Chapter 2
Stoichiometry

• 2-1 Writing Balanced Chemical Equations
• 2-2 Using Balanced Chemical Equations
• 2-3 Limiting Reactant and Percentage Yield
• 2-4 The Stoichiometry of Reactions in Solution
• 2-5 the Scale of Chemical Processes
Chapter 2-1
Balancing Chemical Equations

• Chemical Reactions tell us two things
  – What atoms or molecules are reacting together to form other products
  – How much reactant & product are formed

• A Chemical reaction is a statement of experimental fact:
  \[ \text{KClO}_3 (s) \rightarrow \text{KCl} (s) + \text{O}_2 (g) \]
  – Reactants on left, products on right

• What is equation missing?
• Need balanced reaction—Why?
Chemical Equations

• Because the same atoms are present in a reaction at the beginning and at the end, the amount of matter in a system does not change.

• The Law of the Conservation of Matter
Because of the principle of the conservation of matter, it must have the same number of atoms of the same kind on both sides. This means an equation must be balanced!
2-1 Stoichiometry:

Writing Balanced Chemical Equations

Step 1: Assign 1 as the coefficient of one reactant or product. The best choice is the most complicated species, with the largest number of different elements.

Step 2: Identify, in sequence, elements that appear in only one chemical species for which the coefficient is not yet determined. Choose that coefficient to balance the number of moles of atoms of that element. Continue until all coefficients are identified.

Step 3: It is often desirable to eliminate fractional coefficients. To do so, multiply the entire equation by the smallest integer that eliminates the fractions.
Balancing Equations
Limiting Reactants

excess limiting

**REACTANTS**

**PRODUCTS**

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OFB Chapter 2
Limiting Reactant Short-Cut Method

\[ 2 \text{A} + \text{B} \rightarrow \text{A}_2\text{B} \]

1. Figure out the number of moles of every reactant.
   
   \( \text{moles} = \text{g per Molar Mass} \)

2. Divide each answer by the coefficient that the reactant has in the balanced equation

   \( \text{moles per mole of reactant} \)

3. The reactant for which the answer is the smallest is the limiting reactant.
Chemical Equations

$4 \text{Al}(s) + 3 \text{O}_2(g) \rightarrow 2 \text{Al}_2\text{O}_3(s)$

This equation means

4 Al atoms + 3 O₂ molecules

---give---

2 molecules of Al₂O₃

Or

4 moles of Al + 3 moles of O₂

---give---

2 moles of Al₂O₃
\[
\text{\underline{Balancing Equations}}
\]

\[
\text{\_ \_ } C_3H_8(g) + \text{\underline{\_ \_ }} O_2(g) \rightarrow \text{\_ \_ } CO_2(g) + \text{\_ \_ } H_2O(g)
\]
Chapter 2-1
Balancing Chemical Equations

• Tips for balancing equations

Coefficients

\[ 2 \text{H}_2\text{O}(l) \rightarrow 2 \text{H}_2(g) + 1 \text{O}_2(g) \]

Subscripts

• *Never* change subscripts, only change molar coefficients.

• Balance simple equations by inspection

• Start with heaviest atom, balance, then next heaviest, etc.

• Balance H & O last, there is often H$_2$O, H$_2$, O$_2$, OH$^-$, or H$^+$ in equations
Writing Balanced Chemical Equations

\[ \text{PbO}_2 + \text{Pb} + \text{H}_2\text{SO}_4 \rightarrow \text{PbSO}_4 + \text{H}_2\text{O} \]

**Problem:** Suppose we have 1.45 grams of Pb in the presence of excess lead oxide and sulfuric acid. How many grams of Lead Sulfate are produced?
Mass of one reactant or product is known

- Ratio of known mass to its molar mass

Finding the number of moles of the known species

- Ratio of known to unknown

Finding the number of moles of the unknown species

- Ratio of unknown mass to its molar mass

Mass of one reactant or product is unknown
\[ \text{PbO}_2 + \text{Pb} + 2\text{H}_2\text{SO}_4 \rightarrow 2\text{PbSO}_4 + 2\text{H}_2\text{O} \]

