REACTIONS IN AQUEOUS SOLUTION

4.5 Concentrations of Solutions

4.6 Solution Stoichiometry and Chemical Analysis

Concentrations of Solutions

Solution:

homogeneous mixture of two or more components

Solute + Solvent → Solution

Concentration of solute:

either Amount of solute/amount of solvent

or Amount of solute/amount solution

Amount = moles, mass, or volume

Molarity (*M*)

Molarity: number of moles of solute per liter of solution.

$$M = \frac{\text{moles solute}}{\text{L solution}} \equiv \frac{\text{mol}}{\text{L}} \equiv \frac{\text{mmol}}{\text{mL}}$$

Number of mol = *M* x *V* (L)

Number of mmol = *M* x *V* (mL)

Molarity (*M*)

How to prepare 0.250 L of a 1.00 *M* solution of $CuSO_4$ (159.6 g/mol)?

$$\text{mol } CuSO_4 \text{ required} = \frac{1.00 \text{ mol}}{\cancel{\text{L}}} \times 0.250 \cancel{\text{L}}$$

$$= 0.250 \text{ mol } CuSO_4$$

$$\text{g } CuSO_4 \text{ required} = 0.250 \cancel{\text{mol}} \times \frac{159.6 \text{ g}}{1 \cancel{\text{mol}}}$$

$$= 39.9 \text{ g } CuSO_4$$

$$M = \frac{\text{mol}}{\text{L}} = \frac{0.250 \text{ mol}}{0.250 \text{ L}} = 1.00 \text{ } M$$

Molarity (*M*)

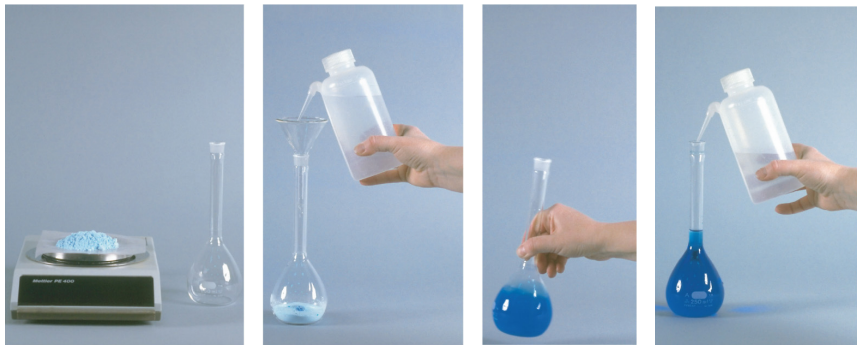
How to prepare 0.250 L of a 1.00 *M* solution of $CuSO_4$ (159.6 g/mol)?

one line calculation:

$$\text{g } CuSO_4 = 0.250 \cancel{\text{ L}} \times \frac{1.00 \cancel{\text{ mol } CuSO_4}}{\cancel{\text{L}}} \times \frac{159.6 \text{ g } CuSO_4}{\cancel{\text{mol } CuSO_4}} = 39.9 \text{ g } CuSO_4$$

Molarity (*M*)

How to prepare 0.250 L of a 1.00 *M* solution of $CuSO_4$ (159.6 g/mol)?



Molarity (*M*)

Calculate the molarity of a solution made by dissolving 5.00 g glucose ($C_6H_{12}O_6$, 180.0 g/mol) in 100.0 mL of solution.

$$M = \frac{\text{mol glucose}}{\text{L solution}} = \frac{0.02777 \text{ mol}}{0.100 \text{ L}}$$

$$\text{mol glucose} = 5.00 \cancel{\text{ g glucose}} \times \frac{1}{180.0 \cancel{\text{ g}}} = 0.02777 \text{ mol glucose}$$

$$\text{L solution} = 100.0 \cancel{\text{ mL}} \times \frac{1 \text{ L}}{1000 \cancel{\text{mL}}} = 0.100 \text{ L}$$

Molarity (*M*)

Calculate the molarity of a solution made by dissolving 5.00 g glucose ($C_6H_{12}O_6$, 180.0 g/mol) in 100.0 mL of solution.

one line calculation:

$$M = \frac{\text{mol glucose}}{\text{L solution}} = 5.00 \cancel{\text{ g glucose}} \times \frac{1 \text{ mol}}{180.0 \cancel{\text{ g}}} \times \frac{1}{100.0 \cancel{\text{ mL}}} \times \frac{1000 \cancel{\text{ mL}}}{\text{L}} = 0.278 \text{ } M$$

