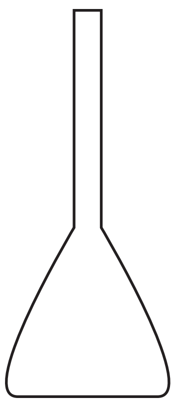
CHAPTER 4: Stoichiometry II: Chemical Reactions in Solution

Solution: homogeneous mixture
Solute: lesser component
Solvent: greater component

4.1 Solutions and Molarity

$$\text{Molarity} = M = \frac{\text{moles of solute}}{\text{liters of solution}} = \frac{n}{V}$$



Calculate the molarity of a solution prepared by dissolving 12.500 g KSCN in enough water to make 250.0 mL solution.

KSCN = (39.10) + (32.07) + (12.01) + (14.01) = 97.19 g/mol

$$n = 12.500 \text{ g} \times \frac{1 \text{ mol}}{97.19 \text{ g}} = 0.1286 \text{ mol}$$

$$M = \frac{n}{V} = \frac{0.1286 \text{ mol}}{0.2500 \text{ L}} = 0.5145 \text{ m/L or } 0.5145 \text{ M}$$

What volume of 0.5145 M KSCN solution contains 0.0500 mol KSCN?

$$V = \frac{n}{M} = \frac{0.0500 \text{ mol}}{0.5145 \text{ mol/L}} = 0.0972 \text{ L} = 97.2 \text{ mL}$$

What mass of K_2CO_3 must be dissolved in 100.00 mL of water in order to obtain a solution which is 1.000 M in $K^+_{(aq)}$ $[K^+] = 0.100$ M

$$K_2CO_{3(s)} \rightarrow 2K^+_{(aq)} + CO_3^{-2}{}_{(aq)}$$

$n(K^+) = MV = (1.000 \text{ M})(0.1000 \text{ L}) = 0.1000 \text{ mol } K^+$

$$0.1000 \text{ mol } K^+ \times \frac{1 \text{ mol } K_2CO_3}{2 \text{ mol } K^+} = 0.05000 \text{ mol } K_2CO_3$$

$$0.05000 \text{ mol } K_2CO_3 \times \frac{138.21 \text{ g } K_2CO_3}{1 \text{ mol } K_2CO_3} = 6.910 \text{ g } K_2CO_3$$

How many moles of Fe are present in 75.00 mL of a 0.2500 M solution of $Fe_2(SO_4)_3$?

$n = MV = (0.2500 \text{ M } Fe_2(SO_4)_3)(0.07500 \text{ L}) = 0.01875 \text{ mol } Fe_2(SO_4)_3$

$$0.01875 \text{ mol } Fe_2(SO_4)_3 \times \frac{2 \text{ mol Fe}}{1 \text{ mol } Fe_2(SO_4)_3} = 0.03750 \text{ mol Fe}$$

Dilution

Dilution is the addition of additional solvent to a solution, which results in a less concentrated solution. During dilution, the number of moles of solute is constant, so

$$n_{initial} = M_iV_i = n_{final} = M_fV_f \quad \text{or} \quad M_iV_i = M_fV_f$$

Concentrated HCl is 12.0 M. How much con HCl is needed to make 5.00 L of 0.50 M HCl?

M_i = 12.0, V_i = unknown, M_f = 0.50 M, V_f = 5.00 L

$$V_i = \frac{M_fV_f}{M_i} = \frac{(0.50\ M)(5.00\ L)}{12.0\ M} = 0.208\ L = 208\ mL$$

4.2 Solution Stoichiometry

What volume of 0.10 M HCl is required to dissolve 0.55 g Mg?

$$Mg + 2\ HCl \rightarrow MgCl_2 + H_2$$

$$0.55\ g\ Mg \times \frac{1\ mol\ Mg}{24.31\ g\ Mg} = 0.0023\ mol\ Mg \times \frac{2\ mol\ HCl}{1\ mol\ Mg} = 0.045\ mol\ HCl\ needed$$

$$M = n/V \quad V = n/M = \frac{0.045\ mol\ HCl}{0.10\ mol/L} = 0.0045\ L\ HCl = 4.5\ mL\ HCl$$

Precipitation Reactions

$$NaCl_{(aq)} + AgNO_{3(aq)} \rightarrow NaNO_{3(aq)} + AgCl_{(s)}$$

overall equation: shows reaction stoichiometry but represents all species as if they were molecular.
precipitate - solid that forms when two solutions are mixed

$$Na^+_{(aq)} + Cl^-_{(aq)} + Ag^+_{(aq)} + NO_3^-{}_{(aq)} \rightarrow Na^+_{(aq)} + NO_3^-{}_{(aq)} + AgCl_{(s)}$$

This is called a complete ionic equation. Na^+ and NO_3^- are called spectator ions.

$$Ag^+_{(aq)} + Cl^-_{(aq)} \rightarrow AgCl_{(s)}$$

Net ionic equation: includes only the ions which actually react. Spectator ions are excluded.

