Chapter 4 - Aqueous Reactions and Solution Stoichiometry

Section 4 - Solution Concentration

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Introduction - Concentrations of Solutions

- A solution is solute dissolved in a solvent.
- To quantify and know exactly how much of a solute is present in a certain amount of solvent, one will need to calculate concentrations.
- Concentrations can be given in:
  - percent solutions e.g., mass/mass % - (g of solute/g of solution) x 100%
  - molarity – mols of solute in liters of solution.

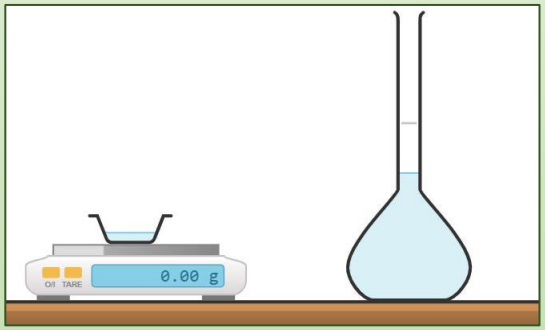
In this chapter we will study **Molarity** – which is moles in a Liter of solution.

Molar Concentration, Molarity (M)

- Molarity is represented by M and the formula is given below

$$\text{Molarity} = \frac{moles\ of\ solute}{L\ of solution} \qquad \text{M} = \frac{mol}{L}$$

- To prepare a solution, the weighed solute, in grams, is added to a volumetric flask, then water is added to bring the solution to the mark on the flask.



- A 3M solution of NaCl means there are 3 moles of NaCl in the solution.
- If you want to make a 200 mL of 2 M $NaNO_3$ solution, you will find the mols of $NaNO_3$ you need to make a 1 L of 2 M solution and then find the grams to make the 200 mL solution. All this can be done using the molarity equation given above and conversion of mols to grams.

Solved Problem: Calculating molarity from grams of solute

Calculate the molarity of a solution prepared by dissolving 25.00 grams of KI into a total volume of 250.0 mL.

Strategy – One way

Grams - > mol -> divide by volume -> convert vol to L (or convert vol to L first).

$$25.00 \text{ g KI} \times \frac{1 \text{ mol KI}}{166.0 \text{ g KI}} \times \frac{1}{250.0 \text{ mL}} \times \frac{1000 \text{ mL}}{1 \text{ L}} = 0.6024\ M$$

Strategy – Another way

1) Calculate mols needed and 2) divide mol by vol in L

$$25.00 \text{ g KI} \times \frac{1 \text{ mol KI}}{166.0 \text{ g KI}} = 0.1506 \text{ mol KI}$$

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

$$\frac{0.1506 \text{ mol KI}}{0.250 \text{ L}} = 0.6024 \text{ M}$$

Solved Problem: Calculating molarity

You place a 3.92 g of potassium dichromate, $K_2Cr_2O_7$, into a 100.0 mL volumetric flask. You then add water to bring the solution up to the mark on the neck of the flask. What is the molarity of $K_2Cr_2O_7$ in the solution?

Strategy

Find mols of solute using molar mass -> divide by L of solution

Molar mass of $K_2Cr_2O_7$ is 294 g/mol

$$M = \frac{mol}{L}$$

Step 1

$$\frac{3.92\ g}{294\ g/mol} = 0.01333\ mol$$

Step 2

$$\frac{0.01333\ mol}{100.0 \times 10^{-3}\ \text{L}} = 0.133\ M$$

OR set up in one step as shown below.

Mol calc. → $3.92\ \text{g} \times \frac{1\ \text{mol}}{294\ \text{g}}$

Volume → $100.0 \times 10^{-3}\ \text{L}$

$$= 0.103\ \text{M}$$

Solved Problem: Calculating volume of solution made

How many millilitres of water is needed to make a 2.50 *M* NaOH from 55.00 grams of the solid?

Strategy

Grams - > mol -> find mols using Molarity -> convert vol to mL

$$55.00\ \text{g NaOH} \times \frac{1\ \text{mol NaOH}}{40.00\ \text{g NaOH}} \times \frac{1\ \text{L}}{2.50\ \text{mol NaOH}} \times \frac{1000\ \text{mL}}{1\ \text{L}} = 550\ \text{mL}$$

Strategy – Another way

1) Calculate mols needed and 2) use molarity formula to find L

$$55.00\ \text{g NaOH} \times \frac{1\ \text{mol NaOH}}{40.00\ \text{g NaOH}} = 1.375\ \text{mol NaOH}$$

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

$$2.50\ M = \frac{1.375\ \text{mol NaOH}}{\text{L}}$$

$$\text{L} = \frac{1.375\ \text{mol NaOH}}{2.50\ \text{mol/L}} = 0.55\ \text{L} = 550\ \text{mL}$$

Solved Problem: Calculating mass of solute in given solution

A solution of sodium chloride used as physiological saline solution and has a concentration of 0.165 *M* NaCl. How many moles of NaCl are in 250. mL of physiological saline? How many grams of NaCl are in the 250. mL of solution?

Strategy

Find mols by multiplying Molarity by L -> use mol mass to find grams.

