

CHAPTER

10

SOLUTIONS AND
COLLOIDS

Q1: Define the basic terms used in solutions.

Ans. Solution: (BISE Swat 2017)

A solution is a homogeneous mixture of two or more substance in which the ratio of constituent (مكون) substances remains the same throughout the solution. Generally a solution consists of two components:

Solute:

"The component present in lesser amount in solution is called solute."

Solvent:

"The component present in greater amount in the solution is called solvent."

Aqueous Solution:

"Aqua" means "water". "The solution in which water is used as a solvent is called aqueous solution." For example solution of sugar / NaCl in water.

Binary Solution:

"A solution which consists of only two components i.e. one solute and the other solvent is called binary solution."

Ternary Solution:

"A solution consists of three components is called ternary solution." Solute used may be solid, liquid or gas. The particles of solute may be ionic or molecular level.

General Properties of Solution:

1. In solution, the solute particle size ranges from 0.1nm – 1nm .
2. Solute particles cannot be seen by naked-eye.
3. Solution is stable if it is not separated on standing.

4. The solute particles cannot be separated by ordinary filtration process.
5. Solution is composed of one phase → every sample of matter with uniform properties and a fixed composition is called phase.
6. At a given temperature and pressure, the composition of solution can be varied to a maximum value upto the saturation value.
7. A solution does not allow a beam of light to scatter (مشتت نور) when passed through it.

Suspension:

"A heterogeneous mixture of two or more than two substances is called a suspension."

1. Solute particle's size in suspension is greater than $1000/10^3 \text{ nm}$.
2. Suspensions do not have uniform composition.
3. In suspension solute particles can be seen with naked-eye.
4. Particles of solute cannot pass through the pores of filter paper and can be separated by filtration.
5. If suspension is allowed to stand, the solute particles settle down at the bottom.
6. Suspensions can scatter light beam.

Example: Finely ground clay mixed with water i.e. muddy water is an example of suspension.

Colloids: (BISE Mardan 2018, Malakand 2018-19)

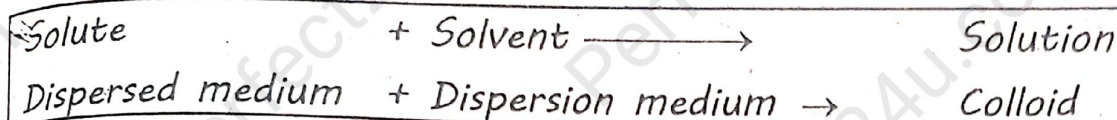
The name "colloid" was introduced by Graham, (Greek: kola means glue, eidos, like).

1. Colloids are heterogeneous mixtures. The solute particles are atoms or aggregate [group] of molecules.
2. Particles size ranges from $1 - 1000 \text{ nm}$.
3. Particles do not settle down on standing and cannot be separated by filtration.
4. Colloids scatter light beam when passed through it, this light scattering phenomenon is called Tyndal effect.
5. Particles cannot be seen with naked-eyed.

Examples: Gum in water, milk, blood serum, sulphur and starch in water.

Note:

Solute and solvent terms [terminology] is used in solution while, dispersed medium [instead of solute] and dispersion medium [instead of solvent] is used in case of colloids.



Q2: Differentiate between solutions, colloids and suspensions.
(BISE Abbottabad 2016)

Ans: Main differences between solutions, suspensions and colloids are given below:

Solution	Suspension	Colloid
It is homogeneous	Heterogeneous	Heterogeneous
The particles are ions or molecules.	The particles are aggregates of molecules or atoms.	The particles are either macromolecules or aggregates of molecules.
Particles ranges between $0.1-1\text{nm}$.	The particles size is larger than 10^3nm .	Particles size lies between $1-10^3\text{nm}$.
Particles do not settle down on standing.	Particles settle out / down.	Particles do not settle down on standing.
Particles readily pass through filter paper [parchment]	Particles do not pass through filter paper [parchment]	The particles pass slowly through filter paper [parchment]
Particles are invisible even under powerful microscope.	The particles are visible under microscope or sometimes with naked-eye.	Particles are invisible under ordinary microscope.
Have uniform composition throughout its bulk.	Do not have uniform composition.	Do not have uniform composition.

Q3: Explain hydrophilic and hydrophobic substances.

Ans: **Hydrophilic Substances:**

"Hydra" means "water", "philic" means "liking or loving".

"Molecules forming ionic or hydrogen bond with the water molecule are

said to be hydrophilic." These substances may be ionic compounds and polar molecules like methyl alcohol $[\text{CH}_3\text{OH}]$. These substances readily dissolve in water. Water is polar in nature and hydrophilic substances breakdown to be surrounded by water. If a molecule is polar in nature it will be hydrophilic.

When water is used as dispersion medium and there exist an attractive force between water molecules and the dispersed particles, the molecules are called hydrophilic.

The hydrophilic molecules containing colloids are very much stable, when such colloids are precipitated, can be directly converted into colloidal form. Therefore these are called reversible colloids.

Hydrophobic Molecules:

"Hydra" means "water" and "phobic" means "repeller / fearing"

Non-polar molecules that repel the water molecules are hydrophobic in nature. If a molecule or compound is non-polar in nature then it will be hydrophobic in nature. Examples of hydrophobic substances are alkanes, oils, fats and greasy substances.

When water is used as dispersion medium and no attractive force exist between water molecules and dispersed particles, the dispersed molecules are called hydrophobic.

The colloids formed by hydrophobic molecules are less stable. When these are precipitated they cannot be converted into colloidal form. These are irreversible colloids.

Q4: Explain the nature of solution in liquid phase.

(BISE Swat, Kohat 2019)

Ans: When a solid comes in contact with a suitable solvent, it dissolves and form a homogeneous mixture called solution. Solubility depends upon the general rules "like dissolves like".

Mechanism:

In a solid solute, the particles are held together through intermolecular or interionic forces. When a solute is put into a solvent, the molecules of solvent try to develop attractive forces with solute particles. If the solute - solvent attraction is stronger than the solute - solute attraction then the solute will be dissolved in solvent and if these forces

are weaker then the solute will remain un-dissolved.

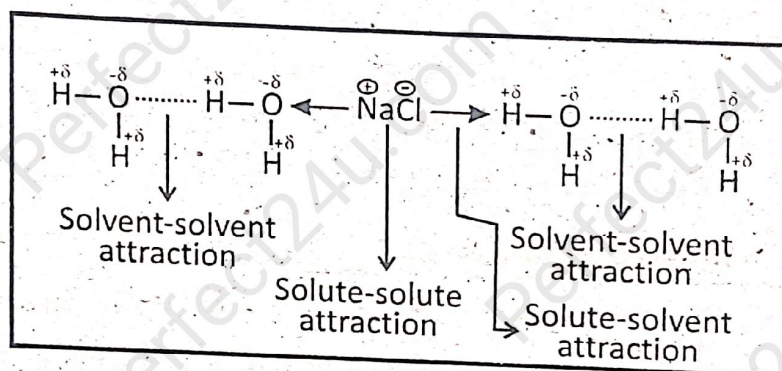
Polar solutes can only be dissolved in polar solvents because the solute-solvent attraction is enough (بکافی) to weaken the solute - solute attraction. For example: solubility of NaCl in water. Polar solutes cannot be dissolved in non-polar solvents because the solute - solvent attraction is weaker and is unable to dissolve the solid solute ions, e.g. CaCl_2 in benzene.

Similarly, non-polar solid solutes cannot be dissolved in polar solvents because no attractive forces are established between solute and solvent molecules. For example: naphthalene in water.

However non-polar solutes can only be dissolved in non-polar solvents, because the attractive forces found in molecules of solute is weaker

than the attractive forces in solute - solvent molecules. Sodium chloride [ionic compound] have strong interionic attractive forces cannot be dissolved in non-polar solvents like ether,

benzene and acetone. It is because the attractive forces between solid and liquid molecules are weaker.



Q5: Explain various types of solutions of liquid in liquid.

Ans: Solutions of liquids in liquids are classified into three classes:

- ❑ Completely miscible liquids
- ❑ Completely immiscible liquids
- ❑ Partially miscible liquids

1. Completely Miscible Liquids:

Liquids which mix up with each other in all proportions and form a homogeneous mixture are called completely miscible liquids.

Examples:

1. Water and ethyl alcohol [$\text{C}_2\text{H}_5\text{OH}$]
2. Ether and alcohol
3. Benzene and toluene

Miscible liquids are usually similar in their chemical structures. For example: the molecules of both water and ethyl alcohol are polar and contain -OH groups that give rise to hydrogen bonding among them.

- During the formation of such solutions, heat may either evolve or absorb.
- The volume of such solutions is less or more than the sum of volumes of two components.
- Components of these solutions are usually separated by fractional distillation process.

2. Completely Immiscible Liquids:

Liquids which do not dissolve into each other at any proportions are called practically or completely immiscible liquids.

Examples:

1. Water and benzene.
2. Water and carbon disulphide $\rightarrow \text{CS}_2$
3. Water and carbon tetrachloride $[\text{CCl}_4]$

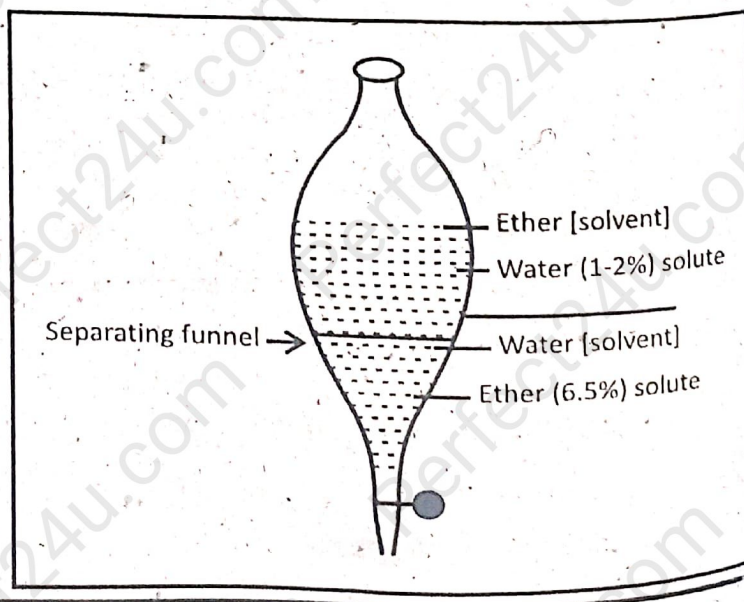
3. Partially Miscible Liquids:

Liquids which mix up into each other upto a limited extent (μ) are called partially miscible liquids. For example:

1. Water and ether system
2. Water - phenol system
3. Water - analine system
4. Water - nicotine system
5. Water - trimethyl amine system

1. Water - Ether System:

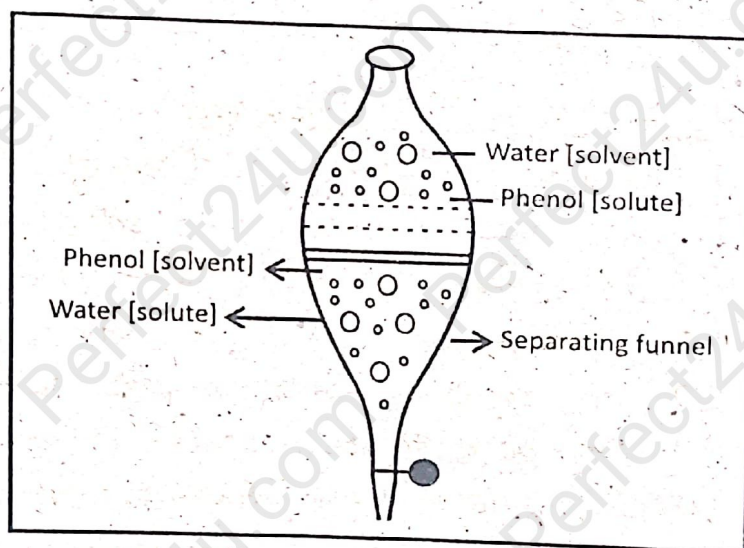
Ether dissolves water upto 1-2% and water dissolves ether upto 6.5%. If we mix them in greater proportion than this we will find that they will separate into two layers. Each layer is the saturated solution of the other liquid. Such solutions are called con-



jugate solutions. The mutual solubility of these conjugate solutions is affected by change in temperature.

