 3 \text{CO} \rightarrow \Delta \rightarrow 2 \text{Fe} + 3 \text{CO}_2 \]

? g CO = 146 g Fe₂O₃

Reaction Stoichiometry

• What mass of carbon dioxide can be produced by the reaction of 0.540 mole of iron(III) oxide with excess carbon monoxide?

\[ \text{Fe}_2\text{O}_3 + 3 \text{CO} \rightarrow \Delta \rightarrow 2 \text{Fe} + 3 \text{CO}_2 \]

? g CO₂ = 0.540 mol Fe₂O₃

Reaction Stoichiometry

• What mass of iron(III) oxide reacted with excess carbon monoxide if the carbon dioxide produced by the reaction had a mass of 8.65 grams?

\[ \text{Fe}_2\text{O}_3 + 3 \text{CO} \rightarrow \Delta \rightarrow 2 \text{Fe} + 3 \text{CO}_2 \]

? g Fe₂O₃ = 8.65 g CO₂

Continuous Variations

• It is possible to identify experimentally the coefficients, \( a \) and \( b \), for the reactants, without knowing the products of the reaction.
• The process that you will use to determine the coefficients is called continuous variations.
  • We prepare a series of mixtures of the two reactants. Each mixture will have the same total volume and the same total number of moles of reactants.
  • In an exothermic reaction, the mixture that generates the most heat energy will be the reaction that completely consumes both A and B. You will use this mixture to establish the coefficients, and therefore the mole ratio, for the reaction.

\[ a \ A + b \ B \rightarrow \text{products} \]
Continuous Variations

- When we monitor the temperature for the reaction, \( aA + bB \rightarrow \text{products} \), the graph to the right was produced.
- From the graph on the right, line A and B cross at 3 mL.
- Therefore, the stoichiometric coefficients are 3:2 and the balanced reaction is:
  \[ 3A + 2B \rightarrow \text{products} \]

Limiting Reactant

- In a given reaction, there is not enough of one reagent to use up the other reagent completely.
- The reagent in short supply LIMITS the quantity of product that can be formed.

Limiting Reactant

- React solid Zn with 0.00300 mol HCl
  \[ \text{Zn} + 2 \text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2 \]
- Rxn 1: Balloon inflates fully, some Zn left.
- Rxn 2: Balloon inflates fully, no Zn left.
- Rxn 3: Balloon does not inflate fully, no Zn left.
- Not enough Zn to use up 0.100 mol HCl
Limiting Reactant

React solid Zn with 0.00300 mol HCl

\[
\text{Zn} + 2 \text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2
\]

Expt
mol Zn 0.00326
mol HCl 0.00300

\[
\text{mol HCl reqd} = 0.00326 \text{ mol Zn} \left( \frac{2 \text{ mol HCl}}{\text{mol Zn}} \right)
\]

We do NOT have 0.00652 mol of HCl
Therefore, HCl is the Limiting Reagent!

Limiting Reactant

React solid Zn with 0.00300 mol HCl

\[
\text{Zn} + 2 \text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2
\]

Expt
mol Zn 0.00326
mol HCl 0.00300

\[
\text{g H}_2 = 0.00300 \text{ mol HCl}
\]

Limiting Reactant

\[
\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}
\]

- How many grams of water can be prepared from 16g CH\textsubscript{4} and 48g O\textsubscript{2}? 

\[
\text{mol CH}_4 = 16\text{g}
\]
\[
\text{mol O}_2 = 48\text{g}
\]

Limiting Reactant

\[
\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}
\]

1.0 mol 1.5 mol  \(\text{? g}\)

\[
\text{mol O}_2 \text{ reqd} = 1.0 \text{ mol CH}_4
\]
Percent Yields

- Theoretical yield is calculated by assuming that the reaction goes to completion.
- Determined from the limiting reactant calculation.
- Actual yield is the amount of a specified pure product made in a given reaction.
- In the laboratory, this is the amount of product that is formed in your beaker, after it is purified and dried.
- Percent yield indicates how much of the product is obtained from a reaction.

\[
\text{\% yield} = \left(\frac{\text{actual yield}}{\text{theoretical yield}}\right) \times 100
\]

---

Percent Yields

- A 10.0 g sample of ethanol, \(C_2H_5OH\), was boiled with excess acetic acid, \(CH_3COOH\), to produce 14.8 g of ethyl acetate, \(CH_3COOC_2H_5\). What is the percent yield?

\[
\text{\% yield} = \left(\frac{\text{actual yield}}{\text{theoretical yield}}\right) \times 100
\]

\[
\begin{align*}
\text{g } C_2H_5OH & = 10.0 \text{ g } C_2H_5OH \\
\text{g } CH_3COOC_2H_5 & = 14.8 \\
\text{\% yield} & = \left(\frac{14.8 \text{ g}}{174.19 \text{ g}}\right) \times 100 = 85.2 \%
\end{align*}
\]

---

Solution Concentration

- Solution is a mixture of two or more substances dissolved in another.
- Solute is the substance present in the smaller amount.
- Solvent is the substance present in the larger amount.
- In aqueous solutions, the solvent is water.
- The concentration of a solution defines the amount of solute dissolved in the solvent.
- The amount of sugar in sweet tea can be defined by its concentration.
- One common unit of concentration is:

\[
\text{mass \%} = \frac{\text{mass of solute}}{\text{total mass}} \times 100
\]