Molar mass NaCl $= 22.98 + 35.45 = 58.43$ g

$$M = \frac{mol}{L}$$

Step 1

$$\text{mol} = M \times L$$
$$= 0.165\ M \times 0.250\ L$$
$$= 0.04125\ \text{mol NaCl}$$

Step 2

$$0.04125\ mol \times \frac{58.43\ \text{g}}{1\ \text{mol}} = 2.41\ \text{g NaCl}$$

Dilution of Solutions

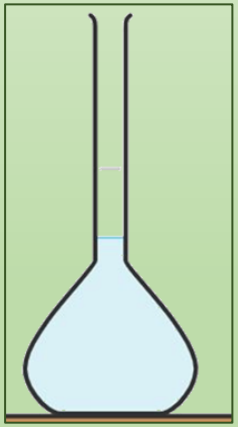
- When a higher concentration solution is used to make a less–concentration solution, the moles of solute are determined by the amount of the higher–concentration solution.
- The number of moles of solute remains constant when more water is added.

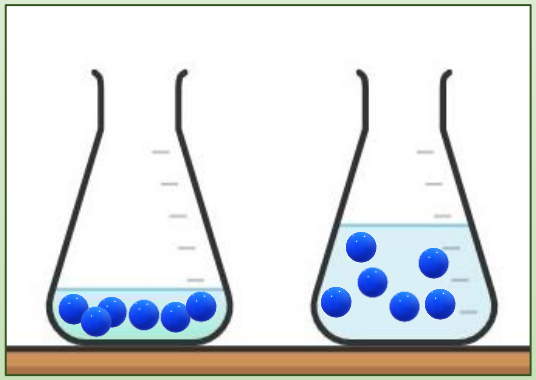
$$M_i V_i = M_f V_f$$

Note:

The units on V_i and V_f must match.

Diluting a solution quantitatively requires a volumetric flask, shown here.





Note: the number of molecules has not changed. Only the volume of solvent is increased.

Solved Problem: Calculating volume of stock needed

A saturated stock solution of NaCl is 6.00 *M*. How much of this stock solution is needed to prepare 1.00–L of physiological saline solution (0.165 *M*)?

$M_i V_i = M_f V_f$

$$V_i = \frac{M_f V_f}{M_i}$$

$$V_i = \frac{(0.165\ \text{M})(1.00\ \text{L})}{6.00\ \text{M}}$$

$V_i = 0.0275$ L or 27.5 mL

Solved Problem: Calculating new molarity

What is the new molarity of a 250.0 mL solution formed from diluting 25.00 mL of a 3.5 M stock solution.

$M_c V_c = M_d V_d$ (***Note***: *I am using c for concentrated and d for diluted in case this kind of formula helps you*)

(3.5 *M*) (25 mL) = M (250.mL)

$$M = \frac{3.5\ M \times 25\ mL}{250\ mL} = 12.5\ \text{mL}$$

(***Note***: *here we can use mL as the units will cross out*)

Solved Problem: Calculating volume of water needed

How much water is needed to make a 500.0 mL of 2.50 M solution using 9.5 M saturated stock solution of HCl?

$M_c V_c = M_d V_d$

(9.5 *M*) (V_c) = (2.50 M) (500 mL)

$$V_c = \frac{2.5 \text{ M x } 500 \text{ mL}}{9.5 \text{ M}} = 131.578 \text{ mL}$$

(***Note***: *we can still use mL in the formula above as final answer will be in mL*)

To finish the problem, we need to find the volume of water needed to be added. Subtract the stock volume from the total volume needed.

(500 – 131.578) mL = 368.422 mL

368.4 mL of water should be added to 131.6 mL of stock solution to make 2.50 M solution.

Concentrations of Ions in Solution

When compounds dissociate into ions, the ions have their own concentration in the solution since the solute is not present anymore.

Consider the equation below where a solution of 1.50 M solution is present.

$$NaCl_{(s)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)}$$

In this solution 1 mol of NaCl gives 1 mol of Na ion and 1 mol of Cl ions. The mol ratio of NaCl and Na^+ ion is 1:1. Hence the concentration of Na^+ is the same as NaCl, 1.50 M. The total concentration of ions in solution is 1.50 M Na^+ and 1.50 M Cl^- ions, a total of 3.0 M.

$$NaCl_{(s)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)}$$
$$1.5\ M \qquad\qquad 1.5\ M \qquad 1.5\ M$$

OR: $$1.5\ M\ NaCl \times \frac{1\ mol\ Na^+}{1\ mol\ NaCl} = 1.5\ M\ Na^+$$

Solved Problem: Calculating concentration of ions

Find the concentration of all species in a 0.25 *M* solution of MgF_2.

$MgF_2 \rightarrow Mg^{2+} + 2F^-$

I mol 1 mol 2 mol

0.25 M 0.25 M (2 x 0.25 M) = 0.50 M

Total concentration = (0.25 M Mg^{2+}) + (0.50 M F^-)

= 0.75 M

Solved Problem: Calculating concentration of ions

Find the total concentration of all species in a 2.6 *M* solution of strontium phosphate.

$$Sr_3(PO_4)_{2\,(s)} \rightarrow 3Sr^{2+}_{(aq)} + 2PO_4^{3-}_{(aq)}$$

Total ions present = $3Sr^{2+}_{(aq)} + 2PO_4^{3-}_{(aq)} = 5$

$$2.60\ M\ Sr_3(PO_4)_2\ x\ \frac{5\ ions}{1\ mol\ Sr_3(PO_4)_2} = 13.0\ \text{M ions}$$

Key Words/Concepts

- Solutions
  - Solvent
  - Solute
- Molarity (mol/L)
- Dilutions ($M_iV_i = M_fV_f$)
- Concentration of ions