2. Phenol - Water System: It is an interesting example of partially miscible liquids. When we mix equal volume of water and phenol, then two layers are formed. The upper layer is a solution of phenol in water. It has lower density. The beneath ($\frac{2}{3}$) / lower layer is a solution of water in phenol. It has greater density. At 25°C the upper layer is 5% solution of phenol in water and lower layer is 30% solution of water in phenol. It means at 25°C, water dissolve 5% phenol and phenol dissolve 30% water. When temperature of phenol - water system increases, the composition of both layers changes. Water starts to move from upper to lower layer and phenol moves from lower to upper layer. At 65.9°C, the two partially miscible liquids become completely miscible and form a homogeneous mixture.

It is called upper consolute temperature (UCT) or critical solution temperature (CST). This homogeneous mixture contains 34% phenol and 66% water. The temper-



ature at which the two conjugate solutions merge / mix into one another is called critical solution temperature. For example: 65.9°C is upper consolute temperature for phenol - water system. 167°C is upper consolute temperature for water - aniline system with 15% water and 85% aniline.

Conjugate Solutions: The two solutions formed by mutual solubility of two partially miscible liquids into each other are called conjugate solutions.

Q6: Define solubility. What factors affect solubility?

Ans. Solubility: (ETEA: 2011,17, BISE Abbottabad 2016)

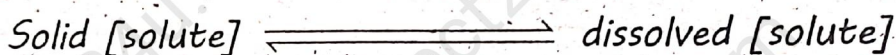
Definition: "The amount of solute required to saturate 100 grams of solvent at a given temperature is called solubility."

Explanation:

$$\text{Solubility} = \frac{\text{Mass of solute in grams}}{\text{Mass of solvent in grams}} \times 100$$

The solubility of NaCl in water is 35.7g at 0°C. When a solute is added to a solvent, the following changes occur:

1. Particles from the surface of the solid solute separate and go into the solution. This process is called dissolution.
2. Some of the particles of the dissolved solute deposit back on the surface of the solid. This is called precipitation.
3. If the solid is present in excess, the rate of ionization becomes equal to the rate of crystallization. Thus a dynamic equilibrium is established.

Factors Affecting Solubility:

1. Nature of Solute and Solvent: There is a general rule that "like dissolve like". It means that solute and solvent of the same nature will be soluble with each other.

- Polar solute is soluble in polar solvent.
- Ionic solute is soluble in polar solvent.
- Non-polar solute is soluble in non-polar solvent.

Different solutes have different solubilities in the same solvent and the solubility of the same solute varies in different solvents. At 20°C

100 grams of water dissolve: 192g NH_4NO_3

100 grams of water dissolve: 6.5g HgCl_2

100 grams of water dissolve: 8.4×10^{-4} g AgBr

At 20°C:

100 grams ethyl alcohol dissolves: 3.8g NH_4NO_3

100 grams ethyl alcohol dissolves: 47.6g HgCl_2

2. Pressure: Pressure has no effect on the solubility of solids and liquids. Generally solubility of gases in a liquid increases with increase in external pressure.

Henry's Law:

"At a constant temperature the solubility of a gas in a liquid is di-

rectly proportional to the external pressure above it.” In cold drinks such as Pepsi, CO_2 gas is dissolved in water under 3-5 atm pressure in a sealed bottle. When the bottle is opened, the external pressure reduces to 1-atm again. As a result solubility of the gas decreases and the excess of CO_2 escape from the solution with effervescence.

3. Temperature: The solubility of a solid in a liquid usually increases with increase in temperature. However there are some exceptions:

- Solubility of KNO_3 and $\text{Al}_2(\text{SO}_4)_3$ increases with increase in temperature.
- Solubility of $\text{Ce}(\text{SO}_4)_3$ and Li_2CO_3 decreases with increase in temperature.
- Solubility of NaCl almost remains constant.
- Solubility of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ increases upto 32.4°C and further decreases with rise in temperature. It is because below 32.4°C , it is in the form of decahydrate and above 32.4°C , it is in anhydrous form. 10 moles of water $[10\text{H}_2\text{O}] = 10 \times 18 = 180\text{grams}$, water is removed.

Substance	Solubility in grams per 100 grams of water					
	0°	10°	20°	30°	40°	50°
KNO_3	13.3	20.9	31.6	45.8	63.9	85.5
$\text{Al}_2(\text{SO}_4)_3$	31.2	33.5	36.4	40.4	46.1	52.2
AgNO_3	122	170	222	300	376	455
NaCl	35.7	35.8	36	36.3	36.6	37
$\text{Ce}(\text{SO}_4)_3$	20.75	-	10.08	6.79	-	4.67
Li_2CO_3	1.54	1.43	1.33	1.25	1.11	1.68
Na_2SO_4	5	9	19.4	40.8	48.8	44.7

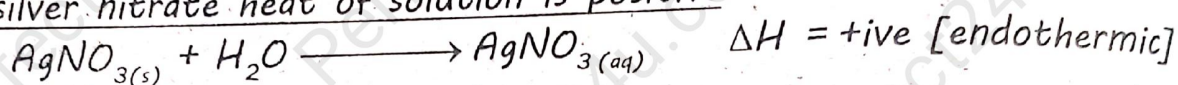
Solubility and Heat of Solution:

“The amount of heat evolved or absorbed when one mole of solute is dissolved in solvent to prepare saturated solution is called heat of solution.”

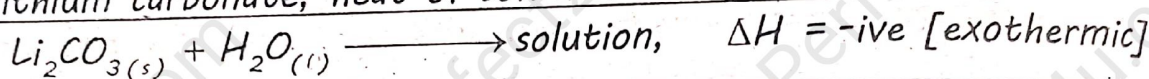
- The change in solubility with temperature is closely related to the heat of solution.
- If the temperature of solution increases, the heat is evolved and therefore heat of solution is negative.
- If the temperature decreases then the heat of solution is posi-

tive, and the solubility of solute will increase with increase in temperature. When the heat of solution is negative then the solubility of solute decreases with increase in temperature.

For silver nitrate heat of solution is positive:



For lithium carbonate, heat of solution is negative:



Q7: Explain concentration units in detail.

Ans: Concentration of Solution: (BISE Swat 2019)

"The amount of solute present in a given amount of solvent or solution is called concentration of a solution."

$$\text{Concentration} = \frac{\text{number of moles}}{\text{volume of solution}} = C = \frac{n}{V}$$

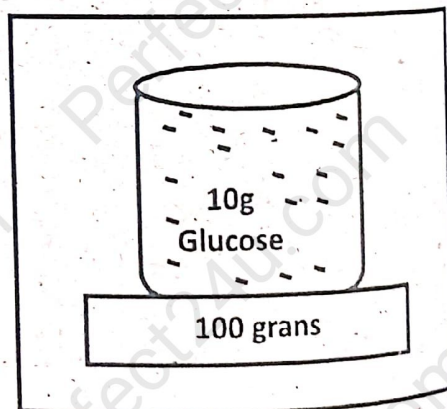
Greater the amount of solute present in a solution, the higher would be its concentration and vice versa. The concentration of a solution can be expressed in different ways, referred as concentration units.

1. Percentage Composition: (BISE Kohat 2019)

The percentage of a solution can be expressed by four ways:

(i) Percentage by Mass [m/m%]/ Mass-Mass Percentage: It is the number of grams of solute dissolved in sufficient amount of solvent to make 100g of solution. For example: 10% solution of glucose by mass means that 10 gram of glucose are dissolved in sufficient water so that solution mass becomes equal to 100 grams.

$$\frac{m}{m} \% = \frac{\text{Mass of solute}}{\text{Volume of solution}} \times 100$$

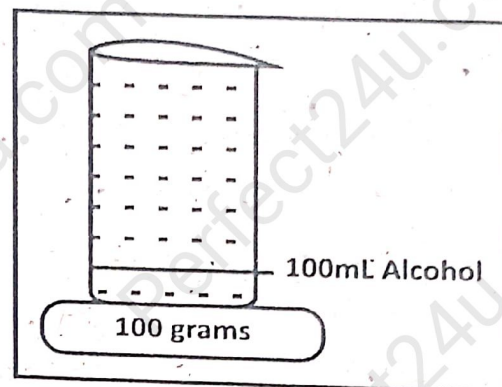


(ii) Mass by Volume Percentage → [m/v%]: It is the mass of solute dissolved per 100 parts by volume of solution. For example: 10 grams of NaOH dissolved per 100cm³ [mL] of solution is 10% m/v solution of NaOH.

$$\frac{m}{v} \% = \frac{\text{Mass of solute}}{\text{Volume of solution}} \times 100$$

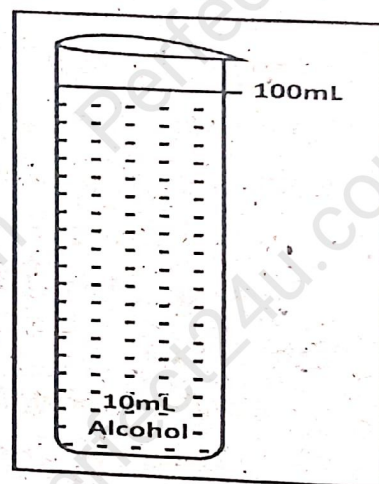
(iii) Volume by Mass Percentage $\rightarrow$ $[v/m\%]$: It is the number of cm^3 [mL] of a solute dissolved per 100 grams of solution. If we dissolve 10cm^3 [mL] of alcohol in water and the total mass of solution is 100 grams, then it is 10% v/m solution of alcohol in water.

$$\frac{v}{m} \% = \frac{\text{Volume of solute}}{\text{Mass of solution}} \times 100$$



(iv) Volume by Volume Percentage $\rightarrow$ $[v/v\%]$: It is the volume of solute present per 100cm^3 [mL] of the solution. For example: 10cm^3 of alcohol is dissolved in water so that the volume of solution is 100cm^3 [mL]. It is 10% v/v solution of alcohol in water.

$$\frac{v}{v} \% = \frac{\text{Volume of solute}}{\text{Volume of solution}} \times 100$$



2. Molarity [M]: (ETEA: 2010-12, 15-19, BISE Malakand 2019)

"The number of moles of solute dissolved in a dm^3 [litre] of solution is called molarity."

$$\text{Molarity [M]} = \frac{\text{No. of moles of solute}}{\text{Volume of solution in } \text{dm}^3}$$

$$M = \frac{\text{Mass of solute}}{\text{Molar mass of solute} \times \text{volume of solution in } \text{dm}^3}$$

$$\text{As No. of moles} = \frac{\text{mass of solute}}{\text{molar mass of solute}}$$

Preparation of 1-Molar Sugar Solution:

If one mole of solute is dissolved to make one litre solution, it is called 1-molar solution. For example: one molar solution of sugar, $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ contains one mole [342 grams] of sugar per dm^3 of solution. It can be prepared by putting 342 grams sugar in one litre volumetric flask and then by adding water, first to dissolve and then dilute the solution until the solution reaches the mark on the flask.