Solubility Rules (table 4.1 pg. 135)

1. Most nitrate salts are soluble
2. Most salts containing alkali metal ions and the ammonium ion are soluble
3. Most chlorides, bromides, and iodides are soluble except for Ag^+, Pb^{+2} and Hg_2^{+2}
4. Most sulfates are soluble except $BaSO_4$, $PbSO_4$, $HgSO_4$, $CaSO_4$
5. Most hydroxides are only slightly soluble except Gr.I (soluble) and Ba, Sr, Ca (partially)
6. Most sulfides, carbonates, chromates, and phosphates are only slightly soluble

$K_2SO_4 + Fe(NO_3)_2 \rightarrow$
$Na_3PO_4 + MgCl_2 \rightarrow$
$(NH_4)_2S + TiCl_4 \rightarrow$

$CaCl_{2(aq)} + AgNO_{3(aq)} \rightarrow$

What is the ppt formed and what mass is formed when 30.0 mL of 0.150 M $CaCl_2$ is added to 15.0 mL of 0.100 M $AgNO_3$?

$$CaCl_{2(aq)} + 2AgNO_{3(aq)} \rightarrow Ca(NO_3)_{2(aq)} + 2AgCl_{(s)}$$

(30.0 mL)(0.150 M $CaCl_2$) = 4.50 mmol $CaCl_2$
(15.0 mL)(0.100 M $AgNO_3$) = 1.50 mmol $AgNO_3$ so this is the limiting reactant

$$1.50 \text{ mmol } AgNO_3 \times \frac{2 \text{ mol AgCl}}{2 \text{ mol } AgNO_3} \times \frac{143.32 \text{ g AgCl}}{1 \text{ mol AgCl}} = 215 \text{ mg AgCl} = 0.215 \text{ g AgCl}$$

4.3 Chemical Analysis by Titration and Precipitation

Acid-Base Reactions Titrations

A titration is an experiment in which the concentration of a solution is determined by accurately measuring the volumes of solutions required to complete a reaction.

1. Put an accurate volume of first reactant in flask (pipet or buret).
2. Add indicator, if necessary. The indicator should change color at or very near the equivalence point of the reaction.
3. Add second reactant by buret; stop when reaction is complete (endpoint).

At endpoint, the number of moles of each reactant are related by the stoichiometric ratio (from the balanced equation)

$$M_aV_a = M_bV_b \times S\left(\frac{A}{B}\right)$$

What volume of 0.4000 M NaOH is needed to neutralize 20.00 mL of .5500 M HCl?

$$(20.00 \text{ mL})(0.5500 \text{ M HCl}) = 11.00 \text{ mmol HCl}$$
$$11.00 \text{ mmol HCl} \times \frac{1 \text{ mol NaOH}}{1 \text{ mol HCl}} = 11.00 \text{ mmol NaOH}$$
$$V = \frac{n}{M} = \frac{11.00 \text{ mmol NaOH}}{0.4000 \text{ M}} = 27.50 \text{ mL NaOH}$$

If it takes 18.50 mL of KOH to titrate 20.00 mL of 0.330 M H_2SO_4, what is the molarity of the KOH?

M_a = 0.330 M
V_a = 20.00 mL
M_b = ?
V_b = 18.50 mL

$$S\left(\frac{A}{B}\right) = \frac{1 \text{ mol acid}}{2 \text{ mol base}}$$

$$(0.330 \text{ M})(20.00 \text{ mL}) = M_b(18.50 \text{ mL}) \times \frac{1}{2}$$

$$Mb = \frac{(2)(0.330 \text{ M})(20.00 \text{ mL})}{(18.50 \text{ mL})} = 0.714 \text{ M}$$

Gravimetric Analysis

The thallium (present as Tl_2SO_4) in a 9.486 g pesticide sample was precipitated as 0.1824 g thallium (I) iodide. Calculate the % Tl_2SO_4 in the sample.

$$0.1824 \text{ g TlI} \times \frac{1 \text{ mol TlI}}{333.27 \text{ g TlI}} = 5.473 \times 10^{-4} \text{ mol TlI} \times \frac{1 \text{ mol } Tl_2SO_4}{2 \text{ mol TlI}} = 2.737 \times 10^{-3} \text{ mol } Tl_2SO_4$$

$$2.737 \times 10^{-3} \text{ mol } Tl_2SO_4 \times \frac{504.80 \text{ g } Tl_2SO_4}{1 \text{ mol } Tl_2SO_4} = 0.1381 \text{ g } Tl_2SO_4$$

$$\frac{0.1381 \text{ g } Tl_2SO_4}{9.486 \text{ g sample}} \times 100\% = 1.456\%$$