CHAPTER

1 SOLUTIONS

Syllabus

- *Types of solutions, expression of concentration of solutions of solids in liquids, solubility of gases in liquids, solid solutions, colligative properties - relative lowering of vapour pressure, Raoult's law, elevation of boiling point, depression of freezing point, osmotic pressure, determination of molecular masses using colligative properties, abnormal molecular mass, Van't Hoff factor.*

Chapter Analysis

List of Topics	2016		2017		2018
	D	OD	D	OD	D/OD
Definitions			1 Q. (2 marks)	1 Q. (5 marks)^	
Ideal and Non-ideal Solution				1 Q. (5 marks)^	
Henry's Law		1 Q. (3 marks)*			
Numerical related to Colligative Properties	1 Q. (5 marks)*	1 Q. (3 marks)	1 Q. (3 marks)	1 Q. (3 marks) 1 Q. (5 marks)^	1 Q. (2 marks)
Colligative Properties	1 Q. (5 marks)*	1 Q. (2 marks)#		1 Q. (2 marks)	
Give Reason					1 Q. (3 marks)

- ** One question of 5 marks with two choices was asked. Both the choices have one numerical of 3 marks related to Freezing Point and one question of 2 marks on Colligative Properties.*
- *# 2 marks question on Henry's Law and Colligative Properties was asked.*
- *^ One question of 5 marks with two choices was asked. First choice has one numerical of 3 marks on Vapour Pressure and one question of 2 marks on Ideal and Non-ideal Solutions. Second choice has one numerical of 3 marks on Freezing Point and one question of 2 marks on Definitions.*

On the basis of above analysis, it can be said that from exam point of view, definitions, Colligative properties and numerical on Colligative Properties are the most important topics of the chapter.

TOPIC-1

Types of Solutions, Expression of Concentration of Solutions and Solubility

Revision Notes

- **Solution :** A homogeneous mixture of two or more pure substances is known as solution.
- If the constituents of the solution are two, it is called binary, if three then ternary, if four then quaternary and so on.

- **Two constituents of the solution are :**
  - **(i) Solute :** A substance that is dissolved in another substance in lesser amount (a solvent), forming a solution. For example : Sugar, salt etc.
  - **(ii) Solvent :** A substance in which another substance is dissolved in larger amount forming a solution. For example : Water, milk etc.

  Note: *Solvent determines the physical state of the solution.*

- **Types of Solutions :** Any state of matter (solid, liquid, or gas) can act both as a solvent and as a solute during the formation of a solution. Therefore, depending upon the physical states of solute and solvent, we can have following nine different types of solutions :

S. No.	Types of Solution	Solute	Solvent	Examples
1.	Solid – Solid	Solid	Solid	Alloys like brass, bronze, etc.
2.	Solid – Liquid	Solid	Liquid	Solution of sugar, salt, urea etc. in water.
3.	Solid – Gas	Solid	Gas	Sublimation of substances like iodine, camphor etc, into air, dust or smoke particles in air.
4.	Liquid – Solid	Liquid	Solid	Hydrated salts, mercury in amalgamated zinc, etc.
5.	Liquid – Liquid	Liquid	Liquid	Alcohol in water, benzene in toluene.
6.	Liquid – Gas	Liquid	Gas	Aerosol, water vapour in air.
7.	Gas – Solid	Gas	Solid	Hydrogen absorbed in palladium.
8.	Gas – Liquid	Gas	Liquid	Aerated drinks.
9.	Gas – Gas	Gas	Gas	Mixture of gases etc.