3. Molality [m]: (ETEA: 2005, 7, 10, 18)

"The number of moles of solute present in one kilogram of solvent is called molality."

➤ It is another concentration unit of solution.

➤ It is represented by small "m".

$$\text{"Molality (m)} = \frac{\text{No. of moles of solute}}{\text{Mass of solvent in kg}}$$

$$\text{Or } m = \frac{\text{Mass of solute}}{\text{Molar mass of solute} \times \text{kilogram of solvent}}$$

Molal Solution:

"Solution having one mole of solute in each kilogram of solvent is called one molal solution."

1. When 58.5 grams NaCl is dissolved in 1000g or 1kg of water the solution will be 1-molal.
2. When 180 grams of glucose is dissolved in 1kg water, the solution will be 1-molal.
3. When 18 grams of glucose is dissolved in 1kg of solvent, the solution will be 0.1 molal.

Molality is Independent of Temperature:**EXAMPLE 10-1:**

4.5 grams of glucose are dissolved in 100 grams water. Calculate the molality of the solution. Molar mass of glucose is 180 grams per mol.

Solution:

Mass of solute [glucose] = 4.5 grams

Mass of solvent [water] = 100 grams

Mass of water in kg = $\frac{100}{1000} = 0.1 \text{ kg}$

Molar mass of glucose = $180 \text{ g} \cdot \text{mol}^{-1}$

Formula used;

$$m = \frac{\text{Mass of solute}}{\text{Molar mass of solute} \times \text{mass of solvent in kg}}$$

$$m = \frac{4.5 \text{ g}}{180 \text{ g} \cdot \text{mol}^{-1} \times 0.1 \text{ kg}} \Rightarrow [0.25 \text{ mol} \cdot \text{kg}^{-1}]$$

PRACTICE PROBLEM 10.1:

A sample has 3.50dm^3 of solution that contains 90 grams of sodium chloride $[\text{NaCl}]$. What is the molarity of that solution?

Solution:

Volume of solution = 3.50dm^3

Mass of solute $[\text{NaCl}] = 90$ grams

Molarity of solution = ?

Molar mass of $\text{NaCl} = 23 + 35.5 \Rightarrow 58.5\text{g}\cdot\text{mol}^{-1}$

Molarity = $\frac{\text{Mass of solute}}{\text{Molar mass of solute} \times \text{volume of solution in dm}^3}$

$$M = \frac{90\text{g}}{58.5\text{g}\cdot\text{mol}^{-1} \times 3.50\text{dm}^3} = \frac{90}{204.75} = 0.44\text{mol}\cdot\text{dm}^{-3}$$

PRACTICE PROBLEM 10.2:

What is the molality of a solution containing 18.2 grams HCl and 250 grams water?

Solution:

Molality (m) = ?

Mass of solute $[\text{HCl}] = 18.2$ grams

Molar mass of $\text{HCl} = 1 + 35.5 = 36.5\text{g}\cdot\text{mol}^{-1}$

Mass of solvent [water] = 250 grams

Mass of solvent in kg = $\frac{250}{1000} = 0.250\text{kg}$

m = $\frac{\text{Mass of solute}}{\text{Molar mass of solute} \times \text{mass of solvent in kg}}$

$$m = \frac{18.2\text{g}}{36.5\text{g}\cdot\text{mol}^{-1} \times 0.250\text{kg}} = \frac{18.2}{9.125} = 1.99\text{mol}\cdot\text{kg}^{-1}$$

Comparison between 1-Molar and 1-Molal Solution:

1. The amount of solute in one molar and one molal solution of any substance is the same.
2. The amount of solvent in 1-molal solution is greater than the solvent in 1-molar solution.
3. One molal solution is dilute as compared to one molar solution.
4. Molality is independent of temperature and molarity is temperature dependent.

4. Mole Fraction [X]: (BISE Mardan 2018)

Mole fraction is defined as "the ratio of the number of moles of one component to the total number of moles of all components present in the solution."

It is denoted by X . If " n_a " is the number of moles of solvent and " n_b " is the number of moles of solute, " X_a " is the mole fraction of solvent and " X_b " is the mole fraction of solute, then total number of moles = $n_T = n_a + n_b$.

$$\text{Mole fraction of solvent} = X_a = \frac{n_a}{n_T}$$

$$\text{Mole fraction of solute} = X_b = \frac{n_b}{n_T}$$

The sum of the mole fractions of all the components of a solution is always equal to 1.

$$X_a + X_b = \frac{n_a}{n_T} + \frac{n_b}{n_T} \Rightarrow \frac{n_a + n_b}{n_T} = \frac{n_T}{n_T} = 1$$

Mole fraction is independent of temperature. Concentrations of more than one solute can easily be expressed by this method.

EXAMPLE 10.2:

A solution contains 20 moles of alcohol and 3-moles of water. Calculate mole fraction of alcohol and water.

Solution:

Number of moles of alcohol = $n_{Alc} = 2$ moles

Number of moles of water = $n_{H_2O} = 3$ moles

Total number of moles = $n_{Alc} + n_{H_2O} = 2 + 3 = 5$ moles

Mole fraction of Alcohol = $X_{Alc} = ?$

Mole fraction of H_2O = $X_{H_2O} = ?$

$$\text{Mole fraction of alcohol} = X_{Alc} = \frac{n_{Alc}}{n_T} = \frac{2}{5} = [0.4]$$

$$\text{Mole fraction of water} = X_{H_2O} = \frac{n_{H_2O}}{n_T} = \frac{3}{5} = [0.6]$$

As the sum of mole fractions of all components in a solution is always equal to 1, so

$$X_{Alc} + X_{H_2O} = \frac{n_{Alc}}{n_T} + \frac{n_{water}}{n_T} = \frac{2}{5} + \frac{3}{5} = \frac{5}{5} = [1]$$

5. Parts Per Million [ppm]:

The number of parts by mass/volume of a solute present in million parts by mass/volume of a solution is called parts per million [ppm].

$$\text{ppm} = \text{million} \Rightarrow 1000000 \Rightarrow 10^6$$

$$\text{ppm} = \frac{\text{Mass or volume of solute}}{\text{Mass or volume of solution}} \times 10^6$$

1. ppm is used for solutions having very low concentration of solute.
2. The amount of pollutant gases in air are expressed in ppm.

EXAMPLE 10.3:

Sea water contain 5.65×10^{-3} gram of dissolved oxygen per kilo-gram of solution. Calculate the concentration of oxygen in ppm in sea water.

Solution:

$$\text{Mass of solute [dissolved oxygen]} = 5.65 \times 10^{-3} \text{ g}$$

$$\text{Mass of solution} = 1 \text{ kg} = 1000 \text{ g} = 10^3 \text{ g}$$

$$\text{Concentration of solution in ppm} = ?$$

$$\text{ppm} = \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 10^6$$

$$\text{ppm} = \frac{5.65 \times 10^{-3} \text{ g}}{10^3 \text{ g}} \times 10^6 \Rightarrow 5.65 \times 10^{-3} \times 10^{-3} \times 10^6 = [5.65 \text{ ppm}]$$

6. Parts Per Billion [ppb]:

"The number of parts [by mass or volume] of a solute per billion parts [by mass or volume] of the solution is called parts per billion."

Parts per billion are used for very less concentrated solution / low concentration of solution.

$$\text{ppb} = \frac{\text{mass or volume of solute}}{\text{mass or volume of solution}} \times 10^9$$

EXAMPLE 10.4:

A 2 dm^3 gas cylinder contains a mixture of various gases. If 5 cm^3 of H_2 gas is present in this mixture. Calculate the concentration of H_2 gas in parts per billion [ppb].

Solution:

Volume of solute [H_2 gas] = 5cm^3

Volume of solution = $2\text{dm}^3 \Rightarrow 2000\text{cm}^3$

Concentration of H_2 gas, in ppb = ?

$$\text{ppb} = \frac{\text{volume of } H_2 [\text{solute}]}{\text{volume of solution}} \times 10^9$$

$$\text{ppb} = \frac{5\text{cm}^3}{2000\text{cm}^3} \times 10^9 \Rightarrow 0.0025 \times 10^9$$

$$\Rightarrow 2.5 \times 10^{-3} \times 10^9 \Rightarrow (2.5 \times 10^6 \text{ ppb})$$

7. Parts Per Trillion [ppt]:

"The number of parts [by mass or volume] of a solute per trillion parts [by mass or volume] of the solution is called parts per trillion."

Parts per trillion is used for further lower concentration of solution.

$$\text{ppt} = \frac{\text{mass or volume of solute}}{\text{mass or volume of solution}} \times 10^{12}$$

Q8: Define and explain Rault's law. Explain the following:

- (i) The solution of volatile solute and solvent [both components are volatile].
- (ii) Non-volatile and non-electrolyte solute in volatile solvent.

Ans: Rault's Law: (ETEA: 2010-12, Kohat 2018)

Statement: "The partial vapours pressure of any volatile component of a solution is equal to the vapours pressure of the pure component multiplied by the mole fraction of that component in solution." (OR)

"The vapours pressure of solution is directly proportional to the mole fraction of solvent."

Explanation: It means that, higher the proportion of solvent in a solution, higher will be the vapour pressure of solution. A pure solvent has a specific vapour pressure at a given temperature.

When a solid solute dissolves in a solvent, it changes the vapour pressure of solvent and similar effect is observed when a liquid solute is dissolved in a liquid solvent. However, there is major difference, a solid solute is usually non-volatile while a liquid solute is volatile. For example: if we analyze the vapours above a sugar solution in water we will find only water vapours. The vapours above a solution of ethanol [ethyl alcohol] and water always contain both water and ethanol. So

solutions can be classified on the basis of nature of solute into two categories:

1. The solution of volatile solute and volatile solvent.
2. The solution of non-volatile and non-electrolyte solute in volatile solvent.