Concentration of Electrolyte

What is the concentration of each ion present in a 0.025 *M* solution of Na_2CO_3?

$$Na_2CO_3 \rightarrow 2Na^+ + CO_3^{2-}$$

$$\frac{\text{mol } Na^+}{\text{L}} = \frac{0.025 \text{ mol } Na_2CO_3}{\text{L}} \times \frac{2 \text{ mol } Na^+}{1 \text{ mol } Na_2CO_3}$$

$$= \frac{0.050 \text{ mol } Na^+}{\text{L}} = 0.050 \ M \ Na^+$$

$$\frac{\text{mol } CO_3^{2-}}{\text{L}} = \frac{0.025 \text{ mol } Na_2CO_3}{\text{L}} \times \frac{1 \text{ mol } CO_3^{2-}}{1 \text{ mol } Na_2CO_3}$$

$$= \frac{0.025 \text{ mol } CO_3^{2-}}{\text{L}} = 0.025 \ M \ CO_3^{2-}$$

How many grams of Na_2SO_4 are there in 15 mL of 0.50 *M* Na_2SO_4?

$$\text{mmol } Na_2SO_4 = 15 \text{ mL} \times \frac{0.50 \text{ mmol } Na_2SO_4}{\text{mL}}$$

$$= 7.5 \text{ mmol } Na_2SO_4$$

$$\text{mg } Na_2SO_4 = 7.5 \text{ mmol } Na_2SO_4 \times \frac{142.0 \text{ mg } Na_2SO_4}{\text{mmol } Na_2SO_4}$$

$$= 1065 \text{ mg } Na_2SO_4$$

$$= 1065 \text{ mg } Na_2SO_4 \times \frac{1 \text{ g}}{1000 \text{ mg}}$$

$$= 1.1 \text{ g } Na_2SO_4$$

How many grams of Na_2SO_4 are there in 15 mL of 0.50 *M* Na_2SO_4?

one line calculation:

$$\text{g } Na_2SO_4 = 15 \text{ mL} \times \frac{0.50 \text{ mmol } Na_2SO_4}{\text{mL}} \times \frac{142.0 \text{ mg } Na_2SO_4}{\text{mmol } Na_2SO_4} \times \frac{1 \text{ g } Na_2SO_4}{1000 \text{ mg } Na_2SO_4}$$

$$= 1.1 \text{ g } Na_2SO_4$$

How many milliliters of 0.50 *M* Na_2SO_4 solution are needed to provide 0.038 mol of this salt?

$$\text{L soln} = 0.038 \text{ mol} \times \frac{\text{L}}{0.50 \text{ mol}} = 0.076 \text{ L}$$

$$\text{mL soln} = 0.076 \text{ L} \times \frac{1000 \text{ mL}}{\text{L}} = 76 \text{ mL solution}$$

one line calculation:

$$\text{mL soln} = 0.038 \text{ mol} \times \frac{\text{L}}{0.50 \text{ mol}} \times \frac{1000 \text{ mL}}{\text{L}}$$

$$= 76 \text{ mL}$$

What is the concentration (*M*) of Na^+ in a solution made by dissolving 23.4 g of Na_2CO_3 in 125.0 mL of solution?

$$M = \frac{\text{mol } Na^+}{\text{L solution}}$$

$$\text{mol } Na_2CO_3 = 23.4 \text{ g } Na_2CO_3 \times \frac{\text{mol } Na_2CO_3}{106.0 \text{ g } Na_2CO_3}$$

$$= 0.22075 \text{ mol } Na_2CO_3$$

$$\text{mol } Na^+ = 0.22075 \text{ mol } Na_2CO_3 \times \frac{2 \text{ mol } Na^+}{1 \text{ mol } Na_2CO_3}$$

$$= 0.4415 \text{ mol } Na^+$$

$$M = \frac{0.4415 \text{ mol } Na^+}{0.1250 \text{ L solution}} = 3.53 \text{ } M \text{ } Na^+$$

What is the concentration (*M*) of Na^+ in a solution made by dissolving 23.4 g of Na_2CO_3 in 125.0 mL of solution?

