CONCENTRATION TERMS-CLASS 10

A solution is a homogenous mixture of two or more substances. The substances making up the solution are called components of the solution. In general, the two components of the solution are solute and solvent.

Solvent is that component of the solution which has same physical state in the pure form as of the solution and mostly present in greater quantity. The other component is called solute, the substance which is dissolved in the solvent. If the physical state of both the components is same, then the component with larger amount is called solvent while that with smaller amount is called solute. For example, if glucose is added to water in a beaker it dissolves to form clear solution. Then glucose is solute and water is solvent.

$$\underset{\text{(Solute)}}{\text{Glucose}} + \underset{\text{(Solvent)}}{\text{Water}} \longrightarrow \underset{\text{(Homogenous mixture)}}{\text{Solution of glucose}}$$

Illustration 1: ***Identify the solutes and the solvents in the following examples.***

(a) 2 grams of copper sulfate is added to 50 ml of water.

(b) 5 ml of water is added to 50 grams of magnesium sulfate.

(c) 10 grams of carbon dioxide is dissolved in one litre of water of give "Soda"

Solution: (a) Copper sulphate is solute as it is less in quantity (2 grams) and water is solvent.

(b) Water is solute and magnesium sulphate is solvent.

(c) Carbon dioxide is solute and water is solvent.

Aqueous, non–aqueous solutions: On the basis of the solvent, solutions can be divided into two types, one is aqueous and another is non-aqueous.

The solutions in which the solvent is water are called **aqueous solutions**. For example, sugar in water or NaCl in water.

The solutions in which the solvent is a liquid other than water are called **non-aqueous solutions**. For example iodine is dissolved in carbon tetrachloride, sulphur dissolved in carbon disulphide.

Concentrate and Dilute Solutions: On the basis of the solute, solutions can be divided into two types one concentrated and another dilute.

Concentrated Solutions: The solutions which contain relatively more amount of the solute.

Dilute Solutions: The solution which contains relatively less amount of the solute.

Unsaturated, Saturated and Supersaturated Solution: On the basis of the solubility solutions can be divided into three types (a) Saturated, (b) Unsaturated and (c) Supersaturated.

- Solutions in which more solute can be dissolved at a given temperature and pressure are called unsaturated solutions. The solution in which the strength of solute is less than the strength of solvent.
- Solutions in which no more solute can dissolve at a given temperature are called saturated solutions. The solution in which the strength of solute is equal to the strength of solvent.
- Solutions in which more solute can be dissolved by increasing the temperature; after the dissolution of the extra solute at higher temperature, the solution is cooled to the room temperature. The solutions thus formed are called supersaturated solutions. The solution in which the strength of solute is greater than the strength of solvent.
- The maximum amount of solute that can be dissolved in 100g of the given solvent at a particular temperature and pressure is called **Solubility** of the solute. For example, solubility of sodium chloride in water at 20°C is 36.0g. This means that at 20°C we can dissolve a maximum of 36g of NaCl in 100g of water to form a saturated solution of NaCl.
- Solubility of solutes whose solution process in exothermic, decreases with increase in temperature. On the other hand, the solubility of solutes solution process is endothermic, increases with increases in temperature.

Factors affecting the solubility: Solubility of a substance depends upon nature of solute, nature of solvent and conditions of temperature and pressure.

1. Nature of Solute and Solubility: Consider the following example. In two separate test tubes take some water and add small amounts of powdered copper sulphate in one and naphthalene in the other. Copper sulphate dissolves and forms a blue solution whereas naphthalene remains undissolved. Now take some kerosene in another set of two test tubes and repeat the experiment with copper sulphate and naphthalene. Shake gently. Naphthalene dissolves and forms a colorless solution whereas copper sulphate remains undissolved. From these examples we understand that copper sulphate is soluble in water and insoluble in kerosene. On the other hand naphthalene is soluble in kerosene and insoluble in water. You learnt earlier that ionic compounds are polar in nature and covalent compounds are non-polar. Both water and copper sulphate are polar compounds. When a non-polar solute is added (naphthalene) dissolves in a non-polar solvent (kerosene) to form a solution. If a polar compound is added as a solute to a non-polar solvent or vice-versa, it does not form a solution and the solubility of that compound in that solvent is said to be zero. We can thus conclude that the solubility depends on the nature of solute and the solvent. The generalized statement is “like dissolves in like”.