- **Aqueous solution :** A solution containing water as solvent is known as aqueous solution. For example, sugar solution.
- **Non-aqueous solution :** A solution containing solvent other than water is known as non-aqueous solution. For example, iodine dissolved in alcohol.
- **Saturated solution :** A solution in which no more solute can be dissolved at the same temperature is known as saturated solution.
- **Unsaturated solution :** A solution in which more amount of solute can be dissolved at the same temperature is known as unsaturated solution.
- **Solubility :** Solubility can be defined as the maximum amount of solute that can be dissolved in 100 g solvent to form a saturated solution at a given temperature.
  - **Causes of Solubility :**
    - **(i) Inter ionic attraction in the solute molecules :** Molecules are stabilised in the lattice due to electrostatic forces and the energy released is known as lattice energy.
    - **(ii)** Inter molecular attraction between solvent molecules.
    - **(iii) Solvation :** It denotes the force of attraction between solute and solvent molecules.
    - **(iv)** Temperature.
  - **Deciding Factors for Solubility :**
    - **(i) Nature of Solute and Solvent :** "Like dissolve like" *i.e.*, polar solvents like water and ammonia can dissolve polar solute or ionic solute while non-polar solvents can dissolve non-polar organic solutes.
    - **(ii) Temperature :** Solubility increases with increase in temperature. It increases for endothermic reaction while it decreases for exothermic reaction.
    - **(iii) Pressure :** The solubility of solid in liquid is not affected significantly by pressure because solids and liquids cannot be compressed.
    - **(iv) Hydration Energy :** It is the amount of energy released when ions formed by 1 mole of ions get hydrated. It is an exothermic process.
- **Method of Expressing Concentration of Solution :** The concentration of solution is the amount of solute present in the given quantity of solute or solvent. It can be expressed in any of the following types :
  - **(i) Mass percentage** $\left(\frac{W}{w}\right)$ **:** It is the amount of solute in grams dissolved per 100 gm of solution.

$$\text{Mass\% of a solute} = \frac{\text{Mass of solute in the solution}}{\text{Total mass of the solution}} \times 100$$

(ii) Volume percentage $\left(\frac{V}{v}\right)$: It is defined as volume of a solute dissolved per 100 ml of solution.

$$\text{Volume\% of a solute} = \frac{\text{Volume of solute}}{\text{Total volume of the solution}} \times 100$$

(iii) Mass by volume percentage $\left(\frac{w}{v}\right)$: It is defined as mass of solute dissolved per 100 ml of solution. It is commonly used in medicine and pharmacy.

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

(iv) Parts per million (ppm) : It can be defined as the parts of a component per million (10^6) parts of the solution. It is used to express the concentration of a solute present in trace quantities.

$$\text{ppm (A)} = \frac{\text{Number of the parts of the component (A)}}{\text{Total number of parts of all the components of the solution}} \times 10^6$$

Parts per million can be expressed in three ways :

(a) Mass to mass

$$\text{ppm (mass to mass)} = \frac{\text{Mass of a component}}{\text{Total mass of solution}} \times 10^6$$

(b) Volume to volume

$$\text{ppm (volume to volume)} = \frac{\text{Volume of a component}}{\text{Total volume of solution}} \times 10^6$$

(c) Mass to volume

$$\text{ppm (mass to volume)} = \frac{\text{Mass of a component}}{\text{Volume of solution}} \times 10^6$$

(v) Mole Fraction : It is the ratio of number of moles of a particular component to the total number of moles of all the components. *e.g.*, mole fraction of component A.

$$\chi_A = \frac{n_A}{n_A + n_B},$$

where n_A is the number of moles of component 'A' and n_B is the number of moles of component 'B'.

Similarly,
$$\chi_B = \frac{n_B}{n_A + n_B}$$

Sum of mole fractions of all the components is always one.

$$\chi_A + \chi_B = 1$$

(vi) Molarity (M) : It is defined as the number of moles of solute per litre of solution.

$$\text{Molarity} = \frac{\text{Number of moles of solute}}{\text{Volume of solution (in Litre)}} \text{ or } M = \frac{n_B}{V} \text{ or } M = \frac{W_B \times 1000}{M_B \times V}$$

where n_B is number of moles of solute, W_B is weight of solute, V is volume of solution in ml, M_B is molar mass of solute. Unit is mol L^{-1} or M (molar)

(vii) Molality (m) : It is defined as the number of moles of solute per 1000 g or 1 kg of solvent.

$$\text{Molality} = \frac{\text{Number of moles of solute}}{\text{Mass of solvent in kg}} \text{ or } m = \frac{n}{W} \text{ or } m = \frac{W_B \times 1000}{W \times W_A}$$

where n is number of moles of solute, W_A is weight of solvent, W_B is quantity of solute, M_B is molar mass of solute. Molality and mole fraction do not change with change in temperature. Unit is mol kg^{-1} or molal (m).