Ideal Solutions:

"Solutions which obey Roult's law are called ideal solutions." Mathematically Roult's law can be written as;

$$P = P^{\circ} X$$

P = vapours pressure of volatile component

P° = vapours pressure of pure component

X = Mole fraction of component in solution.

1. Solutions of Volatile Solute and Volatile Solvent:

Consider an ideal solution of two liquids "A" and "B". According to Roult's law, partial vapour pressure of both components "A" and "B" is given by,

$$P_A = P_A^{\circ} X_A$$

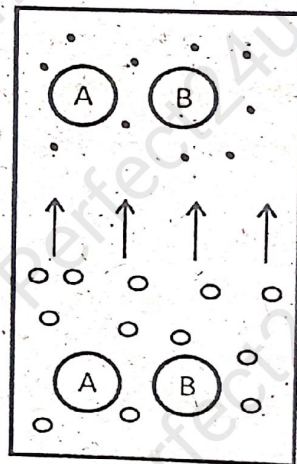
$$P_B = P_B^{\circ} X_B$$

P_A° = vapour pressure of pure component "A"

P_B° = vapour pressure of pure component "B"

X_A = mole fraction of component "A"

X_B = mole fraction of component "B"



Applying Dalton's law of partial pressure, vapour pressure of solution is equal to the sum of the partial pressures of component (A) and component (B).

$$P_T = P_A + P_B$$

$$P_T = P_A^{\circ} X_A + P_B^{\circ} X_B$$

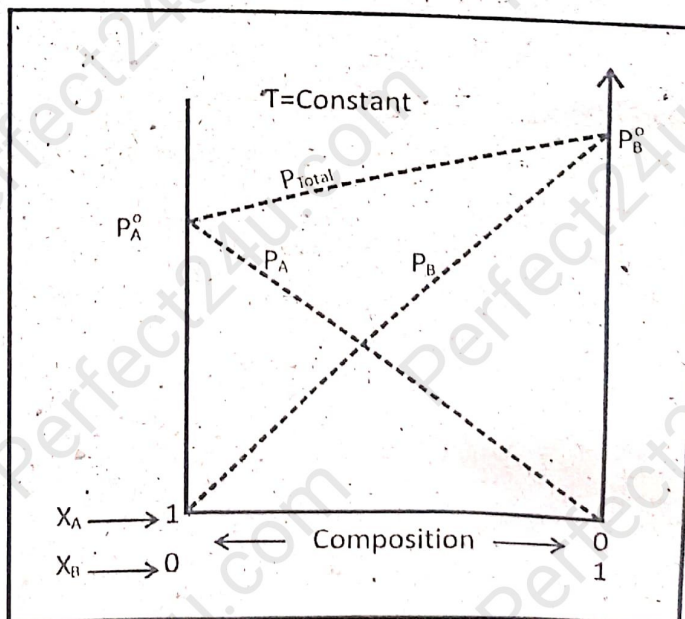
(i)

Putting the values, we know that, the sum of the mole fractions is equal to one, so

$$X_A + X_B = 1$$

Therefore, $X_A = (1 - X_B)$

Putting the value of X_A in equ-



ation (i)

$$P_T = P_A^{\circ}(1 - X_B) + P_B^{\circ}X_B$$

$$P_T = P_A^{\circ} - P_A^{\circ}X_B + P_B^{\circ}X_B$$

Re-arranging the above equation and taking X_B common

$$P_T = (P_B^{\circ} - P_A^{\circ})X_B + P_A^{\circ}$$

This equation shows that when $X_B = 0$ then $X_A = 1$.

It means pure component "A" is present and P_{total} becomes equal to P_A° and if $X_A = 0$, then $X_B = 1$, then pure component "B" is present and P_{total} becomes equal to P_B° .

The graph shows variation of total pressure [solid line/unbroken line] and partial vapour pressure of components [dotted lines] of solution with changes in concentration of both A and B components. At any concentration, the total pressure is the sum of partial pressures of two components.

2. Non-Volatile and Non-Electrolyte Solute in Volatile Solvent: (ETEA: 2018)

Non-electrolytes are those substances which do not dissociate into positive and negative ions in water.

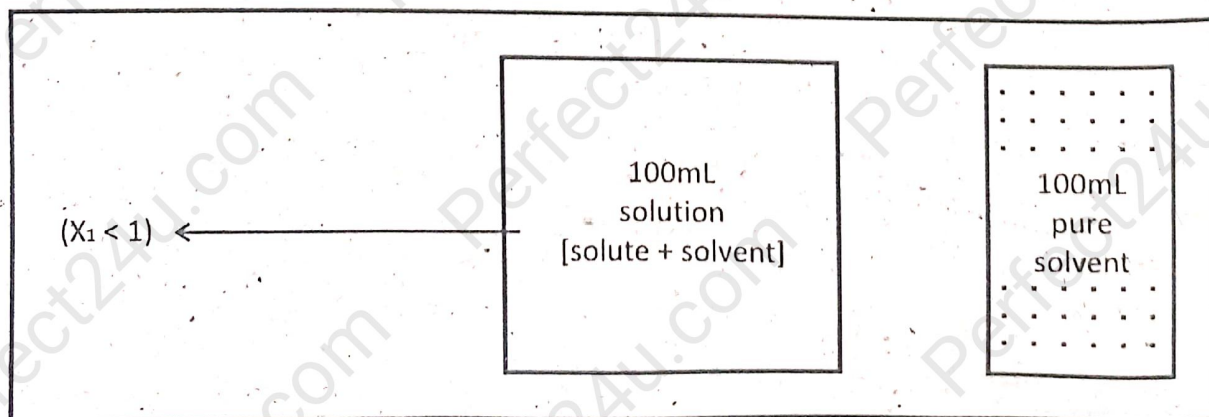
Let we have a solution of two components "A" and "B". Component "A" is solvent with mole fraction X_1 . Component "B" is solute with mole fraction X_2 . P° is the vapour pressure of pure solvent and P is the vapour pressure of solution.

According to Raoult's law, the vapour pressure of solution is directly proportional to the mole fraction of solvent, so

$$P \propto X_1$$

$$P = P^{\circ}X_1 \quad \text{--- (i)}$$

Since mole fraction of solvent (X_1) in any solution is less than unity, so vapour pressure of solution (P) is always less than vapour pressure of pure solvent (P°).



Consequently (نتيجة)، a solute in a solvent tends to lower the vapour pressure of the pure solvent. If the solute is non-volatile it does not contribute to the total vapour pressure and hence equation (i) gives the total vapour pressure above the solution, which in this case is due to solvent only and is always less than P° . the change [lowering] of vapour pressure ΔP is,

$$\Delta P = P^\circ - P \quad \text{--- (ii)}$$

Putting the value of "P" from equation (i) into equation (ii)

$$\Delta P = P^\circ - P^\circ X_1$$

$$\Delta P = P^\circ (1 - X_1)$$

Taking P° as common

$$\Delta P = P^\circ X_2 \quad \text{--- (iii)}$$

$$\text{As } X_1 + X_2 = 1, X_2 = 1 - X_1$$

According to equation (iii), the lowering [decrease] of vapour pressure of solution depends both on vapour pressure of pure solvent and the mole fraction of solute in solution. It means, it depends on the nature of solvent and the concentration of solute and not on the nature of solute. If we consider the relative lowering of vapour pressure i.e. the ratio $\Delta P/P^\circ$, then from equation (iii),

$$\frac{\Delta P}{P^\circ} = \frac{P^\circ X_2}{P^\circ} \quad \text{--- (iv)}$$

$$\frac{\Delta P}{P^\circ} = X_2 \quad \text{--- (v)}$$

P° is cancelled with P°

It shows that relative lowering of vapour pressure of the solution depends only on the mole fraction of solute and is completely independent of either the nature of solute or solvent. It is also independent of temperature.

Q9: Define colligative properties. Name the colligative properties of dilute solution.

Definition:

"Physical properties of solution, which depends upon the number of solute particles and do not de-

	1mole urea 60 grams	1mole glucose 180g	1mole sucrose 342g
F.P = 0°C B.P = 100°C	F.P = -1.86°C B.P = 100.52°C	F.P = -1.86°C B.P = 100.52°C	F.P = -1.86°C B.P = 100.52°C

pend upon their nature and structure are called colligative properties."

It means that when the same number of particles of different solutes are dissolved in the same amount of solvent. The same physical effect is produced. Some of the colligative properties are as:

1. Lowering of vapour pressure
2. Elevation in boiling point (ΔT_b)
3. Depression in freezing point (ΔT_f)
4. Osmotic pressure

Q10: Explain lowering of vapour pressure.

Ans: Lowering of Vapour Pressure: (Swat + Kohat Boards)

Definition: "The decrease in the vapour pressure of a solvent due to the addition of non-volatile solute is called lowering of vapour pressure."

Explanation: A solvent has a definite vapour pressure at a given temperature. When a non-volatile solute is dissolved in it, its vapour pressure decreases. The lowering of vapour pressure is directly proportional to the amount of solute dissolved. Let the vapour pressure of pure solvent = P°

➤ Vapour pressure of solution = P

➤ Lowering of vapour pressure of solution = $P^\circ - P$

➤ Relative lowering of vapour pressure of solution as compared to pure solvent = $\frac{P^\circ - P}{P^\circ}$.

According to Raoult's law, the vapour pressure of solution is directly proportional to the mole fraction of solvent. So,

$$P \propto X_1$$

$$P = P^\circ X_1 \quad \text{--- (i)}$$

$$P = P^\circ (1 - X_2)$$

$$\frac{P}{P^\circ} = 1 - X_2$$

Subtracting both sides from 1, we get,

$$1 - \frac{P}{P^\circ} = 1 - (1 - X_2)$$

$$\frac{1}{1} - \frac{P}{P^\circ} = 1 - 1 + X_2$$

$$\text{As } X_1 + X_2 = 1$$

$$X_1 = (1 - X_2)$$

$$\frac{P^{\circ} - P}{P^{\circ}} = X_2 \quad \text{--- (ii)}$$

Equation (ii) is the mathematical form of Raoult's law. It states that the relative lowering of vapour pressure of solution is equal to the mole fraction of solute present in the solution. We know that,

$$X_2 = \frac{n_2}{n_1 + n_2}$$

So equation (ii) becomes,

$$\frac{P^{\circ} - P}{P^{\circ}} = \frac{\Delta P}{P^{\circ}} = \frac{n_2}{n_1 + n_2} \quad \text{--- (iii)}$$

Equation (iii) represent another form of Raoult's law. As we know that,

$$n_1 = \frac{w_1}{M_1} \text{ and } n_2 = \frac{w_2}{M_2} \text{ so,}$$

$$\frac{\Delta P}{P^{\circ}} = \frac{\frac{w_2}{M_2}}{\frac{w_1}{M_1} + \frac{w_2}{M_2}} \quad \text{--- (iv)}$$

For a very dilute solution $n_2 \ll n_1$ therefore $(n_1 + n_2) = n_1$ thus

$\frac{w_2}{M_2}$ can be neglected from the denominator so equation (iv) can be written as,

$$\frac{\Delta P}{P^{\circ}} = \frac{w_2 \div M_2}{w_1 \div M_1}$$

$$\frac{\Delta P}{P^{\circ}} = \frac{w_2 \cdot M_1}{M_2 \cdot w_1} \quad \text{--- (v)}$$

Equation (v) can be used to calculate molecular mass of the dissolved substance, if relative lowering of vapour pressure and the definite weight of solute in a given amount of solvent are known.