---

Solution Concentration

- What mass of NaOH is required to prepare 250.0 g of solution that is 8.00% w/w NaOH?

\[
g \text{ NaOH} = 250.0 \text{ g soln}
\]

- Calculate the mass of 8.00% w/w NaOH solution that contains 32.0 g of NaOH.
• Calculate the mass of NaOH in 300.0 mL of an 8.00% w/w NaOH solution. Density is 1.09 g/mL.

\[ g \text{ NaOH} = 300 \text{ mL soln} \]

• The amount of solute in a solution is given by its concentration.

\[
\text{Molarity (M)} = \frac{\text{moles of solute}}{\text{liters of solution}}
\]

• Calculate the number of moles of H\(_2\)SO\(_4\) in 500 mL of 0.324 M H\(_2\)SO\(_4\) solution.

\[ \text{mol H}_2\text{SO}_4 = 0.500 \text{L soln} \]

• Dissolve 5.00 g of NiCl\(_2\)•6 H\(_2\)O in enough water to make 250 mL of solution. Calculate molarity.

\[ M = \left( \frac{5.00 \text{g NiCl}_2\cdot6\text{H}_2\text{O}}{0.250 \text{L soln}} \right) \]
Solution Concentration

• Calculate the molarity of a solution that contains 12.5 g of sulfuric acid in 1.75 L of solution.

\[
M = \frac{12.5 \text{ g}}{1.75 \text{ L soln}}
\]

Solution Concentration

• Determine the mass of calcium nitrate required to prepare 3.50 L of 0.800 M Ca(NO₃)₂.

? g Ca(NO₃)₂ = 3.50 L

Solution Concentration

• The specific gravity of concentrated HCl is 1.185 and it is 36.31% w/w HCl. What is its molarity?

specific gravity = 1.185 tells us density = 1.185 g/mL or 1185 g/L

? mol HCl/L = \frac{1185 \text{ g solution}}{L \text{ solution}}

Dilutions

• Common method to dilute a solution involves the use of volumetric flask, pipet, and suction bulb.

\[
M_1 \cdot V_1 = M_2 \cdot V_2
\]
Dilutions

• If 10.0 mL of 12.0 M HCl is added to enough water to give 100. mL of solution, what is the concentration of the solution?

\[ M_1 V_1 = M_2 V_2 \]
\[ 12.0 \text{ M} \times 10.0 \text{ mL} = M_2 \times 100.0 \text{ mL} \]

Dilutions

• What volume of 18.0 M sulfuric acid is required to make 2.50 L of a 2.40 M sulfuric acid solution?

\[ M_1 V_1 = M_2 V_2 \]
\[ V_1 = \frac{M_2 \times V_2}{M_1} \]

Solutions in Chemical Reactions

• What volume of 0.500 M BaCl\(_2\) is required to completely react with 4.32 g of Na\(_2\)SO\(_4\)?

\[ \text{Na}_2\text{SO}_4 + \text{BaCl}_2 \rightarrow \text{BaSO}_4 + 2\text{NaCl} \]

\[ 1 \text{ L BaCl}_2 = 4.32 \text{ g Na}_2\text{SO}_4 \]
What volume of 0.200 M NaOH will react with 50.0 mL of 0.200 M aluminum nitrate?

\[3\text{NaOH} + \text{Al(NO}_3\text{)}_3 \rightarrow 3\text{NaNO}_3 + \text{Al(OH)}_3\]

\[\text{ml NaOH} = \text{50.0 mL Al(NO}_3\text{)}_3 \text{ soln} \times \frac{3}{1}\]

What mass of Al(OH)\(_3\) precipitates in the previous example?

\[? \text{ g Al(OH)}_3 = \text{50.0 mL Al(NO}_3\text{)}_3 \text{ soln} \times \frac{1}{3} \times \frac{1}{3} \times \frac{2}{134} \times 16\]

Titrations are a method of determining the concentration of an unknown solution from the known concentration of a solution and solution reaction stoichiometry.

- Requires special lab glassware
  - Buret, pipet, and flasks
- Must have an indicator also

What is the molarity of a KOH solution if 38.7 mL of the KOH solution is required to react with 43.2 mL of 0.223 M HCl?

\[\text{HCl} + \text{KOH} \rightarrow \text{KCl} + \text{H}_2\text{O}\]

\[43.2 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times 0.223 \text{ M HCl} = 0.00963 \text{ mol HCl}\]
Solutions in Chemical Reactions

What is the molarity of a barium hydroxide solution if 44.1 mL of 0.103 M HCl is required to react with 38.3 mL of the Ba(OH)₂ solution?

\[ 2\text{HCl} + \text{Ba(OH)}_2 \rightarrow \text{BaCl}_2 + 2\text{H}_2\text{O} \]

\[(44.1 \text{ mL HCl})(0.103 \text{ M HCl}) = 4.54 \text{ mmol HCl} \]

\[
\text{Molarity of HCl} = \frac{4.54 \text{ mmol HCl}}{44.1 \text{ mL HCl}} = 0.103 \text{ M HCl} \]

\[
\text{Molarity of Ba(OH)}_2 = \frac{4.54 \text{ mmol HCl}}{38.3 \text{ mL Ba(OH)}_2} \approx 0.118 \text{ M Ba(OH)}_2 \]