(viii) Normality (N) : It is defined as number of gram equivalents of solute dissolved per litre of solution.

$$\text{Normality} = \frac{\text{Number of gram equivalent of solute}}{\text{Volume of solution in Litre}} \text{ or } N = \frac{W_B \times 1000}{E_B \times V}$$

where W_B is mass of solute, E_B is equivalent weight of solute, V is volume of solution in Litre.

- **Relationship between Molarity (M) and Molality (m) :**

$$\text{Molality } (m) = \frac{1000M}{M \times M_B - 1000d}$$

where m is molality, M is molarity, d is density of the solution and M_B is molar mass of solute.

- **Relationship between mole fraction of solute (χ_B) and molality (m) :**

$$\boxed{m = \frac{\chi_B \times 1000}{(1-\chi_B)\times M_A}}$$

where χ_B is mole fraction of solute, m is molality and M_A is molar mass of solvent.

- **Henry's Law :** The relationship between pressure and solubility is guided by Henry's Law. According to this law, "The mass of a gas dissolved in given volume of the liquid at a constant temperature depends upon the pressure applied."

  It can also be stated as the partial pressure of the gas in vapour phase (p) is proportional to the mole fraction of the gas (χ) in the solution.

$$p = K_H\chi,$$

where K_H = Henry's constant.

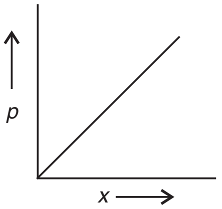


Fig. 1 : The slope of the line is the Henry's constant, K_H

- **Applications of Henry's law :**
  - **(i)** To increase the solubility of CO_2 in soda water and soft drinks, the bottle is sealed under high pressure.
  - **(ii)** To avoid the toxic effects of high concentration of nitrogen in blood, the tanks used by scuba divers are filled with air diluted with, He (11.7%), N_2 (56.2%) and oxygen (32.1%).
  - **(iii)** At high altitudes, low blood oxygen causes climber to become weak and make them unable to think clearly, which are symptoms of a condition known as anoxia.
- **Limitations of Henry's law :** This law is applicable only when :
  - **(i)** The pressure of gas is not too high and temperature is not too low.
  - **(ii)** The gas should not undergo any chemical change.
  - **(iii)** The gas should not undergo association or dissociation in the solution.

Know the Formulae

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

$$x_1 = \frac{n_1}{n_1+n_2},\ x_2 = \frac{n_2}{n_1+n_2}\quad (x_1+x_2=1)$$

- $$\text{Molarity (M)} = \frac{\text{Number of moles of solute}}{\text{Volume in solution in Litre}}$$
- $$\text{Molality } (m) = \frac{\text{Number of moles of solute}}{\text{Mass of solvent in kg}}$$
- $$\text{Normality (N)} = \frac{\text{Number of gram equivalent of solute}}{\text{Volume of solution in Litre}}$$
- $$\text{Mass percentage}\left(\frac{W}{w}\right) = \frac{\text{Mass of solute in the solution}}{\text{Total mass of the solution}}\times 100$$
- $$\text{Volume percentage}\left(\frac{V}{v}\right) = \frac{\text{Volume of solute}}{\text{Total volume of the solution}}\times 100$$

