SOLUTION

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"Solution is a mixture of two or more substances whose composition can be varied within certain limits". By homogeneous mixture we mean that its composition and properties are uniform throughout the mixture. The substances making up the solution are called components of the solution. Depending upon the total components present in the solution. It is called the binary solution (two components), tertiary solution (three components), quaternary solutions. (four components).

For simplicity we shall consider only binary solutions. The components of a binary solutions are generally referred to as solute and the solvent. In general, component which is present in large quantity is called solvent while the component which is present in lesser quantity is termed the solute. In other words, a solute is a substance that dissolves and a solvent is a substance in which dissolution takes place. For example, if a crystal of sugar is dropped into a beaker of water, it dissolves to form a solution. In this case, sugar is solute and water is solvent. The solvent determines the physical state in which solution exists. In a solution, the particles are of molecular size (about 1000 pm) and the different components cannot be separated by any of the physical methods such as filtration, settling and centrifugation, etc.

Type of Solution	Solute	Solvent	Common Examples
Gaseous Solutions	Gas	Gas	Mixture of oxygen and nitrogen gases
	Liquid	Gas	Chloroform mixed with nitrogen gas
	Solid	Gas	Camphor in nitrogen gas
Liquid Solutions	Gas	Liquid	Oxygen dissolved in water
	Liquid	Liquid	Ethanol dissolved in water
	Solid	Liquid	Glucose dissolved in water
Solid Solutions	Gas	Solid	Solution of hydrogen in palladium
	Liquid	Solid	Amalgam of mercury with sodium
	Solid	Solid	Copper dissolved in gold

Out of these nine types of solutions, three solutions, namely solid in liquid, liquid in liquid and gas in liquid are very common. In all the three types of solutions, liquid act as solvent. The solution in which water is the solvent are called aqueous solution while those in which water is not the solvent are called non-aqueous solutions. The common non-aqueous solvents are ether, benzene and carbon tetrachloride, etc.

Methods for expressing the concentration of a solution: units of concentration-Composition of a solution can be described by expressing its concentration. "The concentration of a solution may be defined as the amount of solute present in the given quantity of the solution". It can be described either qualitatively or quantitatively. For example, qualitatively we can simply say that the solution is dilute which means relatively very small quantity of solute is present or the solution is concentrated which means that relatively large quantity of solute is present. However, it is better to express concentration of the solution quantitatively. The concentration of the solution may be expressed by several ways as discussed ahead.

1. Mass Percentage: "The mass percentage of a component in a given solution is the mass of the component per 100 g of the solution."

$$\text{Mass \% of component} = \frac{\textit{mass of the component in the solution}}{\textit{total mass of the solution}} \text{ X } 100$$

For example, if W_A is the mass of component A and W_B is the mass of component B in a solution then

Mass percentage of A = $\frac{W_A}{W_A + W_B}$ X 100

This can be expressed as w/w. For example, a 10% (w/w) solution of sodium chloride means that 10 g of sodium chloride is present in 90 g of water so that the total mass of the solution is 100 g or simply 10 g of sodium chloride is present in 100 g of solution. Concentrations described by mass percentage are commonly used in the industrial chemical applications. For example, commercial bleaching solution contains 3.62 mass percentage of sodium hypochlorite in water.

Example: If 11 g of oxalic acid are dissolved in 500ml of solution (density = 1.1g/ml). What is the mass % of oxalic acid in solution?

Solution: 11 g of oxalic acid are present in 500ml of solution

Density of solution = 1.1 g/ml

Mass of solution = 500ml X 1.1 g/ml = 550 g

Mass of oxalic acid=11 g Mass % of oxalic acid = $\frac{11}{550}$ X 100 = 2%

2. Volume Percentage: In case of a liquid dissolved in another liquid, it is convenient to express the concentrations in volume percentage.

"The volume percentage is defined as the volume of the component per 100 parts by volume of the solution".

For example, if V_A and V_B are the volume of two components A and B respectively in a solution, then

Volume % of A = $\frac{volume\ of\ A}{volume\ of\ A\ +\ volume\ B}$ X 100

This may be expressed as v/v. For example, 10% by volume of ethanol solution means that 10 ml of ethanol is dissolved in enough water so that the total volume of the solution is 100ml. Solutions containing liquids are commonly expressed as volume percentage. For example, a 35% (v/v) solution of Ethylene glycol behaves as antifreeze and is used in cars for cooling the engines. At this concentration, the antifreeze solution lowers the freezing point of water to 255.4 K (or -17.6^oC). **Mass by volume percentage (w/v):** Sometimes we express the concentration as weight/volume. It is the mass of solute dissolved in 100 ml of the solution. This unit is commonly used in medicine and pharmacy. For example, a 10% solution of sodium chloride (w/v) means that 10 gram of sodium chloride are dissolved in 100 ml of solution.

