3.5 Solution Stoichiometry

- Solutions – homogeneous mixtures
  - Solvent and solute(s)
  - Solution concentration

Molarity \((M)\)

- Measure of the solute concentration

\[
M = \left( \frac{\text{amount of solute (mol)}}{\text{volume of solution (L)}} \right) \quad \text{or} \quad M = \frac{n}{V}
\]

- Units – molar \((M)\)
  \(1 \text{ M} = 1 \text{ mol/L}\)

Example:

Calculate the molarity of a solution prepared by dissolving 5.33 g NaOH in water using a 100.0 mL volumetric flask.

\[
\Rightarrow \text{convert the mass to moles:} \\
5.33 \text{ g NaOH} \times \left( \frac{1 \text{ mol NaOH}}{40.00 \text{ g NaOH}} \right) = 0.133 \text{ mol NaOH}
\]

\[
\Rightarrow \text{convert volume to liters:} \quad 100.0 \text{ mL} = 0.1000 \text{ L}
\]

\[
\Rightarrow \text{divide moles by solution volume:} \\
0.133 \text{ mol NaOH} \div 0.1000 \text{ L solution} = 1.33 \text{ mol NaOH/L} \rightarrow 1.33 \text{ M NaOH}
\]

Example as a conversion factor

Example:

Calculate the mass of NaOH in 2.50 L of 1.33 M NaOH solution.

\[
2.50 \text{ L} \left( \frac{1.33 \text{ mol NaOH}}{1 \text{ L}} \right) \left( \frac{40.00 \text{ g NaOH}}{1 \text{ mol NaOH}} \right) = 133 \text{ g NaOH}
\]

Example:

Calculate the volume of 1.33 M NaOH solution that contains 5.00 mol NaOH.

\[
5.00 \text{ mol NaOH} \times \left( \frac{1 \text{ L}}{1.33 \text{ mol NaOH}} \right) = 3.76 \text{ L}
\]

- Preparation of solutions with known molarity
  - Transfer a known mass of solute in a volumetric flask
  - Dissolve in small amount of water
  - Add water to the mark
**Dilution**
- Reducing the concentration of the solute by adding more solvent
- Stock solutions – concentrated solutions used to store reagents
- Dilution Procedure
  - Use a pipette to measure a small volume of the concentrated solution and transfer it to a volumetric flask
  - Add solvent to fill the volumetric flask to the mark

**Dilution calculations**
- dilution doesn’t change the total # of moles of solute in the solution
\[ n = M \times V \quad n_d = n_c \quad M_d \times V_d = M_c \times V_c \]

**Example:**
Calculate the molarity of a solution prepared by dilution of 5.00 mL 2.0 M HCl stock solution to 100.0 mL.
\[ M_d = \frac{M_c \times V_c}{V_d} = \frac{2.0 \text{ M} \times 5.00 \text{ mL}}{100.0 \text{ mL}} = 0.10 \text{ M} \]

**Stoichiometric calculations in solution**
- For a reaction involving substances A and B

**Example:**
What volume of 0.0836 M H$_2$SO$_4$ solution will react completely with 16.4 mL 0.255 M KOH.
⇒ balanced equation:
\[ 2\text{KOH(aq)} + \text{H}_2\text{SO}_4(aq) \rightarrow \text{K}_2\text{SO}_4(aq) + 2\text{H}_2\text{O}(l) \]
⇒ mole ratio: [1 mol H$_2$SO$_4$/2 mol KOH]
\[
16.4 \times 10^{-3} \text{L} \times \left( \frac{0.255 \text{ mol KOH}}{1 \text{ L}} \right) \times \left( \frac{1 \text{ mol H}_2\text{SO}_4}{2 \text{ mol KOH}} \right) \times \left( \frac{1 \text{ L}}{0.0836 \text{ mol H}_2\text{SO}_4} \right) = 25.0 \times 10^{-3} \text{L} = 25.0 \text{ mL}
\]
Limiting reactant problems in solution

Example:

What mass of H₂ gas can be produced by the reaction of 2.5 g Zn with 2.0 L 0.15 M HCl solution. The other product is ZnCl₂(aq).

⇒ balanced equation:

\[ \text{Zn(s)} + 2\text{HCl(aq)} \rightarrow \text{ZnCl}_2(\text{aq}) + \text{H}_2(\text{g}) \]

⇒ mole ratios: [1 mol H₂/2 mol HCl]

[1 mol H₂/1 mol Zn]

⇒ Calculate the mass of H₂ produced based on both reactants and choose the smaller amount

⇒ calculation based on HCl:

\[ 2.0 \text{ L} \times \left( \frac{0.15 \text{ mol HCl}}{1 \text{ L}} \right) \times \left( \frac{1 \text{ mol H}_2}{2 \text{ mol HCl}} \right) \times \left( \frac{2.02 \text{ g H}_2}{1 \text{ mol H}_2} \right) = 0.30 \text{ g H}_2 \]

⇒ calculation based on Zn:

\[ 2.5 \text{ g Zn} \times \left( \frac{1 \text{ mol Zn}}{65.4 \text{ g Zn}} \right) \times \left( \frac{1 \text{ mol H}_2}{1 \text{ mol Zn}} \right) \times \left( \frac{2.02 \text{ g H}_2}{1 \text{ mol H}_2} \right) = 0.077 \text{ g H}_2 \]

⇒ The calculation based on Zn yields less product so Zn is the limiting reactant