- $$\text{Mass by volume percentage}\left(\frac{W}{v}\right) = \frac{\text{Mass of solute}}{\text{Volume of solution}}\times 100$$
- $p = K_H.\, x$
  where K_H = Henry's law constant
  p = partial pressure of the gas in vapour phase
  x = mole fraction of the gas in the solution
- $$\text{ppm of component A} = \frac{\text{Mass of component A}}{\text{Total mass of solution}}\times 10^6$$
- $$m = \frac{M\times 1000}{1000\times d - M\times \text{Mol. wt. (solute)}}$$

Know the Terms

- **Homogeneous mixture :** A mixture in which composition and properties are uniform throughout.
- **Concentrated solution :** Solutions in which amount of solute is relatively large.
- **Dilute solution :** Solutions in which amount of solute is relatively very small.

Very Short Answer-Objective Type Questions (1 mark each)

A. Multiple Choice Questions:

Q. 1. Which of the following units is useful in relating concentration of solution with its vapour pressure?
(a) Mole fraction (b) Parts per million
(c) Mass percentage (d) Molality

U **[NCERT Exemp. Q. 1, Page 17]**

Ans. Correct option : (a)

Q. 2. The unit of ebullioscopic constant is ....
(a) K kg mol^{-1} or K (molality)$^{-1}$
(b) mol kg K^{-1} or K^{-1} (molality)
(c) kg mol^{-1} K^{-1} or K^{-1} (molality)$^{-1}$
(d) K mol kg^{-1} or K (molality)

R **[NCERT Exemp. Q. 10, Page 18]**

Ans. Correct option : (a)

Explanation : It is the unit of ebullioscopic constant (K).

k = K kg mol^{-1} or K (molality)$^{-1}$

Q. 3. Maximum amount of a solid solute that can be dissolved in a specified amount of a given liquid solvent does not depend upon ....
(a) temperature (b) nature of solute
(c) pressure (d) pressure of solvent

U **[NCERT Exemp. Q. 5, Page 18]**

Ans. Correct option : (c)

Explanation : The solubility of a solid in liquid does not depend up on pressure because solid is incompressible practically.

Q. 4. A beaker contains a solution of substance 'A'. Precipitation of substance 'A' takes place when small amount of 'A' is added to the solution. The solution is _________.
(a) saturated (b) supersaturated
(c) unsaturated (d) concentrated

A **[NCERT Exemp. Q. 14, Page 17]**

Ans. Correct option : (b)

Explanation : When a small amount of solute is added to its solution, it does not dissolve and gets precipitated then, this type of solution is called as supersaturated solution.

Q. 5. On dissolving sugar in water at room temperature solution feels cool to touch. Under which of the following cases dissolution of sugar will be most rapid?
(a) Sugar crystals in cold water
(b) Sugar crystals in hot water
(c) Powdered sugar in cold water
(d) Powdered sugar in hot water

A&E **[NCERT Exemp. Q. 2, Page 17]**

Ans. Correct option : (d)

Explanation : High temperature will favour dissolution. Powdered sugar has large surface area and hence, it is favourable for dissolution.

Q. 6. 4L of 0.02 M aqueous solution of NaCl was diluted by adding one litre of water. The molality of the resultant solution is ....
(a) 0.004 (b) 0.008
(c) 0.012 (d) 0.016

A **[NCERT Exemp. Q. 24, Page 21]**

Ans. Correct option : (d)

Explanation :

$$M = \frac{n}{V} = 0.02 = \frac{n}{4}$$

$$n = 0.08$$

$$m = \frac{n}{\text{Mass of water in kg}} = \frac{0.08}{5} = 0.016$$

B. Match the following :

Q. 1. Match the species given in Column I with those mentioned in Column II.

	Column I		**Column II**
(i)	**Saturated solution**	**(a)**	**Solution having same osmotic pressure at a given temperature as that of given solution.**
(ii)	**Binary solution**	**(b)**	**A solution whose osmotic pressure is less than that of another.**
(iii)	**Isotonic solution**	**(c)**	**Solution with two components.**
(iv)	**Hypotonic solution**	**(d)**	**A solution which contains maximum amount of solute that can be dissolved in a given amount of solvent at a given temperature.**
(v)	**Solid solution**	**(e)**	**A solution whose osmotic pressure is more than that of another.**
(vi)	**Hypertonic solution**	**(f)**	**A solution in solid phase.**

[NCERT Exemp. Q. 47, Page 25]

Ans.