Q17: Define and explain elevation in boiling point [ebullioscopy] " ΔT_b "

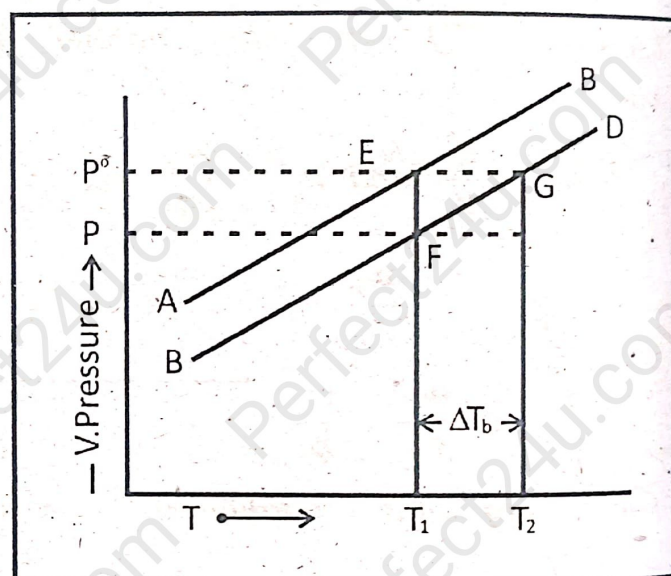
Ans: Elevation in Boiling Point [ΔT_b]: (ETEA: 2018)

Definition: "The increase in the boiling point of a solvent due to the addition of a non-volatile solute is called elevation in boiling point."

Explanation: A solvent boils when its vapour pressure becomes equal to atmospheric pressure. Since the addition of non-volatile solute to the solvent decreases its vapour pressure, therefore its boiling point rises. It means that a solution boils at higher temperature than the pure solvent. The increase in boiling point of a solution depends upon the number of solute particles in a solution and nature of the solvent but do not depends upon the nature of solute particles.

Thus one mole of glucose and one mole of sugar dissolved in 1kg of solvent causes the same elevation in boiling point of water which is 0.52° .

In simple words 1-molal solution of glucose and 1-molal solution of sucrose both boils at 100.52° . Consider the diagram, in which the vapour pressure of the solvent and solution is plotted against temperature.



The upper curve AB is for pure solvent and lower curve CD is for solution. Let the solvent and solution boils when their vapour pressure becomes equal to the external pressure " P ". This occurs for a solvent at lower temperature (T_1) and for solution at high temperature (T_2). The reason is that the solution has lower vapour pressure than the solvent.

The elevation in boiling point of a solution (ΔT_b) is directly proportional to the molarity of the solution.

$$\Delta T_b \propto m$$

$$\Delta T_b = K_b m \quad \text{--- (i)}$$

K_b = molal boiling point constant / ebullioscopic constant. The elevation in boiling point that occurs when one mole of the non-volatile solute is dissolved in 1kg solvent is called molal boiling point constant or ebullioscopic constant.

Molal boiling point constant for water = 0.52°

Molal boiling point constant for CCl_4 = 5.02°

Molality of solution is given by:

$$m = \frac{\text{Mass of solute (grams)}}{\text{Molar mass of solute} \times \text{mass of solvent in grams} / 1000}$$

$$m = \frac{w_2}{M_2 \times w_1 / 1000} \Rightarrow m = \frac{w_2 \times 1000}{M_2 \times w_1} \quad \text{(ii)}$$

Putting the values of molality from equation (ii) into (i)

$$\Delta T_b = K_b \cdot \frac{w_2 \cdot 1000}{M_2 \cdot w_1}$$

$$M_2 = \frac{K_b \cdot w_2 \cdot 1000}{\Delta T_b \cdot w_1} \quad \text{(iii)}$$

Equation (iii) is used to calculate molar mass of the solute. The unit of " K_b " is $^{\circ}\text{C} \cdot \text{kg} \cdot \text{mol}^{-1}$.

EXAMPLE 10-5:

The boiling point of 50 grams of carbon tetrachloride (CCl_4) was raised by 0.402K when 0.5126g of naphthalene (molar mass = $128\text{g} \cdot \text{mol}^{-1}$) was dissolved in it. Calculate the ebullioscopic constant for " CCl_4 ".

Solution:

$$\text{Mass of } \text{CCl}_4 = w_1 = 50\text{g}$$

$$\text{Mass of naphthalene} = w_2 = 0.5126\text{g}$$

$$\text{Molar mass of naphthalene} = M_2 = 128\text{g} \cdot \text{mol}^{-1}$$

$$\text{Elevation in boiling point} = \Delta T_b = 0.402\text{K}$$

$$\text{Ebullioscopic constant} = K_b = ?$$

Formula used;

$$\Delta T_b = K_b \cdot \frac{w_2 \cdot 1000}{M_2 \cdot w_1}$$

$$K_b = \frac{\Delta T_b \cdot w_1 \cdot M_2}{w_2 \cdot 1000}$$

$$K_b = \frac{0.402\text{K} \cdot 50\text{g} \cdot 128\text{g} \cdot \text{mol}^{-1}}{0.5126\text{g} \cdot 1000}$$

$$K_b = \frac{2572.8}{512.6} = [5.02\text{K} \cdot \text{g} \cdot \text{mol}^{-1}]$$

Q12: Define and explain depression in freezing point of solution [ΔT_f].
(ETEA: 2011, BISE Swat 2017, Abbottabad + Bannu Boards)

Ans: Depression in Freezing Point [Cryoscopy]:

Definition: "The difference between the freezing point of the pure solvent and solution is called the depression in freezing point."

Freezing point is the temperature at which a liquid and its solid phase have the same vapour pressure. When

some amount of solute is dissolved in a solvent, vapour pressure of the solvent decreases so solution freezes at lower temperature than the pure solvent. As this property depends upon the number of solute particles, so 1-mole of glucose, 1-mole sugar and 1-mole urea dissolved in 1kg solvent (water) in separate containers, produce the same depression in freezing point, which is 1.86° .

In the given diagram, vapour pressure is plotted against temperature. The curve "ABC" is for solvent. At point "B" the liquid solvent and solid solvent have the same vapour pressure " P° ". Thus the solvent freezes at temperature T_1 . The curve "DEC" is for solution. It meets the curve "BC" [curve of frozen solvent] at "E". This is the point where vapour pressure of the solution and solid solvent are equal and the solution freezes.

Since $P < P^\circ$, therefore the solution freezes at a lower temperature T_2 . Depression in freezing point is denoted by ΔT_f .

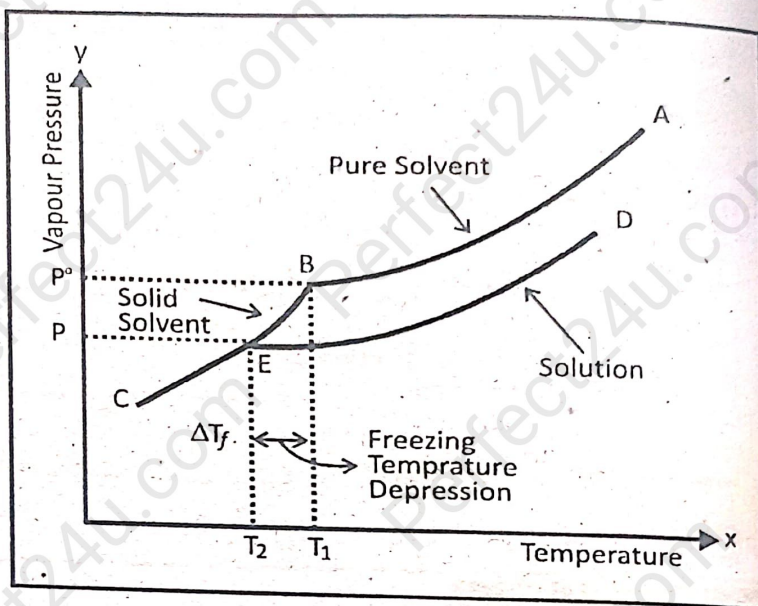
$$\Delta T_f = F.P \text{ of solvent} - F.P \text{ of solution}$$

The depression in freezing point is directly proportional to the molality of solution (m).

$$\Delta T_f \propto m$$

$$\Delta T_f = K_f m \quad \text{--- (i)}$$

K_f = molal freezing point constant / cryoscopic constant. The depres-



sion in freezing point that occurs when one mole of a solute is dissolved in 1kg of solvent is called molal freezing point constant. We know that,

$$m = \frac{\text{Mass of solute (grams)}}{\text{Molar mass of solute} \times \text{mass of solvent in grams} / 1000}$$

$$m = \frac{w_2}{M_2 \cdot w_1 / 1000} \Rightarrow \frac{w_2 \cdot 1000}{M_2 \cdot w_1} \quad \text{(ii)}$$

Now putting the value of "m" in equation (i) from equation (ii), we get,

$$\Delta T_f = \frac{K_f \cdot w_2 \cdot 1000}{M_2 \cdot w_1}$$

$$M_2 = \frac{K_f \cdot w_2 \cdot 1000}{\Delta T_f \cdot w_1} \quad \text{(iii)}$$

Equation (iii) is used to determine the molecular mass of solute.

EXAMPLE 10-6:

If 3.60 grams of glucose is dissolved in 100g of water and the freezing point depression is found to be 0.372K. Calculate the molar mass of glucose. K_f for water is $1.86\text{K} \cdot \text{kg} \cdot \text{mol}^{-1}$.

Solution:

Weight of glucose = $w_2 = 3.60\text{g}$

Weight of water = $w_1 = 100\text{g}$

Freezing point depression = $\Delta T_f = 0.372\text{K}$

Molal freezing point constant for water = $K_f = 1.86\text{K} \cdot \text{kg} \cdot \text{mol}^{-1}$

Molecular mass of glucose $M_2 = ?$

Formula used:

$$\Delta T_f = K_f \cdot \frac{w_2 \cdot 1000}{M_2 \cdot w_1}$$

$$M_2 = \frac{K_f \cdot w_2 \cdot 1000}{\Delta T_f \cdot w_1}$$

$$M_2 = \frac{1.86\text{K} \cdot \text{kg} \cdot \text{mol}^{-1} \times 1000 \times 3.60\text{g}}{0.372\text{K} \times 100\text{g}}$$

$$= 180\text{g} \cdot \text{mol}^{-1}$$

$$[M_2 = 180\text{g} \cdot \text{mol}^{-1}]$$

Q13: Explain osmosis phenomenon and osmotic pressure.