2. (a.) Solid Solubility and Temperature: Take some water in each of three test tubes and prepare saturated solutions of sodium nitrate ($NaNO_3$), sodium chloride (NaCl) and cerium sulphate ($Ce_2(SO_4)_3$. $9H_2O$. Observe the quantities of the undissolved solutes in these test tubes. Now gently heat the contents. We notice that while sodium nitrate dissolves completely on heating. From this experiment, we understand that the solubility increases in some cases (e.g.: $NaNO_3$), remains the same (e.g.: NaCl) or decreases in some other cases ($Ce(SO_4)_3.9H_2O$.

Let us now see the solubilities of gases such as CO_2, O_2 and SO_2 etc., in water. The solubilities of different gases at different temperatures. From this table, it is clear, that in general, on increasing the temperature, the solubility decreases. An illustrative example of gas/liquid solution behaviour is that of “soda”, a common drink. Soda is a solution of carbon dioxide in water. We usually drink “soda” after taking heavy food. When we open this soda bottle and pour into a glass, we see bubbles escaping. These bubbles are CO_2 gas. After some time or after gently heating the soda, we do not see any bubbles. This is due to total expulsion of CO_2 from water.

2. (b.) Gas Solubility and Temperature

Solubility of a gas in water tends to decrease with increasing temperature, and solubility of a gas in an organic solvent tends to increase with increasing temperature.

The Effect of Pressure on Solubility

For solids and liquids, known as condensed phases, the pressure dependence of solubility is typically weak and is usually neglected in practice. However, the solubility of gases shows significant variability based on pressure. Typically, a gas will increase in solubility with an increase in pressure. This effect can be mathematically described using an equation called Henry’s law.

Applications of Gas Solubility

In order for deep-sea divers to breathe underwater, they must inhale highly compressed air in deep water, resulting in more nitrogen dissolving in their blood, tissues, and joints. If a diver returns to the surface too rapidly, the nitrogen gas diffuses out of the blood too quickly, causing pain and possibly death. This condition is known as “the bends.”

To prevent the bends, a diver must return to the surface slowly, so that the gases will adjust to the partial decrease in pressure and diffuse more slowly. A diver can also breathe a mixture of compressed helium and oxygen gas, since helium is only one-fifth as soluble in blood as nitrogen.

Under the water, our bodies are similar to a soda bottle under pressure. Imagine dropping the bottle and trying to open it. In order to prevent the soda from fizzing out, you open the cap slowly to let the pressure decrease.

On land, we breathe about 78 percent nitrogen and 21 percent oxygen, but our bodies use mostly the oxygen. When we’re underwater, however, the high pressure of water surrounding our bodies causes nitrogen to build up in our blood and tissues. Like in the case of the bottle of soda, if we move around or come up from the water too quickly, the nitrogen will be released from our bodies too quickly, creating bubbles in our blood and causing “the bends.”

Concentration of Solutions

The term concentration or strength of a solution refers to the amount of solute present in a definite amount of solvent or solution.

Standard solution: A solution whose concentration is known is called a standard solution. The concentration of a solution is often measured in grams per litre or decimetre cubed $\left(\frac{\text{gms. or dm}^3}{\text{lt.}}\right)$.

A solution whose concentration is accurately known is called a **Standard Solution**. A standard solution can be prepared by weighing method in the following way:

- The mass of solute needed is calculated and weighed.
- The solute is dissolved in some distilled water in a beaker.
- The solution is transferred into a volumetric flask.
- More distilled water is added to obtain the required volume. The flask is stoppered and shaken.
- The level of the solution in the flask is made up to the mark calibrated on the stem of the flask.