	Column I		**Column II**
(i)	Saturated solution	**(d)**	A solution which contains maximum amount of solute that can be dissolved in a given amount of solvent at a given temperature.
(ii)	Binary solution	**(c)**	Solution with two components.
(iii)	Isotonic solution	**(a)**	Solution having same osmotic pressure at a given temperature as that of given solution.
(iv)	Hypotonic solution	**(b)**	A solution whose osmotic pressure is less than that of another.
(v)	Solid solution	**(f)**	A solution in solid phase.
(vi)	Hypertonic solution	**(e)**	A solution whose osmotic pressure is more than that of another.

C. Answer the following:

Q. 1. Define mole fraction.

R **[CBSE OD 2013; OD Delhi 2012]**

Ans. Mole fraction is the ratio of the number of moles of one component to the total number of moles in a mixture. **1**

Answering Tip

- As it is a 1 mark question, write only the definition.

Q. 2. State Henry's law about partial pressure of a gas in a mixture. R **[CBSE OD 2012]**

Ans. Henry's law states that the mass of a gas dissolved in given volume of the liquid at constant temperature depends upon the pressure applied. **1**

Short Answer Type Questions

(2 marks each)

Q. 1. Define the following terms :

(i) Mole fraction (*x*)

(ii) Molality of a solution (*m*)

R **[CBSE Comptt. OD 2015]**

Ans. (i) Mole fraction of a component =

$$\frac{\text{Number of moles of the component}}{\text{Total number of moles of all the components}} \quad 1$$

(ii) Molality (m) is defined as the number of moles of the solute per kilogram (kg) of the solvent.

OR

$$\text{Molality } (m) = \frac{\text{Moles of solute}}{\text{Mass of solvent in kg}} \quad 1$$

[CBSE Marking Scheme 2015]

AI Q. 2. Calculate the molality of ethanol solution in which the mole fraction of water is 0.88.

A **[CBSE SQP 2018-19]**

Ans. Mole fraction of water, $X_{H_2O} = 0.88$

Mole fraction of ethanol, $X_{C_2H_5OH} = 1 - 0.88 = 0.12$ ½

$$X_{C_2H_5OH} = \frac{n_2}{n_1 + n_2} \quad ...(1)$$

n_2 = number of moles of ethanol.

n_1 = number of moles of water.

Molality of ethanol means the number of moles of ethanol present in 1000 g of water.

$$n_1 = \frac{1000}{18} = 55.5 \text{ moles} \quad ½$$

Substituting the value of n_1 in equation (1)

$$\frac{n_2}{55.5 + n_2} = 0.12 \quad ½$$

$$n_2 = 7.57 \text{ moles} \quad ½$$

Molality of ethanol (C_2H_5OH) = 7.57 m

Alternatively,

Mole fraction of water = 0.88 ½

Mole fraction of ethanol = 1-0.88 = 0.12 ½

Therefore 0.12 moles of ethanol are present in 0.88 moles of water.

Mass of water = 0.88 x 18 =15.84 g of water. ½

Molality = number of moles of solute (ethanol) present in 1000 g of solvent (water)

$= 12 \times 1000 / 15.84$

$= 7.57$ m ½

Molality of ethanol (C_2H_5OH) = 7.57 m

[CBSE Marking Scheme 2018]

Commonly Made Error

- Students get confused between the terms molarity and molality.

Answering Tip

- Students should remember that molarity is volume based concept and molality is mass based concept.