Ans Osmosis:

Definition: "The movement of solvent molecules from high concentration region to lower concentration region through a semi-permeable membrane is called osmosis."

Osmosis phenomenon was 1st observed and reported by Abbe Nellet in 1784. A membrane which allows the passage of solvent molecules only and not the solute through it is called a semi-permeable membrane.

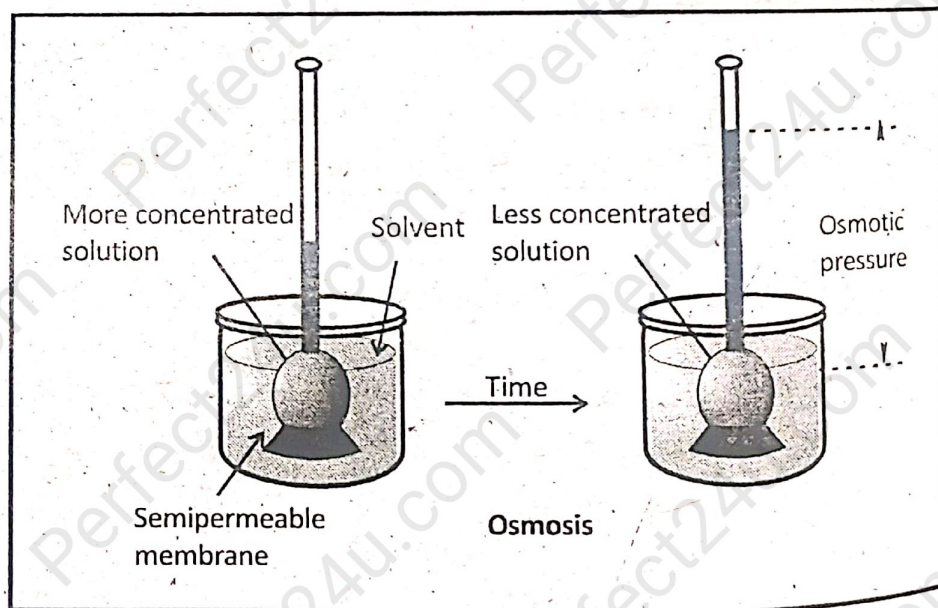
Osmosis also takes place when a dilute solution is separated from a concentrated solution, the solvent molecules from dilute solution pass through the membrane towards the concentrated solution region.

For low molecular mass solutes in water the best semi-permeable membrane is a film of copper ferrocyanide $\text{Cu}_2\text{Fe}(\text{CN})_6$.

For high molecular weight solutes in organic solvents the membranes used, most frequently are thin films of either cellulose or cellulose nitrate.

Experiment:

A semi-permeable membrane i.e. egg membrane is tied over the end of a thistle funnel. It is then filled with a solution of sugar and dipped into a beaker containing water.



The level of sugar solution is marked in the glass tube of thistle funnel. After some time the level of sugar solution becomes higher in the glass tube. This occurs due to the movement of water molecules from higher concentration region [beaker] to lower concentration region [thistle funnel].

End Osmosis:

"The flow of solvent molecules from the outside beaker into the inside

solution in thistle funnel through a semi-permeable membrane is called end osmosis.”

When pressure is applied on the glass tube, water molecules from sugar solution move to pure solvent across a membrane.

Ex-Osmosis / Reverse Osmosis:

“The movement of water molecules from lower concentration region [sugar solution] to higher concentration region [pure solvent] by applying external pressure is called reverse osmosis / ex-osmosis.”

Osmotic Pressure:

Definition: “The mechanical pressure which must be applied on a solution to prevent osmosis of solvent into solution through a semi-permeable membrane is called osmotic pressure of the solution.”

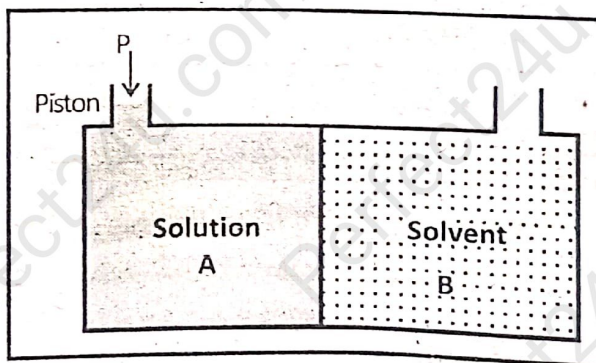
Explanation: Osmotic pressure is denoted by π “ π ”. This pressure for a given solution depends on a number of factors but is independent of the nature of membrane. PFEFFER experimentally proved that, at constant temperature the osmotic pressure is directly proportional to the concentration of solution.

% Concentration [C]	Osmotic Pressure [mmHg]
1 mol·dm ⁻³	535 mmHg
2 mol·dm ⁻³	1016 mmHg
2.47 mol·dm ⁻³	1518 mmHg
4 mol·dm ⁻³	2082 mmHg
6 mol·dm ⁻³	3075 mmHg

Experiment:

Look at the figure, the closed chamber is divided by a semi-permeable membrane into two compartments. The left compartment “A” is filled with the solution and the top opening of the compartment is provided

with a moveable piston while the right compartment “B” contains the pure solvent, and its mouth is open to atmosphere. The solvent will pass through the semi-permeable membrane into the solution com-



partment due to osmosis and will push the piston upward. The upward movement of the piston can be prevented by applying pressure on the piston to keep it in the original position.

“The pressure that must be applied on the solution in order to prevent the osmosis is called osmotic pressure.”

If two solutions have the same concentration on both sides, no osmosis will occur and the solutions are said to be isotonic [having same osmotic pressure].

Q14: Write down the impacts (اثرات) of osmosis on daily life.

Ans: Impacts of Osmosis: (BISE Kohat 2018)

1. Osmosis process is used in many industries.
2. The victims (ضحايا) of ship wreckage purify sea water, which has very high concentration of salts, by reverse osmosis to make it drinkable.
3. By osmotic pressure the plant cell become turgid [swell بچونا] and these turgid cells provide support to weak parts of plant.
4. Ascent of sap (عُلول کا اوپر چڑھنا) in plants from roots to upper parts takes place by osmosis and osmotic pressure.
5. Isotonic [same osmotic pressure] solutions have been prepared to prevent plasmolysis (سُکنا) [shrinkage of cytoplasm] and hemolysis [deficiency of red blood cells].
6. The concept of osmotic pressure can be used to calculate molar mass of substances, especially of polymers.
7. The mineral water sold in market is purified by reverse osmosis process.

Q15: Explain salvation process and water of crystallization.

Ans: Salvation Process: (BISE D-I Khan 2017)

“The process during which solvent molecules surrounded and interact with solute ions is called salvation.”

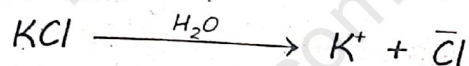
Hydration:

“The process during which water molecules surrounded and interact with solute ions is called hydration.”

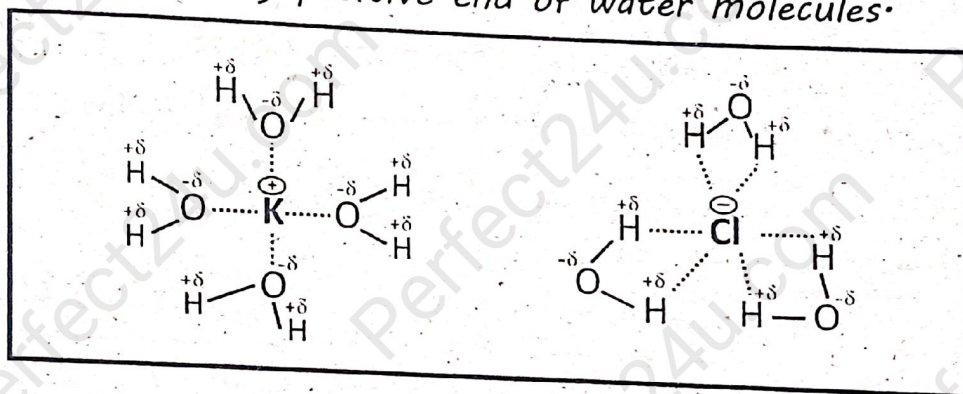
Explanation: If an ionic solute is added to a polar solvent, the positive

pole of solvent molecule attracts the negative ion and negative pole attracts the positive ion. In this way, the attractive forces between positive and negative ions of solute break and they move far apart from each other. Both the positive and negative ions are surrounded by a sphere of solvent molecules and keep them in the dissolved form. This process is called salvation.

When an ionic salt like KCl is added to water, it will ionize into K^+ and Cl^- ions.



K^+ ions will be attracted by negative end of water molecules and Cl^- ions will be attracted by positive end of water molecules.



Ionic compounds are salvated by polar solvents like water. However non-polar solutes are salvated by non-polar solvents. The forces involved in case of non-polar solutes are Vander Waal forces. The forces involved in case of polar solvents are ion-dipole forces.

Water of Crystallization:

"The number of water molecules which remain attached with the crystals of a salt during its crystallization from a saturated solution is called water of crystallization."

Hydrated Ions:

"The ions surrounded by water molecules are called hydrated ions."

The hydration of ions depends upon:

- ✧ Size of ions
- ✧ Magnitude of charge

Ions with smaller size and high charge density are surrounded by more number of water molecules. Whenever an acid - base neutralization

reaction takes place salt and water are formed. In order to get solid salt water is evaporated by heating. In some types of salts, some of the water molecules remain inside the salt crystals that is just a physical presence of water molecules and is called water of crystallization.

Some salts absorb water molecules from the atmosphere if kept open and get hydrated.

Examples:

$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$: Copper sulphate pentahydrate, Neela thotha (نیلا تھوٹھا)

$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$: Calcium sulphate dihydrate [gypsum]

$\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$: Magnesium chloride hexahydrate

$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$: Magnesium sulphate heptahydrate [Epsom]

$\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$: Sodium carbonate decahydrate [washing soda]

The hydrates loses water molecules on heating and becomes anhydrous.



(Hydrated form "blue")

(Anhydrous form "colourless")

Q16: What are colloids? Explain some important properties of colloids.

Ans: Colloids:

A colloidal dispersion is a heterogeneous mixture in which one substance is dispersed as very fine particles in another substance. Here the terms dispersed phase and dispersion medium are used instead of solute and solvent.

1. Colloids are heterogeneous in nature.
2. Particles size ranges from 1 – 1000nm.
3. It is intermediate between solution and suspension.
4. Particles in colloids remain suspended and do not settle down at the bottom at the bottom of mixture.
5. These particles are visible only under high resolving microscope.
6. Particles pass slowly through filter paper.