3. Parts per million: When a solute is present in very minute amounts (trace quantities), concentration is expressed in parts per million abbreviated as ppm. "It is the parts of a component per million parts of the solution."

It is expressed as:

ppm A = $\frac{mass\ of\ component\ A}{Total\ mass\ of\ solution}$ X 10^6

Like percentage, concentration in parts per million can also be expressed as mass to mass, volume to volume or mass to volume.

For example, suppose a litre of public supply water contains about 3 X 10^{-3} gram of chlorine. The mass percentage of chlorine is:

Mass % of chlorine = $\frac{3.0\ x\ 10^{-3}}{1000}$ X 100 = 3X 10^{-4}

The parts per million parts of chlorine is: ppm of chlorine = $\frac{3x10^{-3}x10^6}{1000}$= 3

Thus, instead of expressing concentration of chlorine as 3 x 10^{-4} % it is better to express as 3 ppm.

Similarly, a litre of sea water (1030g) contains 6 x 10^{-3} g of dissolved O_2. Its mass % is:

Mass % of O_2 = $\frac{6\ x\ 10^{-3}}{1030}$ X 100 = 5.8 x 10^{-4} %

The part per million parts of dissolved O_2 is ppm of O_2 = $\frac{6\ x\ 10^{-3}}{1030}$ X 10^6 = 5.8 ppm

Atmospheric pollution in cities due to harmful gases is generally expressed in ppm though in this case the values refer to volumes rather than masses.

For example, the concentration of Sulphur dioxide in Delhi has been found to be as high as 10 ppm. This means that 10 cm^3 of Sulphur dioxide are present in 10^6 cm^3 (or 10^3 L) of air. The concentration of atmospheric pollutants in cities is generally expressed in terms of μg/ml .

4. Molarity of a solution: It is the number of moles of the solute dissolved per litre of the solution. It is represented as 'M'. Thus, a solution which contains one-gram mole of the solution dissolved per litre of the solution is regarded as 1 molar solution. For example, 1M sodium carbonate (molar mass = 106) solution has 106 gram of the solute present per litre of the solution.

$$\text{Molarity} = \frac{Moles\ of\ solute}{volume\ of\ solution\ in\ litres}$$

It is convenient to express volume in cm^3 or mL so that

$$\text{Molarity} = \frac{Moles\ of\ solute}{Volume\ of\ solution\ (in\ mL\ or\ cm3} \text{ X } 1000$$

Thus, the unit of molarity are moles per litre (mol L^{-1}) or moles per cubic decimeter (mol dm^{-3}). The symbol M is used for mol/L or mol/dm^3 and it represents molarity.

If n_B moles of solute are present in V ml of solution, then -

$$\text{Molarity} = \frac{n_B}{V} \text{ X } 1000$$

Moles of solute can be calculated as:

$$\text{Moles of solute} = \frac{Mass\ of\ solute}{Molar\ mass\ of\ solute}$$

Molarity is one of the common measures of expressing concentration which is frequently used in the laboratory. However, it has one disadvantage, it changes with temperature because of expansion or contraction of the liquid with temperature. 2.46 g sodium hydroxide (molar mass = 40) are dissolved in water and the solution is made to 100 cm^3 in a volumetric flask.

Example: Calculate the molarity of the solution.

Solution: Amount of NaOH = 2.46 g

Volume of solution = 100 cm^3

$$\text{Moles of NaOH} = \frac{Mass\ of\ NaOH}{Molar\ mass} = \frac{2.46\ g}{40\ g/mol} = 0.0615 \text{ mol}$$

$$\text{Molarity} = \frac{Moles\ of\ NaOH}{Volume\ of\ solution} \text{ X } 1000$$

$$= \frac{0.0615\ mol}{100} \text{ X } 1000 \text{ ml/L} = 0.615 \text{ mol/L} = 0.615\text{M}$$

5. Molality of a Solution: It is the number of moles of the solute dissolved per 1000 gram (or 1kg) of the solvent. It is denoted by m. Thus, a solution which contains one gram mole of a solute dissolved in 1 kg of water is regarded as 1 molal solution. For example, 1.0 m solution of potassium chloride means that one mole (74.5 g) of potassium chloride is dissolved in 1 kg or 1000 gram of water. Mathematically,

$$\text{Molality (m)} = \frac{Moles\ of\ solute}{Weight\ of\ solvent\ in\ Kg}$$

or $$= \frac{Moles\ of\ solute}{mass\ of\ solvent\ in\ gram} \text{ X } 1000$$

Thus, the units of molality are moles per kilogram i.e., mol/Kg. If n_B moles of solute are dissolved in W grams of solvent, then Molality = $\frac{n_B}{W}$ X 1000.