So the units are expressed as $g.L^{-3}$ or $g.dm^{-3}$, or $\frac{g}{dm^3}$, which was $\frac{g}{L}$.

$$\text{Concentration} = \frac{\text{mass}}{\text{volume}} = c = \frac{m}{V}$$

Concentration in $g.dm^{-3}$, mass in g, volume in dm^3

It's really important remember that 1 dm^3 = 1000 cm^3 or 1000 ml and $\frac{cm^3}{1000} = dm^3$. Rearrangements of the formula using the triangle to help give…

Mass = concentration x volume $(m = c \times V)$ and

Volume = mass / concentration ($V = \frac{m}{c}$)

In the example questions I have used the shorthand formulae $c = m / V$, $m = c \times V$ and $V = \frac{m}{c}$ and

A standard solution is one of accurately known concentration.
Three simple examples to illustrate using the formula (formula triangle on right)

(a) What is the concentration of a salt solution if you dissolve 10g of sodium chloride in 250 cm^3 of water?

250 cm^3 is equal to $\frac{250}{1000}$ = 0.25dm^3

Therefore the concentration $c = \frac{m}{V}$ = 10/0.25 = 40 g/dm^3

(40g/litre in old units, still in common use!)

(b) What mass of the salt is required to make 200 cm^3 of concentration 15g/dm^3?

$V = \frac{200}{1000}$ = 0.2 dm^3

$m = c \times V$ = 15 x 0.2 = 3.0 g

(c) If you were given 8.0 g of salt, what volume of water, in dm^3 and cm^3, should you dissolve it in, to give a salt solution of concentration of 5.0g/dm^3?

$$V = \frac{m}{c} = \frac{8.0}{5.0} = 1.6\ dm^3 = 8.0 / 5.0 = 1.6\ dm^3$$

$$V = 1.6 \times 1000 = 1600\ cm^3$$

Expression of concentration: There are various ways of expressing concentration of solutions, are namely: (a) Percentage (b) Grams per liter, (c) Molarity (d) Molality (e) Normality (f) Mole fraction etc.

(A) The Percentage (%) Composition of Solutions: This may be expressed in any one of the following ways:

(i) Weight–weight system (w/W): In this system, the concentration is defined as the weight–units of solute present in 100 weights–units of solutions. An example is given below to illustrate the idea.

$$\text{Percentage by mass} = \frac{\text{mass of solute (w)}}{\text{mass of solution (W)}} \times 100 \text{ (or)}$$

$$= \frac{\text{mass of solute (w)}}{\text{volume of solution (V) x density of solution (d)}} \text{x} 100 \quad \text{(or)}$$

$$= \text{mass fraction x 100.} \left[\text{mass fraction} = \frac{\text{mass of solute (w)}}{\text{mass of solution (W)}} \right].$$

For Example 15% Na_2CO_3 solution (w/W) means 15 gm of Na_2CO_3 is present in 100 gm of solution. That means 100gm of solution contains 15gm of Na_2CO_3 + 85gm of water.

Illustration 2: ***10 grams of sodium carbonate are present in 120 grams of its aqueous solution. Calculate the weight percentage.***

Solution: Weight of solute, w = $\frac{w}{w+W}$ x 100

$$W\% = \frac{10}{120} \text{x} 100$$

$$W\% = 8.33$$

Illustration 3: ***The weight percentage of NaCl solution is 10. If the weight of solution is 150grams. Calculate the weight of NaCl and water.***

Solution: Weight percentage $\frac{w}{w+W}$ x 100

$$10 \ \frac{w}{w+W} \text{ x } 100$$

$$w = \frac{10 \text{x} 150}{100} = 135 \text{ grams.}$$

Exercise 1: ***Which of the following has maximum weight percentage?***

(a) 5gr. of sodium carbonate is added to 95 gr. of water.
(b) 15gr. of oxalic acid is present is 150 gr. of its aqueous solution.
(c) 10gr. of sodium chloride is dissolved in 190 gr. of water.
(d) 25gr. of potassium iodine is present 400 gr. of its aqueous solution.