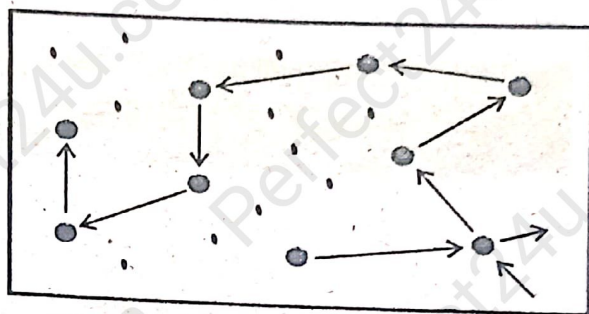
Properties of Colloids:

1. Optical Properties: As colloidal particles are large enough so when light is passed through colloids, these particles scatter light in all directions. This light scattering phenomenon is called Tyndal effect. This

effect explains the tail of comet (ذئار سفاء) and blue colour of sky [blue colour is scattered more].

2. Brownian Movement: [Zig-Zag movement ذئار سفاء حركاء] The random

movement of particles suspended in liquid or gas is called Brownian movement. The colloidal particles move randomly [zig-zag path]. The colloidal particles are bombarded by the fast moving particles of the medium and



changes their direction of movement. The higher the temperature, the more vigorous (ذئار) is the movement and hitting by the molecules. The zig-zag motion of colloidal particles can be observed by an ultra microscope.

3. Filterability: Colloidal particles can pass through the pores of ordinary filter paper so these can be removed by specially designed filters. These filters have very small pores. These filters are called ultra-filters and the process is called ultra-filtration.

4. Diffusibility: The size of colloidal particles is larger as compared to solute particles in solution so they have little power of diffusion.

5. Colour: The colour of colloidal solution depends on size and shape of colloidal particles and the wavelength of scattered light, e.g. silver sols with different particles size, show different colours. Sol is special term used for colloids.

6. Effect of Temperature Change: It has been observed that a change in temperature coagulate colloids. When an egg is boiled or fired, small colloidal particles convert into a lump (ذئار) by coagulation. Exposing to sunlight may help Jellies set. Blood stains (نابء) must be washed from clothes with cold water. Washing with hot water, protein materials coagulate and become difficult to remove. By heating milk, coagulation of casein in milk occurs. [Casein: protein present in milk]

Q17: Explain types of colloids. (ETEA: 2017)

Ans Colloids are classified on two basis. Basis of classification of colloids:

✧ Components [Physical state of matter]

✧ Behaviour [Attractive or repulsive forces]

(a) On the basis of physical state of dispersed phase and dispersion medium colloids can be classified into the following types.

No.	Dispersed Phase	Dispersion Medium	Special Name	Example of Colloid
	Gas	Gas	-	Impossible because form homogeneous mixture
1	Gas	Liquid	Foam	Soap lather, soda water, froath etc.
2	Gas	Solid	Solid form	Cake, bread, lava
3	Liquid	Gas	Aerosol	Mist, fog, clouds
4	Liquid	Liquid	Emulsion	Milk, cream, butter, oil in water
5	Liquid	Solid	Gel	Curd, chees, jellies, butter, shoe polish
6	Solid	Gas	Solid aerosol	Smoke, dust
7	Solid	Liquid	Sol	Paint, ink
8	Solid	Solid	Solid sol	Alloys, coloured glass, gem stone

Emulsion:

A mixture of two or more liquids that are normally immiscible / one is present as droplets of microscopic size.

Aerosol:

The dispersion of solid particles of microscopic size in gaseous media such as dust and smoke.

(b) Behaviour Towards Liquids:

Depending on the force of attraction or repulsion between the dispersed particles and dispersion medium colloids may be:

LYOPHILIC AND LYOPHOBIC

Lyophilic Colloids:

“Lyo” means “liquid” and “philic” means “lover / liking”. “Lyophilic” means “liquid loving / solvent attracting”. If the dispersion medium is water then the term “hydrophilic is used. In hydrophilic colloids:

1. Dispersed particles generally have same chemical nature as that of

dispersion medium, such as $-OH$ group is capable to form hydrogen bond.

2. When such colloids are once precipitated they can be directly re-turned into the colloidal form.
3. These are called reversible colloids.
4. Examples are lassi, gel, starch solution and rubber solution.

Lyophobic Colloids:

“Lyo” means “liquid” and “phobic” means “repeller”. If the dispersed phase particles has little or no affinity for the dispersion medium then such colloids are called lyophobic.

- Lyophobic means liquid fearing / solvent heating.
 - If water is used as a solvent / dispersion medium then the term hydrophobic is used.
1. No attractive force exists between dispersed phase and dispersion medium particles.
 2. Hydrophobic / lyophobic colloids are less stable.
 3. If such colloids are once precipitated they cannot be directly re-covered into colloidal form and are irreversible colloids.
 4. These are difficult to form and need a stabilizing agent.
 5. Examples are: sols of metals like silver and gold, sols of metal hydroxides.

Difference between Lyophilic and Lyophobic Colloids:

LYOPHILIC	LYOPHOBIC
1. The particles of sols migrate towards anode or cathode in an electric field.	1. The sol particles may or may not migrate in an electric field.
2. The solid obtained after evaporation may be reconverted to the sol by simply shaking them with the dispersion medium.	2. The precipitated mass cannot be brought back into the colloidal state by simply shaking them with the dispersion medium.
3. These sols are reversible.	3. These are irreversible.
4. The surface tension of the sol is lower than that of the dispersion medium.	4. The surface tension of the sol is the same as that of the dispersion medium.
5. The viscosity of sol is higher	5. The viscosity of the sol is the

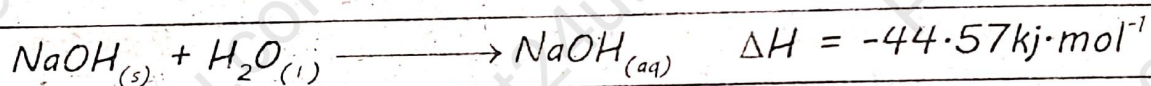
than that of the dispersion medium.	same as that of the dispersion medium.
6. Examples are: gum, starch, gelatin, rubber etc.	6. Examples are: metal sulphide sol and metals sols etc.

Q18: Define heat of solution. What are its applications?

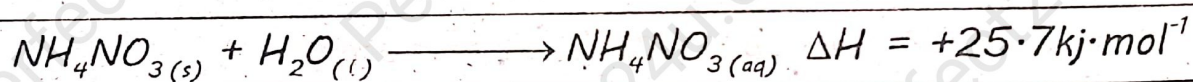
Ans: Heat of Solution: (ETEA: 2018)

Definition: "The amount of heat evolved or absorbed when a definite amount of solute is dissolved in excess of solvent is called heat of solution."

Explanation: If solid sodium hydroxide [NaOH] is dissolved in water the temperature of water will rise. This is an exothermic process.



When ammonium nitrate [NH₄NO₃] is dissolved in water, temperature of water decreases. This is an endothermic process.



From the above examples it becomes clear that heat is either evolved or absorbed during the process of solution formation. The dissolution process consists of three steps:

1. Breaking of Solute – Solute Attraction:

This is an endothermic process and $\Delta H = \text{positive}$.

2. Breaking of Solvent – Solvent Attraction:

This is an endothermic process [$\Delta H = \text{positive}$]

3. Resulting New Solvent – Solvent Attraction:

This is an exothermic process [$\Delta H = \text{negative}$]

The value of heat of solution is the net effect of these three heats i.e. the algebraic sum of these three heats. If the amount of heat evolved is higher than the heat absorbed, the dissolution process will be exothermic and vice versa.

In the gaseous state, the attractive forces between the gas molecules are very weak. Thus when gases are dissolved in a solvent, the solute-solute interaction has little effect. So energy is always evolved when a gas is dissolved in a solvent. It is because only the solute-solvent interactions are operative.

Exercise

1. Choose the correct option from the given options:

1. In atmospheric gaseous solution, nitrogen is a:
✓ (a) Solvent (b) Solute
(c) Mixture (d) Dispersed phase
2. In ice cream, sugar is:
✓ (a) Solute (b) Mixture
(c) Solvent (d) None
3. Elevation of boiling point is a property:
(a) Additive (b) Constitutive
✓ (c) Colligative (d) None
4. Change in enthalpy ΔH_{sol} is heat of solution which is:
(a) Positive (b) Negative
(c) Zero ✓ (d) May be positive or negative
5. Freezing point of solution as compared to the solvent is,
(a) Higher ✓ (b) Lower
(c) Variable (d) Remains the same
6. Phenol - water system is the example of:
(a) Completely miscible liquids
(b) Completely immiscible liquids
✓ (c) Partially miscible liquids
(d) None
7. Fog is an example of:
(a) Solution ✓ (b) Colloid
(c) Suspension (d) Coarse mixture
8. Which of the following solute would not form a solution, if added to water?
(a) KCl ✓ (b) CH_4 (c) HCl (d) NH_3
9. Vapour pressure of a given liquid will decrease if:
(a) Surface area of liquid is increased
(b) Total volume of liquid in the container is decreased
(c) Volume of the vapour phase is increased
✓ (d) The temperature is decreased
10. For a dilute solution, Raoult's law states that;
(a) The lowering of vapours pressure is equal to the mole fraction

of solute

✓ (b) Relative lowering of vapours pressure is equal to the mole fraction of solute

(c) The relative lowering of vapours pressure is proportional to the amount of solute.

(d) The vapours pressure of solution is equal to the mole fraction of solvent

11. The boiling point of C_6H_6 , CH_3OH , $C_6H_5-NH_2$ and $C_6H_5NO_2$ are 80° , 65° , 184° and 112° respectively. Which one will show the highest vapour pressure at room temperature?

(a) C_6H_6

✓ (b) CH_3OH

(c) $C_6H_5-NH_2$

(d) $C_6H_5-NO_2$

12. The process in which the water molecules surround and interact with the solute ions or molecules is called:

(a) Neutralization

✓ (b) Hydration

(c) Hydrolysis

(d) hydrogenation

13. The molarity of pure water in itself is:

(a) 18

(b) 50

(c) 59.5

✓ (d) 55.6

2. Briefly answer the following questions:

Q1: Define the following concentration units: (i) ppm (ii) ppb (iii) ppt (iv) mole fraction

Ans:

(i) ppm → Please see question number 7.

(ii) ppb → Please see question number 7.

(iii) ppt → Please see question number 7.

(iv) Mole fraction → Please see question number 7.

Q2: Which concentration unit, from molarity and molality depends on temperature?

Ans: Molarity depends upon temperature because in molarity we take total solution as 1dm^3 and volume has direct relation with temperature. On the other hand, in molality we take mass [1kg solvent] and then add one mole solute. As mass is not affected by change in temperature so molality is independent of temperature.

$$\left[\text{Molarity} = \frac{\text{No. of moles of solute}}{\text{Volume of solution in dm}^3} \right]$$

$$\left[\text{Molality} = \frac{\text{No. of moles of solute}}{\text{Mass of solution in kilogram}} \right]$$

Q3: Prove mathematically that sum of the mole fractions of all the components of a solution is equal to one.

Ans: Let we have a solution of a solute and solvent.