Example: Calculate the molality of a solution containing 20.7g of potassium carbonate dissolved in 500 ml of solution (assume density of the solution = 1 gram/ ml)

Solution: Mass of K_2CO_3 = 20.7 g

Molar mass of K_2CO_3 = 138 g/mol

Moles of K_2CO_3 = $\frac{20.7\ g}{138\ g/mol}$ = 0.15 mol

Mass of solution = (500 ml) X (1g/ml) = 500 g

Amount of water = 500-20.7 = 479.3 g

Molality = $\frac{Moles\ of\ solute}{Mass\ of\ solvent\ in\ gram}$ X 1000 = $\frac{0.15\ mol}{479.3\ g}$ x 1000 = 0.313 m

Example: 2.5 gram of ethanoic acid (CH_3COOH) is dissolved in 75 grams of benzene. Calculate the molality of the solution.

Solution: Molar mass of CH_3COOH = 60 g/mol

Moles of ethanoic acid = $\frac{2.5\ g}{60\ g/mol}$ = 0.0417 mol

Mass of benzene = 75 g

Molality of CH_3COOH = $\frac{Moles\ of\ ethanoic\ acid}{mass\ of\ benzene\ in\ g}$ X 1000

=$\frac{0.0417\ mol}{75\ g}$ X 1000= 0.556 mol/Kg = 0.556 m

6. **Mole fraction:** It is the ratio of number of moles of one component to the total number of moles (solute and solvent) present in the solution.

Mole fraction of a component = $\frac{Number\ of\ moles\ of\ the\ component}{Total\ number\ of\ moles\ of\ all\ component}$

It is denoted by X and a subscript used on the right-hand side of X denote the component. (x_A).

Let us suppose that a solution contains n_A mole of solute and n_B moles of the solvent. Mole fraction of solute (x_A) = $\frac{n_A}{n_{A+}n_B}$

Mole fraction of solvent (x_B) = $\frac{n_B}{n_{A+}n_B}$

The sum of mole fraction of all the components in solution is always equal to 1 as shown below:

$x_A + x_B = \frac{n_A}{n_A + n_B} + \frac{n_B}{n_A + n_B} = 1$

Thus, if the mole fraction of one component of a binary solution is known, that of the can be calculated. For example, the mole fraction x_A is related to x_B as: $x_A = 1 - x_B$ or $x_B = 1 - x_A$

Example: Calculate the mole fraction of ethylene glycol ($C_2H_6O_2$) in a solution containing 20% of $C_2H_6O_2$ by mass.

Solution: 20% ethylene glycol solution means that 20 gram of Ethylene glycol is present in 100 grams of solution or 20 g of ethylene glycol is present in 80 grams of water.

Molar mass of $C_2H_6O_2$ = 2X12+6x1+2x16 = 62g/mol

Moles of $C_2H_6O_2$ = $\frac{20\ g}{62\frac{g}{mol}}$ = 0.322 mol

Mass of water = $\frac{80\ g}{18}$ = 4.444

$X_{glycol} = \frac{Moles\ of\ ethylene\ glycol}{Moles\ of\ ethylene + Moles\ of\ water} = \frac{0.322}{0.322+4.444} = 0.068$

$X_{water} = \frac{4.444}{0.322+4.444} = 0.932$

$X_{water} = 1 - 0.068 = 0.932$

7. Normality: It is the number of gram equivalents of the solute dissolved per litre of the solution. It is denoted by N

$$\text{Normality (N)} = \frac{Number\ of\ gram\ equivalents\ of\ solute}{Volume\ of\ solution\ in\ litres}$$

$$\text{Or Normality} = \frac{Number\ of\ gram\ equivalents\ of\ solute}{Volume\ of\ solution\ in\ mL} \times 1000$$

Thus, the units of normality are gram equivalent per litre.

Gram equivalent of solute can be calculated as: Gram equivalent of solute = $\frac{mass\ of\ solute}{Equivalent\ mass}$

Like molarity, normality of a solution also changes with temperature. Relationship between molarity and normality of the solution of an acid or a base:

Normality of solution of an acid = molarity x basicity

Normality of solution of a base = molarity x acidity

E.g., 1M H_2SO_4 sol. = 2N H_2SO_4 sol.

1M $Ca(OH)_2$ = 2N $Ca(OH)_2$

Example: Calculate the normality of solution containing 31.5g of hydrated oxalic acid ($H_2C_2O_4 . 2H_2O$) in 1250 ml of solution.

Solution: Mass of oxalic acid = 31.5 g

Equivalent of oxalic acid = $\frac{31.5}{63} = 0.5$

(Eq.wt. of oxalic acid 126/2 = 63)

Volume of solution = 1250 mL

Normality = $\frac{0.5}{1250}\ x\ 1000 = 0.4\ N$