- **Mass of one reactants or product is known**
  - Ratio of known mass to its molar mass
  - Finding the number of moles of the known species
  - Ratio of known to unknown
  - Finding the number of moles of the unknown species
  - Ratio of unknown mass to its molar mass
  - Mass of one reactant or product is unknown
Problem #16b, page 83:

What mass (in grams) of the first reactant ... would be required to react completely with 1.000 g of the second reactant?

\[
\text{XeF}_4 + 2 \text{H}_2\text{O} \rightarrow \text{Xe} + 4 \text{HF} + \text{O}_2
\]

\[x \text{ g XeF}_4 = 1.000 \text{ g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.015 \text{ g H}_2\text{O}} \times \frac{2 \text{ mol H}_2\text{O}}{1 \text{ mol XeF}_4} \times \frac{207.28 \text{ g XeF}_4}{1 \text{ mol XeF}_4}
\]

\[= 5.753 \text{ g XeF}_4\]
At one point in the purification of silicon, gaseous SiHCl$_3$ reacts with gaseous H$_2$ to give gaseous HCl and solid Si.

(a) Determine the chemical amount (in moles) of H$_2$ required to react with 160.4 mol of SiHCl$_3$.
(b) Determine the chemical amount of HCl that is produced.
(c) Determine the mass (in grams) of Si that is produced.

\[
\text{SiHCl}_3 \ (g) + \ H_2 \ (g) \rightarrow 3 \ \text{HCl} \ (g) + \ \text{Si} \ (s)
\]
At one point in the purification of silicon, gaseous SiHCl$_3$ reacts with gaseous H$_2$ to give gaseous HCl and solid Si.

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\[
\text{SiHCl}_3 \ (g) + \text{H}_2 \ (g) \rightarrow 3 \ \text{HCl} \ (g) + \text{Si} \ (s)
\]
Volume Relationships of Gases in Chemical Equations

Exercise 2-5:

Some H\(_2\) and N\(_2\) react to form 5.00 L of NH\(_3\)(g), according to the equation

\[ 3 \text{H}_2(g) + \text{N}_2(g) \rightarrow 2 \text{N}_\text{2} \text{H}_3(g). \]

What volume of H\(_2\)(g) reacted, assuming that the pressure and temperature are the same after the reaction as before?
The Stoichiometry of Reactions in Solution

The actual amount of solute (the substance dissolved in the solvent) in any given volume of solution depends on how concentrated or dilute the solution happens to be.

This is expressed by a ratio.

The concentration \((c)\) of a solute in a solution equals the chemical amount of the solute \((n)\) divided by the volume \((V)\) of the entire solution.
Exercise 2-9

Calculate the molarity of a solution by dissolving 10.0 g of Al(NO₃)₃ in enough water to make 250.0 mL of solution.

\[ n_{\text{Al(NO}_3\text{)₃}} = \frac{10.0 \text{ g Al(NO}_3\text{)₃}}{1 \text{ mol Al(NO}_3\text{)₃ / 213.0 g Al(NO}_3\text{)₃}} \times (1 \text{ mol Al(NO}_3\text{)₃ / 213.0 g Al(NO}_3\text{)₃}) \]

\[ V_{\text{solution}} = 250.0 \text{ mL} \times (1 \text{ L / 1000 mL}) \]

\[ c_{\text{Al(NO}_3\text{)₃}} = \frac{0.0469 \text{ mol Al(NO}_3\text{)₃}}{0.250 \text{ L}} \]

Recall: Molarity is expressed in moles per liter
Chapter 2
Stoichiometry

• Example / exercise
  – all 2-1 to 2-12

• Problems
  – 2a-e, 4a-i, 14, 16a-d, 18, 20, 34, 38