Mole fraction of solvent = X_1

Mole fraction of solute = X_2

Number of moles of solvent = n_1

Number of moles of solute = n_2

Total number of moles of solute and solvent = n_T

$$n_T = n_1 + n_2$$

$$\text{Mole fraction of solvent} = X_1 = \frac{n_1}{n_T}$$

$$\text{Mole fraction of solute} = X_2 = \frac{n_2}{n_T}$$

$$X_1 + X_2 = \frac{n_1}{n_T} + \frac{n_2}{n_T} \Rightarrow \frac{n_1 + n_2}{n_T} = \frac{n_T}{n_T} = [1]$$

Q4: Define and name four colligative properties.

Ans: "Physical properties of solution which depends upon the number of solute particles and do not depends upon the nature and structure of solute are called colligative properties."

Names of four colligative properties are:

1. Lowering of vapour pressure.
2. Elevation in boiling point.
3. Depression in freezing point.
4. Osmotic pressure.

Q5: Define osmosis and give its applications in daily life.

Ans: "The movement of solvent molecules from high concentration region to lower concentration region across a semi-permeable membrane is called osmosis."

For applications please see question number 14.

Numerical Questions

Q1: Calculate molarity (M) of the following solutions:

- (i) 2 gram of H_2SO_4 / 2dm^3 of aqueous solution
- (ii) 0.4 gram of NaOH / 100cm^3 of aqueous solution
- (iii) 0.5 gram Na_2CO_3 / 250cm^3 of aqueous solution.

Solution:

(i) Mass of solute = H_2SO_4 = 2 grams

Molar mass of H_2SO_4 [solute] = $98\text{g}\cdot\text{mol}^{-1}$

Volume of solution = 2dm^3

Formula used;

$$M = \frac{\text{Mass of solute}}{\text{Molar mass of solute} \times \text{volume of solution in } \text{dm}^3}$$

$$M = \frac{2}{98 \times 2} = \frac{2}{196} = [0.01 \text{ mol}\cdot\text{dm}^{-3}]$$

(ii) 0.4 gram of NaOH / 100cm^3 of H_2O :

Mass of solute (NaOH) = 0.4 gram

Molar mass of solute = 40g/mol

Volume of solution in cm^3 = 100cm^3

$$\text{Volume of solution in } \text{dm}^3 = \frac{100}{1000} = 0.1\text{dm}^3$$

$$M = \frac{\text{Mass of solute}}{\text{Molar mass of solute} \times \text{volume of solution in } \text{dm}^3}$$

$$M = \frac{0.4}{40 \times 0.1} = \frac{0.4}{4} \rightarrow \frac{4}{4 \times 10} \rightarrow \frac{4}{40} \rightarrow [0.1 \text{ mol}\cdot\text{dm}^{-3}]$$

(iii) Molarity of 0.5 grams Na_2CO_3 / 250cm^3 of H_2O :

Mass of solute [Na_2CO_3] = 0.5 gram

Molar mass of solute [Na_2CO_3] = 106g/mol

Volume of solution in cm^3 = 250cm^3

$$\text{Volume of solution in } \text{dm}^3 = \frac{250}{1000} = 0.25\text{dm}^3$$

$$M = \frac{\text{Mass of solute}}{\text{Molar mass of solute} \times \text{volume of solution in } \text{dm}^3}$$

$$M = \frac{0.5 \cancel{g}}{106 \cancel{g} \cdot \text{mol}^{-1} \times 0.25 \text{ dm}^3} = \frac{0.5}{26.5} = \frac{5 \times 10}{265 \times 10}$$

$$= \frac{50}{2650} = (0.02 \text{ mol} \cdot \text{dm}^{-3})$$

Q2: Calculate mole fraction of each component in the following solutions:

- (i) 2.5 moles of H_2O and 1.5 moles of NaCl
- (ii) 500 grams of H_2O and 600 grams of glucose
- (iii) 800 grams of H_2O and 120 grams of acetone $(\text{CH}_3)_2\text{CO}$

Solution:

(i) Number of moles of $\text{H}_2\text{O} = n_{\text{H}_2\text{O}} = 2.5 \text{ mole}$

Number of moles of $\text{NaCl} = n_{\text{NaCl}} = 1.5 \text{ mole}$

Total number of moles = $n_T = n_{\text{H}_2\text{O}} + n_{\text{NaCl}}$

$$n_T = (2.5 + 1.5 = 4 \text{ moles})$$

Mole fraction of $\text{H}_2\text{O} = X_{\text{H}_2\text{O}} = \frac{2.5}{4} = (0.625)$

Mole fraction of $\text{NaCl} = X_{\text{NaCl}} = \frac{1.5}{4} = (0.375)$

(ii) Number of moles of water = $n_w = \frac{m}{M} = \frac{500}{18} = (27.77 \text{ moles})$

Number of moles of glucose = $n_{\text{Glucose}} = \frac{m}{M} = \frac{600}{180} = (3.33 \text{ moles})$

Total number of moles = $n_T = n_{\text{Glucose}} + n_{\text{H}_2\text{O}}$

$$n_T = 3.33 + 27.77 = (31.10 \text{ mole})$$

Mole fraction of water = $X_{\text{H}_2\text{O}} = \frac{27.77}{31.10} = (0.89)$

Mole fraction of glucose = $X_{\text{Glucose}} = \frac{3.33}{31.10} = (0.107) \approx 0.11$

(iii) Number of moles of water = $n_w = \frac{m}{M} = \frac{800}{18} = (44.44 \text{ moles})$

Number of moles of acetone = $n_{\text{acetone}} = \frac{m}{M} = \frac{120}{58}$

$$= n_{\text{acetone}} = (2.06 \text{ moles})$$

$$\text{Total number of moles} = n_T = 44.44 + 2.06 = (46.51 \text{ moles})$$

$$\text{Mole fraction of } H_2O = \frac{44.44}{46.51} = (0.95)$$

$$\text{Mole fraction of acetone} = \frac{2.06}{46.51} = (0.05)$$

Q3: A 3cm^3 cylinder contains a mixture of oxygen, nitrogen and chlorine gases. If their amounts are $4.64 \times 10^{-5}\text{g}$, $3.5 \times 10^{-4}\text{g}$ and $2.3 \times 10^{-5}\text{g}$ respectively. Calculate the concentration of each in:

(i) Parts per million (ppm)

(ii) Parts per trillion (ppt)

Solution: Concentration of each component in ppm;

$$\text{ppm} = \frac{\text{mass of solute}}{\text{volume of solution}} \times 10^6$$

$$\begin{aligned} \text{ppm of } O_2 &= \frac{4.64 \times 10^{-5}}{3} \times 10^6 = 1.546 \times 10^{-5} \times 10^6 \\ &= 1.546 \times 10^1 = (15.46 \text{ ppm}) \end{aligned}$$

$$\begin{aligned} \text{ppm of } N_2 &= \frac{3.5 \times 10^{-4}}{3} \times 10^6 = 1.16 \times 10^{-4} \times 10^6 \\ &= 1.16 \times 10^2 = (116.6) \end{aligned}$$

$$\begin{aligned} \text{ppm of } Cl_2 &= \frac{2.3 \times 10^{-5}}{3} \times 10^6 = 0.766 \times 10^{-5} \times 10^6 \\ &= 0.776 \times 10^1 = (7.66 \text{ ppm}) \end{aligned}$$

(ii) Concentration of each component in ppb:

$$\text{ppb} = \frac{\text{Mass / volume of solute}}{\text{Mass / volume of solution}} \times 10^9$$

$$\text{ppb of } O_2 = \frac{4.64 \times 10^{-5}}{3} \times 10^9 = 1.546 \times 10^{-5} \times 10^9 = [1.546 \times 10^4]$$

$$\text{ppb of } N_2 = \frac{3.5 \times 10^{-4}}{3} \times 10^9 = 1.16 \times 10^{-4} \times 10^9 = [1.16 \times 10^5]$$

$$\begin{aligned} \text{ppb of } Cl_2 &= \frac{2.3 \times 10^{-5}}{3} \times 10^9 = 0.766 \times 10^{-5} \times 10^9 \\ &= 0.766 \times 10^4 \\ &= (7.66 \times 10^3 \text{ ppb}) \end{aligned}$$

Q4: In an experiment 6.4 grams of an organic compound was dissolved in 25.6 gram of benzene and 1°C depression of freezing point was observed. Calculate the molecular weight of the substance [K_f of benzene = 5.12]

Solution:

Depression in freezing point: $\Delta T_f = 1^\circ$

Weight of solute: $w_2 = 6.4$ gram

Weight of solvent: $w_1 = 25.6$ gram

Molar mass of solute: $M_2 = ?$

Cryoscopic constant = $K_f = 5.12$

Formula used;

$$\Delta T_f = K_f \cdot \frac{w_2 \times 1000}{M_2 \cdot w_1}$$

$$M_2 = \frac{K_f \cdot w_2 \cdot 1000}{\Delta T_f \cdot w_1}$$

$$M_2 = \frac{5.12 \times 6.4 \times 1000}{1 \times 25.6} = \frac{32768}{25.6} = (1280 \text{ g} \cdot \text{mol}^{-1})$$

Q5: Calculate molecular weight of iodine [I_2], when a solution containing 1.19 grams iodine in 35 grams of ether shows a raise in boiling point by 0.296°C [K_b for ether = 2.22].

Solution:

Molecular weight of iodine [I_2] = $M_2 = ?$

Weight of solute [iodine] = $w_2 = 1.19$ gram

Weight of solvent = $w_1 = 35$ g

Elevation in boiling point = $\Delta T_b = 0.296^\circ$

Ebullioscopic constant = $K_b = 2.22$

Formula used:

$$\Delta T_b = K_b \cdot \frac{w_2 \cdot 1000}{M_2 \cdot w_1}$$

$$M_2 = \frac{K_b \cdot w_2 \cdot 1000}{\Delta T_b \cdot w_1}$$

$$M_2 = \frac{2.22 \times 1.19 \times 1000}{0.296 \times 35}$$

$$M_2 = \frac{2641.8}{10.36} = [255 \text{ grams/mol}]$$

Descriptive Questions

Q1: How a given mixture can be differentiate into a true solution or coarse suspension?

Ans: The coarse mixture / suspension means, the substance, particles or things that can be seen because of its large size in a mixture without using a microscope.

1. Look at the two given mixtures, if you see suspended particles by naked eye it will be a suspension and if you don't see any suspended particles it will be a true solution.
2. Allow the two solutions to stand for some time, if precipitation takes place, the container will contain a suspension, and the container in which no precipitation takes place will have solution.

Q2: Define solubility, what are the factors that affect the solubility of a substance?

Ans: Please see question number 6.

Q3: Classify colloids on the basis of their behaviour towards medium and the physical states of matter.

Ans: Please see question number 17.

Q4: Give the statement of Rault's law. Explain the lowering of vapour pressure of a solution based on this law.

Ans: Please see question number 10.

Q5: Explain the phenomenon of osmosis. (BISE Kohat 2018)

Ans: Please see question number 13.

Q6: Explain the phenomenon of depression of freezing point. How molecular mass of solute can be calculated on the basis of depression in freezing point?

Ans: Please see question number 12.

Q7: Explain the elevation of boiling point, how molecular mass of solute can be calculated on the basis of elevation of boiling point?

Ans: Please see question number 11.

