Unites of Concentration

Concentration by percent

There are several ways of expressing the concentration of a solution by using a percentage.

The percentage solution could be expressed in terms of weight percent (% w/w), volume percent (% v/v) and weight-to-volume percent (% w/v)

units of solute present in 100 units of solution.

$$\left(\frac{\text{wt}}{\text{wt}}\%\right) = \frac{\text{wt solute (g)}}{\text{wt solution or sample (g)}} \times 100$$
$$= \frac{\text{wt solute (mg)}}{\text{wt solution or sample (mg)}} \times 100$$
$$\left(\frac{\text{wt}}{\text{V}}\%\right) = \frac{\text{wt solute (g)}}{\text{V solution or sample (mL)}} \times 100$$
$$= \frac{\text{wt solute (mg)}}{\text{V solution or sample (}\mu\text{L)}} \times 100$$
$$\left(\frac{\text{V}}{\text{V}}\%\right) = \frac{\text{V solute (mL)}}{\text{V solution or sample (mL)}} \times 100$$
$$= \frac{\text{V solute (}\mu\text{L)}}{\text{V solution or sample (}\mu\text{L)}} \times 100$$

The mass/mass percent (% m/m) is defined as the mass of a solute divided by the mass of a solution times 100:

$$\%\,\text{m/m} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 100\%$$

mass of solution = mass of solute + mass solvent

If you can measure the masses of the solute and the solution, determining the mass/mass percent is easy. Each mass must be expressed in the same units to determine the proper concentration.

Suppose that a solution was prepared by dissolving 25.0g of sugar into 100.0g of water. The mass of the solution is

mass of solution= 25.0g sugar + 100.0g water = 125.0 g

The percent by mass would be calculated by:

$$\text{Percent by mass} = \frac{25.0 \text{ g sugar}}{125.0 \text{ g solution}} \times 100\% = 20.0\% \text{ sugar}$$

Example:-Calculate the weight percentage of solution prepare by mixing 5.0g AgNO3 with 100mL water (density 1g/cm3).

Solution:

$$\left(\frac{\text{wt}}{\text{wt}}\%\right) = \frac{\text{wt solute (g)}}{\text{wt solution (g)}} \times 100$$
$$= \frac{\text{wt solute } (AgNO_3)\text{(g)}}{\text{wt solute + wt solvent } (H_2O) \text{ (g)}} \times 100$$
$$= \frac{5 \text{ g}}{5 \text{ g} + (100 \text{ mL} \times 1 \frac{\text{g}}{\text{mL}})} \times 100$$
$$= \frac{5 \text{ g}}{105 \text{ g}} \times 100 = 4.76\%$$

Example:-Calculate number of grams in 500mL NaCl solution (wt/v % = 0.859%).

Solution:

$$\left(\frac{wt}{V}\%\right) = \frac{\text{wt solute (g)}}{\text{V solution (mL)}} \times 100$$

$$0.859\ \% = \frac{\text{wt NaCl (g)}}{500} \times 100$$

$$\text{wt NaCl} = \frac{0.859 \times 500}{100} = 4.25\ \text{g NaCl}$$

Example:-Calculate the weight of glucose in litter solution(wt/v % = 5 %).

Solution:

$$\left(\frac{wt}{V}\%\right) = \frac{\text{wt solute (g)}}{\text{V solution (mL)}} \times 100$$

$$\left(\frac{wt}{V}\%\right) = \frac{\text{wt glucose (g)}}{\text{V solution (mL)}} \times 100$$

$$5\% = \frac{\text{wt glucose (g)}}{1000\ \text{(mL)}} \times 100$$

$$\text{wt glucose} = \frac{5 \times 1000}{100} = 50\ \text{g}$$

Example:-Calculate the volume percentage of solution preparing by mixing 50mL methyl alcohol with 200mL water.

Solution:

$$\left(\frac{V}{V}\%\right) = \frac{\text{V solute (mL)}}{\text{V solution or sample (mL)}} \times 100$$

$$= \frac{\text{V methyl alcohol (mL)}}{\text{V methyl alcohol + V water (mL)}} \times 100$$

$$= \frac{50\ \text{mL}}{(50 + 200)\text{mL}} \times 100 = 20\%$$

Molal concentration (Molality) m

(5) Molal concentration (Molality) m:-The solution concentration produce from dissolved solute (mole) in solvent (kg), molality does not change with temperature and used for physicochemical measurements.

$$\text{Molality (m)} = \frac{\text{wt}}{\text{M. wt}} \times \frac{1000}{\text{wt (g)}}$$