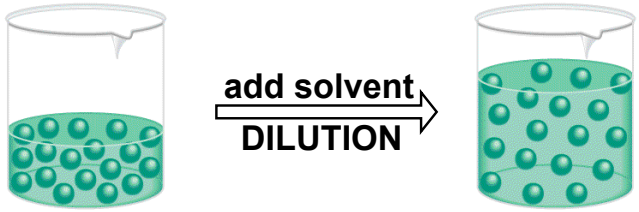
$$\frac{23.4 \text{ g } Na_2CO_3}{125 \text{ mL solution}} \Rightarrow \frac{\text{mol } Na^+}{\text{L solution}}$$

$$\frac{23.4 \text{ g } Na_2CO_3}{125 \text{ mL solution}} \times \frac{\text{mol } Na_2CO_3}{106.0 \text{ g } Na_2CO_3} \times \frac{2 \text{ mol } Na^+}{1 \text{ mol } Na_2CO_3}$$

$$\times \frac{1000 \text{ mL}}{1 \text{ L}} = \frac{3.53 \text{ mol } Na^+}{\text{L solution}} = 3.53 \text{ } M \text{ } Na^+$$

DILUTION OF SOLUTIONS

making a less concentrated solution from a more concentrated one.



Moles of solute before dilution (i)	=	Moles of solute after dilution (f)
$M_i V_i$	=	$M_f V_f$

Dilution of Solutions

How would you prepare 500. mL of 0.200 *M* $CuSO_4$ from a stock solution of 4.00 *M* $CuSO_4$?

$M_i = 4.00$ $V_i = ?$ L $M_f = 0.200$ $V_f = 500$ mL

$M_i V_i = M_f V_f$ *Only for 1:1 mol ratio*

$$V_i = \frac{M_f V_f}{M_i} = \frac{0.200 \times 500.}{4.00} = 25.0 \text{ mL}$$

Dilution of Solutions

How would you prepare 500. mL of 0.200 *M* $CuSO_4$ from a stock solution of 4.00 *M* $CuSO_4$?

$$\text{mmol after dilution} = 500.\ \cancel{\text{mL}} \times \frac{0.200\ \text{mmol}}{\cancel{\text{mL}}}$$

$$= 100.\ \text{mmol}$$

$$\text{mL before dilution} = 100.\ \cancel{\text{mmol}} \times \frac{\text{mL}}{4.00\ \cancel{\text{mmol}}}$$

$$= 25.0\ \text{mL}$$

Dilution of Solutions

Calculate the concentration of K^+ in a solution made by diluting 2.50 mL of a 5.0 *M* $K_2Cr_2O_7$ solution to 250.0 mL.

$M_i = 5.00 \quad V_i = 2.50\ \text{mL} \quad M_f = ? \quad V_f = 250.0\ \text{mL}$

$M_i V_i = M_f V_f$ *Only for 1:1 mol ratio*

$$M_f = \frac{M_i V_i}{V_f} = \frac{(5.0)(2.50)}{(250.0)} = 0.050\ M\ K_2Cr_2O_7$$

$$\frac{0.050\ \cancel{\text{mol } K_2Cr_2O_7}}{\text{L}} \times \frac{2\ \text{mol } K^+}{\cancel{\text{mol } K_2Cr_2O_7}} = 0.10\ M\ K^+$$

Solutions Stoichiometry

How many grams of NaOH are needed to neutralize 20.0 mL of 0.150 *M* H_2SO_4 solution?

$$2\ NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2\ H_2O$$

$$\text{mmol } H_2SO_4 = 20.0\ \cancel{\text{mL}} \times \frac{0.150\ \text{mmol } H_2SO_4}{\cancel{\text{mL}}}$$

$$= 3.00\ \text{mmol } H_2SO_4$$

$$\text{mmol NaOH} = 3.00\ \cancel{\text{mmol } H_2SO_4} \times \frac{2\ \text{mmol NaOH}}{1\ \cancel{\text{mmol } H_2SO_4}}$$

$$= 6.00\ \text{mmol NaOH}$$

$$\text{g NaOH} = 6.00\ \cancel{\text{mmol NaOH}} \times \frac{40\ \cancel{\text{mg}}\ \text{NaOH}}{\cancel{\text{mmol NaOH}}} \times \frac{10^{-3}\ \text{g}}{\cancel{\text{mg}}}$$

$$= 0.240\ \text{g NaOH}$$

Solutions Stoichiometry

How many grams of NaOH are needed to neutralize 20.0 mL of 0.150 *M* H_2SO_4 solution?