(ii) Weight–volume system (w/V): In this system, the concentration is expressed in terms of the weight units of solute contained in 100 volume–units of the solution. This is also called percent by volume.

$$\text{Percentage by volume} = \frac{\text{mass of solute (w)}}{\text{volume of solution (V)}} \text{x} 100$$

Example: A 10% glucose solution (w/V) means that 10 weight units of glucose are present in 100 volume units of the solution, e.g., 10 g of glucose in 100 cm^3 of solution.

(iii) Volume–volume system (v/V): In this system, the concentration is expressed in terms of the volume–units of solute in 100 volume–units of solution. This is also called percentage by strength.

$$\text{Percentage by strength} = \frac{\text{volume of solute (v)}}{\text{Volume of solution (V)}} \text{x} 100$$

For example 5% C_2H_5OH solution (v/v) means that 5 volume units (ml or L), of C_2H_5OH are present in 100 volume units of solution. That means the solution contains 5ml/liters of C_2H_5OH + 95 ml/liter of water

Illustration 4: ***15ml of hexane is mixed with 45 ml of heptane. Calculate the V% of this solution.***

Solution: Total volume of solution = v + V = 15 + 45 = 60ml

$$V\% = \frac{v}{v+V} \text{ x } 100 = \frac{15}{60} \text{ x } 100 = 25$$

Illustration 5: ***A solution is formed by dissolving "X" in alcohol. The V% of such alcoholic solution is 20. If the volume of the solution is 250ml, calculate the volumes of alcohol and solute "X"***

Solution: V% = $\frac{v}{v+V}$ x 100

$20 = \frac{v}{250}$ x 100, v = 50 ml., V = 250 – 50 = 200 ml.

(B) Gram per Liter (g/l): This is actually a special case of weight–volume concentration system. It is defined as the number of grams of solute dissolves in one liter of the solution.

Example: 2gm/L NaOH solution: It means that 2 gm of NaOH is dissolved in 1 liter of solution.

(a) Molarity (M): The number of moles of solute present in one liter of solution is called molarity.

$$\text{Molarity} = \frac{\text{No. of moles of solute (n)}}{\text{volume of the solution (V in lt.)}} \text{ (or)}$$

$$= \frac{\text{No. of moles solute (n)}}{\text{Volume of solution (V in ml.)}} \text{x} 1000 \text{ (or)}$$

$$= \frac{\text{mass / weight of solute (w)}}{\text{gram molecular weight of solute (gmw) x volume of solution (V in ml.)}} \text{x} 1000$$

$$\text{The number of moles of solute} = \frac{\text{weight of solute (w)}}{\text{molecular weight of solute (gmw)}}$$

For **example**, the concentration of a solution is 2M that means two moles of solute dissolved in one liter of solution.

Illustration 6: ***2.12 grams of sodium carbonate Na_2CO_3 is present in 250 ml of its solution. Calculate the molarity of the solution. (Molecular weight of Na_2CO_3 is 106).***

Solution: $\text{Molarity} = \frac{w}{\text{gm.mol.wt}} \text{x} \frac{1}{V} \text{ (V in liters)}$

W = 2.12 gr.
gm. mol. wt = 106
V = 250 ml. = 250/1000 = 0.25 lit.

$$\text{Molarity} = \frac{2.12}{106} \text{x} \frac{1}{0.25} = 0.08\text{M}.$$

Illustration 7: Calculate the amount of the oxalic acid ($H_2C_2O_4.2H_2O$) in 500ml of 0.2M solution. (Molecular weight of oxalic acid is 126).