Molality is different from Molarity .Molality is based on mass, and is independent of temperature or pressure (unlike molarity)

Example:-Calculate the molal concentration for solution preparing from mixing 4 g NaOH with 500 g water.

$$\text{Molality (m)} = \frac{\text{wt}}{\text{M. wt}} \times \frac{1000}{\text{wt (g)}}$$

$$= \frac{4\text{ g}}{40\text{ g/mol}} \times \frac{1000}{500} = 0.2\text{ m}$$

Example:11.7 gm of sodium chloride is dissolved in 400 ml of water. Find molality of the solution.

$$\text{Moles of sodium chloride} = \frac{11.7}{(23+35.5)} = \frac{11.7}{58.5} = 0.2$$

$$\Rightarrow \text{Mass of the solvent} = 400X1 = 400 \quad gm = 0.4 \quad kg$$

$$\Rightarrow \text{Molality, m} = \frac{0.2}{0.4} = 0.5 \quad m$$

Density of solution in terms of molarity and molality

Working on the relation of molality developed in previous section :

$$m = \frac{1000M}{1000d - MM_O}$$

$$\Rightarrow \frac{1}{m} = \frac{1000d - MM_O}{1000M} = \frac{d}{M} - \frac{M_O}{1000}$$

$$\Rightarrow d = M\left(\frac{1}{m} + \frac{M_O}{1000}\right)$$

Problem : The molality and molarity of a solution of sulphuric acid are 90 and 10 respectively Determine density of the solution.

Solution : Using relation :

$$\Rightarrow d = M\left(\frac{1}{m} + \frac{M_O}{1000}\right)$$

$$\Rightarrow d = 10\left(\frac{1}{90} + \frac{98}{1000}\right) = 10X(0.011 + 0.98) = 10X0.991 = 9.91 \quad gm/cc$$

Calculating Molality - II

Problem: Determine the **molality** and **molarity** of a solution prepared by dissolving 75.0g $Ba(NO_3)_{2\,(s)}$ in to 374.00g of water at 25⁰C.

Plan: We convert the quantity of $Ba(NO_3)_2$ to moles using the molar mass and then divide by the volume of H_2O in liters (using water density = 0.99707 g/ml³).

Solution: molar mass of $Ba(NO_3)_2$ = 261.32 g/mol

$$\text{moles } Ba(NO_3)_2 = \frac{75.0 \text{ g}}{261.32 \text{ g/mol}} = \mathbf{0.28700 \text{ mole}}$$

$$\textbf{molality} = \frac{\mathbf{0.28700 \text{ mole}}}{0.37400 \text{ kg}} = \mathbf{0.76739 \text{ m}} = \mathbf{0.767 \text{ m}}$$

molarity - we need the volume of solution, and can assume that addition of the salt did not change the total volume.

$$\frac{374.00 \text{ g } H_2O}{0.99707 \text{ g/ml}} = \mathbf{375.099 \text{ ml} = 0.375099 \text{ l}}$$

$$\mathbf{M} = \frac{0.28700 \text{ mole}}{0.375099 \text{ l}} = \mathbf{0.765 \text{ M}}$$

Mole fraction concentration(X)

(6)Mole fraction concentration(X):- The ratio between number of mole for solute or solvent to solution, the terms used in physical chemistry .

$$\text{Mole fraction for solute }(X_1) = \frac{\text{no. mole solute }(n_1)}{\text{no. mole solute }(n_1) + \text{no. mole solute }(n_2)}$$

Example:-One litter of acetic acid solution contain 80.8 g of acetic acid, the solution density 1.00978 g/cm3.Calculate the mole fraction for solute(x1) and solvent(x2) .

Solution:

$$\text{Mole fraction for solute }(X_1) = \frac{\text{no. mole solute }(n_1)}{\text{no. mole solute }(n_1) + \text{no. mole solute }(n_2)}$$

$$= \frac{\left(\frac{\text{wt}}{\text{M.wt}}\right)_{CH_3COOH}}{\left(\frac{\text{wt}}{\text{M.wt}}\right)_{CH_3COOH} + \text{density}\times\text{volume}}$$

$$= \frac{\frac{80.8}{60}}{\frac{80.8}{60} + \left(\frac{1.009791\text{ cm}^3\times 1000\text{ cm}^3 - 80.8}{18}\right)} = 0.025$$

$$\text{Mole fraction for solvent }(X_2) = \frac{\text{no. mole solvent}}{\text{no. mole solvent} + \text{no. mole solute}}$$

$$= \frac{\frac{1.0097\times 1000 - 80.8}{18}}{\left(\frac{1.0097\times 1000 - 80.8}{18}\right) + \frac{80.8}{60.1}} = 0.975$$

$$X_1 + X_2 = 1\text{ unit} = 0.025 + 0.975 = 1.00\text{ unit}$$

Expressing Concentrations in Mole Fraction

Problem: A sample of alcohol contains 118g of ethanol (C_2H_5OH), and 375.0g of water. What are the mole fractions of each?