$2\ NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2\ H_2O$

one line calculation:

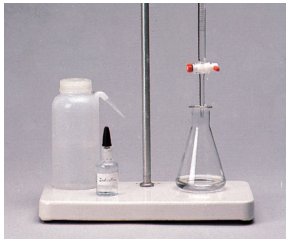
$$g\ NaOH = 20.0\ \cancel{mL} \times \frac{0.150\ \cancel{mmol\ H_2SO_4}}{\cancel{mL}} \times \frac{2\ \cancel{mmol\ NaOH}}{1\ \cancel{mmol\ H_2SO_4}} \times \frac{40\ \cancel{mg}\ NaOH}{\cancel{mmol\ NaOH}} \times \frac{10^{-3}\ g}{\cancel{mg}}$$

$$= 0.240\ g\ NaOH$$

TITRATIONS

Titrations

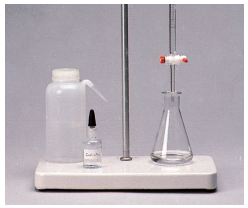
A solution of accurately known concentration (standard solution) is gradually added to another solution of unknown concentration until the reaction between the two solutions is complete.



When the reaction is complete?

Equivalence Point:

when stoichiometric amounts of the two solutions are reacted.



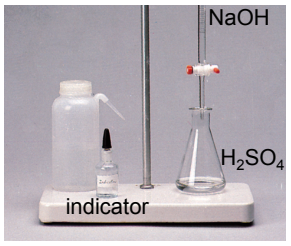
How to know it?

Use an indicator:

a substance that changes color at or near the equivalence point.

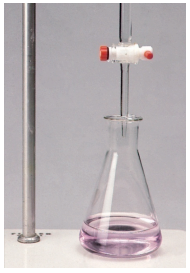
End Point:

The point at which the indicator changes color



Add base slowly until

indicator changes color



Before the end point **At the end point**

TITRATIONS

What is the molarity of an NaOH solution if 48.0 mL neutralizes 35.0 mL of 0.144 M H_2SO_4?

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$$

$$\text{mmol } H_2SO_4 = 35.0 \text{ mL} \times \frac{0.144 \text{ mmol}}{\text{mL}} = 5.04 \text{ mmol}$$

$$\text{mmol NaOH} = 5.04 \text{ mmol } H_2SO_4 \times \frac{2 \text{ mmol NaOH}}{1 \text{ mmol } H_2SO_4}$$

$$= 10.08 \text{ mmol NaOH}$$

$$M_{NaOH} = \frac{10.08 \text{ mmol NaOH}}{48.0 \text{ mL}} = 0.210 \ M$$

TITRATIONS

What is the molarity of an NaOH solution if 48.0 mL neutralizes 35.0 mL of 0.144 M H_2SO_4?

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$$

one line calculation:

$$M_{NaOH} = 35.0 \text{ mL} \times \frac{0.144 \text{ mmol } H_2SO_4}{\text{mL}} \times \frac{2 \text{ mmol NaOH}}{1 \text{ mmol } H_2SO_4} \times \frac{1}{48.0 \text{ mL}}$$

$$= 0.210 \ M \text{ NaOH}$$

How many mL of a 0.206 *M* HI solution are required to titrate 22.5 mL of a 0.374 *M* $KMnO_4$ solution?

$$10HI + 2KMnO_4 + 3H_2SO_4 \rightarrow 5I_2 + 2MnSO_4 + K_2SO_4 + 8H_2O$$

$$\text{mmol } KMnO_4 = 22.5 \text{ mL} \times \frac{0.374 \text{ mmol } KMnO_4}{\text{mL}}$$

$$= 8.415 \text{ mmol } KMnO_4$$

$$\text{mmol HI} = 8.415 \text{ mmol } KMnO_4 \times \frac{10 \text{ mmol HI}}{2 \text{ mmol } KMnO_4}$$

$$= 42.075 \text{ mmol HI}$$

$$mL_{HI} = 42.075 \text{ mmol HI} \times \frac{\text{mL}}{0.206 \text{ mmol HI}} = 204 \text{ mL}$$

How many mL of a 0.206 *M* HI solution are required to titrate 22.5 mL of a 0.374 *M* $KMnO_4$ solution?

$$10HI + 2KMnO_4 + 3H_2SO_4 \rightarrow 5I_2 + 2MnSO_4 + K_2SO_4 + 8H_2O$$

one line calculation:

$$mL_{HI} = 22.5 \text{ mL} \times \frac{0.374 \text{ mmol } KMnO_4}{\text{mL}} \times \frac{10 \text{ mmol HI}}{2 \text{ mmol } KMnO_4} \times \frac{\text{mL}}{0.206 \text{ mmol HI}}$$

$$= 204 \text{ mL}$$