Solution: $\text{Molarity} = \frac{w}{\text{gm.mol.wt.}} \text{ x } \frac{1}{V} \text{(V in litres)}$

W = ? ; gm.mol.wt. = 126
V = 500ml. = 500/1000 = 0.5 lit
Molarity = 0.2

$$0.2 = \frac{w}{126} \text{x} \frac{1}{0.5} \text{; w = 0.2 x 126 x 0.5 = 12.6 gr.}$$

Exercise 2:	***Calculate the number of moles of NaOH present in 750ml. of 0.4M solution. (Molecular weight of NaOH is 40).***

(b) Molality (m): The number of moles of solute present in one kg of solvent is called molality.

$$\text{Molality} = \frac{\text{No. of moles of solute (n)}}{\text{weight of the solvent (W in kg)}} \text{ (or)}$$

$$= \frac{\text{No. of moles solute (n)}}{\text{weight of solvent (W in gm)}} \text{x} 1000$$

For example, the concentration of solution is 2m, which means 2 moles of solute dissolved in one kg of solvent.

Illustration 8: ***Calculate the molality of a solution containing 6.3gm of HNO_3 dissolved in 250gm of water.***

Solution: $\text{Molality} = \frac{\text{No. of moles of solute}}{\text{weight of the solvent}} \text{ x 1000}$

$$= \frac{\text{weight of the } HNO_3}{\text{Mol.Wt. of } HNO_3 \text{ x weight of the solvent (in gms)}} \text{x} 1000 = \frac{6.3 \text{x} 1000}{63 \text{x} 250} = 0.4 \text{ m.}$$

Exercise 3: ***Calculate the molality of a solution having 8.4 gm of $NaHCO_3$ dissolved in 500gm of water.***

(c) Mole Fraction: It is the ratio to the number of moles of solute and number of moles of solution. The number of moles of solution is equal to number of moles of solute plus number of moles of solvent.

$$\text{Mole Fraction of solute} = \frac{\text{No. of moles of solute (n)}}{\text{No. of moles of solute (n)} + \text{No. of moles of solvent (N)}}$$

$$\text{Mole Fraction of solvent} = \frac{\text{No. of moles of solvent (N)}}{\text{No. of moles of solute (n)} + \text{No. of moles of solvent (N)}}$$

Illustration 9: ***2 moles of sodium carbonate are dissolved in 3 moles of water. Calculate the mole fraction of sodium carbonate and water.***

Solution: Total number of moles = 2 + 3 = 5

Mole fraction of Na_2CO_3 ($X\ Na_2\ CO_3$) = $\frac{\text{No. of moles of } Na_2CO_3}{\text{Total no. of moles in the solution}} = \frac{2}{5} = 0.4$

Mole fraction of water ($X\ Na_2\ CO_3$) = $\frac{3}{5} = 0.6$

$X\ Na_2CO_3 + X\ H_2O = 0.4 + 0.6 = 1$

Illustration 10: ***4 grams of NaOH (Mol. Wt. = 40) is dissolved in 16.2 grams of water (Mol. Wt. = 18). Calculate the mole fraction of NaOH and water.***

Solution: Number moles of NaOH = $\frac{\text{Wt. of NaOH}}{\text{gm.mol.wt. of water}} = \frac{4}{40} = 0.1$

Number moles of Water = $\frac{\text{Wt. of water}}{\text{gm.mol.wt of Water}} = \frac{16.2}{18} = 0.9$

Mole fraction of NaOH (X NaOH) = $\frac{\text{No. of moles of NaOH}}{\text{total no. of moles}} = \frac{0.1}{(0.1+0.9)} = 0.1$

$\chi_{NaOH} + \chi_{H_2O} = 1 \qquad \chi_{H_2O} = 1 - 0.1 = 0.9$

Exercise 4:Calculate the mole fraction of Na_2CO_3 containing 10.6 gm of Na_2CO_3 dissolved in 16.2 gm of water.

(d) Normality (N): The number of equivalents present in one liter of solution is called Normality.

$$\text{Normality} = \frac{\text{No. of equivalents}}{\text{Volume of solution (V in lt.)}} \text{ (or)}$$

$$= \frac{\text{No. of equivalents}}{\text{Volume of solution (V in ml.)}} \text{x1000 (or)}$$

$$= \frac{\text{weight of solute (w)}}{\text{equivalent weight (Eq.W) x volume of solution (V in ml.)}} \text{x1000}$$

Calculation of Equivalent weight (Eq.W):

(a) Acids: For acids, equivalent weight = $\frac{\text{molecular weight of acid}}{\text{basicity}}$

Basicity of an acid is the number of replaceable H ions.