Plan: we know the mass and formula of each compound so we convert both to moles and apply the definition of mole fraction.

Solution:

$$\text{Moles Ethanol} = \frac{\text{118g Ethanol}}{\text{43g Ethanol/mol}} = \text{2.744 mol Ethanol}$$

$$\text{Moles Water} = \frac{395\text{g } H_2O}{18\text{g } H_2O\text{/mol}} = 21.94 \text{ mol } H_2O$$

$$X_{\text{Ethanol}} = \frac{2.744}{21.94 + 2.744} = \mathbf{0.11117}$$

$$X_{\text{Water}} = \frac{21.94}{21.94 + 2.744} = \mathbf{0.88883}$$

Converting Concentration Units

Problem: Commercial concentrated Hydrochloric acid is 11.8 M HCl and has a density of 1.190g/ml. Calculate the (a) mass% HCl, (b) molality and (c) mole fraction of HCl.

Plan: We know Molarity and density. (a) For mass% HCl we need the mass of HCl and water (the solvent). Assume 1L of solution, from the density we know the mass of the solution, and from the molecular mass of HCl we calculate its mass. (b) We know moles of HCl and mass of water (c) we use moles HCl from(a) and use the mass of water to get moles of water then calculate mole fractions and add them to check!

Solution:

(a) assume 1L of HCl solution → 11.8 moles HCl

$$\text{11.8 moles HCl} \times \frac{\text{36.46g HCl}}{\text{mole HCl}} = \mathbf{430.228g\ HCl}$$

Converting Concentration Units - II

(a) cont.

$$1\text{L solution} \times \frac{1000\text{ mL}}{1\text{ L solution}} \times \frac{1.190\text{ g soln}}{\text{mL soln}} = 1190\text{g solution}$$

$$\text{mass \% HCl} = \frac{430.228\text{ g HCl}}{1190.\text{g solution}} \times 100\% = \mathbf{36.1536\ \%\ HCl}$$

(b) mass of H_2O = mass of solution - mass of HCl =

1190g solution - 430.228g HCl = 759.772g H_2O

1190g solution

$$\frac{11.8\text{ moles HCl}}{0.759772\text{ kg } H_2O} = \mathbf{15.53\ m\ HCl}$$

(c) $\frac{759.772\text{g } H_2O}{18.016\text{g } H_2O/\text{mol } H_2O}$ = **42.172 mole H_2O**

Total moles = 42.172 + 11.8 = 53.972=**54.0**

$X_{HCl} = \frac{11.8}{\mathbf{54.0}} = \mathbf{0.219}$ $X_{H2O} = \frac{42.172}{\mathbf{54.0}} = \mathbf{0.781}$

Determine the mole fraction of KCl in 3000 grams of aqueous solution containing 37.3 grams of Potassium Chloride KCl.

1. **Convert grams KCl to moles KCl using the molecular weight of KCl**

$$37.3\text{ g KCl}\frac{1\text{ mole KCl}}{74.6\text{ g KCl}} = 0.5\text{ mole KCl}$$

2. **Determine the grams of pure solvent water from the given grams of solution and solute**

Total grams = 3000 grams = Mass of solute + Mass of water

Mass of pure solvent = (3000 - 37.3) gram

= 2962.7 gram

Determine the mole fraction of KCl in 3000 grams of aqueous solution containing 37.3 grams of Potassium Chloride KCl.

3. Convert grams of solvent H_2O to mols

$$(2962.7 \text{ grams water}) \frac{1 \text{ mol}}{18.0 \text{ grams}} = 164.6 \text{ mols } H_2O$$

4. Apply the definition for mole fraction mole fraction = moles of KCl / Total mols of KCl and water =
0.5 / (0.5 + 164.6) = 0.5 / 165.1 = 0.00303

(* (The relationship between molarity or normality with percentage concentration:-**

Example:-Calculate the molar concentration for 0.85% (w/v%) sodium chloride solution.

$$M = \frac{wt\,(g)}{M.wt} \times \frac{1000}{V\,mL} = \frac{wt\,(g)}{M.wt} \times \frac{1000}{100} = \frac{wt}{V}\% \times \frac{1000}{M.wt} = \frac{0.85}{100} \times \frac{1000}{58.5}$$

$$= 0.145M$$