For example, HCl contain one replaceable hydrogen, so the basicity of HCl is one. Similarly, HNO_3, HNO_2, $HClO_4$, HPO_3 having only one replaceable hydrogen ions. So, the basicity of these acids is one respectively. For all these acids, the equivalent weight equal to molecular weight.

H_2SO_4 contains two replaceable hydrogen ions, so the basicity of H_2SO_4 is two. Similarly, H_3PO_3, H_2CO_3 and Oxalic acid ($C_2H_2O_4$) having only two replaceable hydrogen ions. So, the basicity of these acids is two respectively. So for all these acids, equivalent weight = $\frac{\text{molecular weight}}{2}$.

H_3PO_4 contains three replaceable hydrogen ions, so the basicity of H_3PO_4 is three. So the equivalent weight of H_3PO_4 = $\frac{\text{molecular weight}}{3}$.

(b) Bases: For bases the equivalent weight = $\frac{\text{molecular weight of base}}{\text{acidity}}$.

Acidity of a base is the number of replaceable OH^- ions.

For example, NaOH contains only one replaceable OH^- ions, so the acidity of NaOH is one. Similarly, KOH, $Cu(OH)_2$, AgOH, CsOH, NH_4OH all have only one replaceable OH^- ion. So the acidity of all these bases is one.

$Mg(OH)_2$ contains two replaceable OH^- ions, so the acidity of $Mg(OH)_2$ is two. Similarly, $Ba(OH)_2$, $Ca(OH)_2$, $Cu(OH)_2$, $Fe(OH)_2$, $Zn(OH)_2$ all have only two replaceable OH^- ion. So the acidity of all these bases is two.

$Al(OH)_3$ contains three replaceable OH^- ions, so the acidity of $Al(OH)_3$ is three. Similarly, $Bi(OH)_3$, $Cr(OH)_3$ and $Fe(OH)_3$, all have three replaceable OH^- ion. So the acidity of all these bases is three.

(c) Salts: The equivalent weight of salt = $\frac{\text{molecular weight of the salt}}{\text{total charge on the cation or anion}}$

For example, in NaCl the charge on the cation is one. So, the equivalent weight of NaCl is equal to molecular weight. In Na_2CO_3 the total charge on the cation is two. So the equivalent weight of Na_2CO_3 is $\frac{\text{molecular weight}}{2}$.

Equivalent weight of NaCl = $\frac{\text{molecular weight}}{1} = \frac{58.5}{1} = 58.5$

Equivalent weight of Na_2CO_3 = $\frac{\text{molecular weight}}{2} = \frac{106}{2} = 53$

Equivalent weight of $AlCl_3$ = $\frac{\text{molecular weight}}{3} = \frac{133.5}{3} = 44.5$

Similarly you can calculate the equivalent weight of any salts.

Illustration 11: ***Calculate the Normality of solution containing 4.9gm of H_2SO_4 dissolved in 500ml of solution.***

Solution: Normality (N) = $\frac{\text{No. of equivalents x 1000}}{\text{Volume in ml.}}$. ; [Equivalent weight of H_2SO_4 = 49]

Equivalents = $\frac{\text{weight of } H_2SO_4}{\text{Equivalent wt. of } H_2SO_4}$; No. of equivalents = $\frac{4.9}{49}$ = 0.1

N = 0.1 x 1000 / 500 = 0.2 N

Exercise 5: ***Calculate the Normality of solution containing 5.7 gms of $Al_2(SO4)_3$ dissolved in 500ml of solution.***

ANSWERS TO EXERCISES

Exercise 1: (a) 5 (b) 10 (c) 5 (d) 6.25

Exercise 2: 0.3 Moles. **Exercise 3:** 0.2 m **Exercise 4:** 0.1

Exercise 5: 0.2 N **Exercise 6:** Dispersed phase is Carbon particles Dispersion medium is air