Q. 3. State Henry's law. What is the effect of temperature on the solubility of a gas in a liquid ?

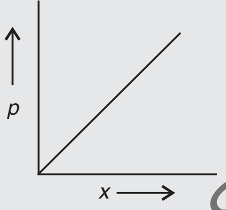
R + U **[CBSE Delhi 2014]**

Ans. The relationship between pressure and solubility is guided by Henry's law. According to this law, "The mass of a gas dissolved in given volume of the liquid at a constant temperature depends upon the pressure which is applied."

It can also be stated as the partial pressure of the gas in vapour phase (p) is proportional to the mole fraction of the gas (χ) in the solution.

$$p = K_H\chi,$$

where K_H = Henry's constant.



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Effect of Temperature on the Solubility : The solubility of a gas decreases with increase in temperature. This is because dissolution of gases in the liquids is an exothermic process. Therefore, according to Le-Chatelier's principle, the increase in temperature results in decrease in the solubility of the gas. **[CBSE Marking Scheme 2014] 1**

AI Q. 4. State Henry's law and mention two of its important applications.

R + U **[CBSE Comptt. OD 2012]**

Ans. Henry's law : Refer Topic 1 Q. 3. of S.A.T.Q. **1**

Applications of Henry's Law :

(i) To increase the solubility of CO_2 in soda water and soft drinks, the bottle is sealed under high pressure.

(ii) At high altitude, low blood oxygen causes climber to become weak and make them unable to think clearly, which are symptoms of a condition known as anoxia. **1**

Answering Tips

- Carefully note units of Henry's constant in numericals.

Q. 5. Explain the solubility rule "like dissolves like" in terms of intermolecular forces that exist in solutions. C **[NCERT Exemp. Q 38, Page 24]**

Ans. A substance (solute) dissolves in a solvent if the intermolecular interactions are similar in both components. For example : polar solutes dissolve in polar solvents and non-polar solutes in non-polar solvents thus we can say "like dissolves like". **2**

Long Answer Type Questions-I

(3 marks each)

Q. 1. The partial pressure of ethane over a saturated solution containing 6.56×10^{-2} g of ethane is 1 bar. If the solution were to contain 5.0×10^{-2} g of ethane, then what will be the partial pressure of the gas ? A **[CBSE Comptt. Delhi 2013]**

Ans. According to Henry's law,

$$m = K_H p$$

$$\Rightarrow \quad K_H = \frac{m}{p} = \frac{6.56\times10^{-2}\,(\text{g})}{1\,(\text{bar})} \quad 1$$

$$= 6.56 \times 10^{-2}\ \text{g bar}^{-1} \quad ½$$

In the second case,

$$p = \frac{m}{K_H}$$

$$= \frac{5.0\times10^{-2}\,(\text{g})}{6.56\times10^{-2}\left(\text{g bar}^{-1}\right)} \quad 1$$

$$= 0.762\ \text{bar} \quad ½$$

Answering Tip

- Write each step while solving a numerical. Always mention appropriate units.

Q. 2. Calculate the mole fraction of benzene in solution containing 30% by mass in carbon tetrachloride. A **[NCERT]**

Ans. Let the total mass of the solution be 100 g and the mass of benzene be 30 g.

$\therefore$ Mass of carbon tetrachloride

$= (100 - 30)$ g $= 70$ g [½]

Molar mass of benzene (C_6H_6) $= (6 \times 12 + 6 \times 1)$ g mol^{-1}

$= 78$ g mol^{-1}

$\therefore$ Number of moles of $C_6H_6 = \frac{30}{78}$ mol [1]

$= 0.3846$ mol

Molar mass of carbon tetrachloride (CCl_4)

$= 1 \times 12 + 4 \times 35.5 = 154$ g mol^{-1}

$\therefore$ Number of moles of $CCl_4 = \frac{70}{154}$ mol

$= 0.4545$ mol [1]

Thus, the mole fraction of C_6H_6 is given as :

$$\frac{\text{Number of moles of } C_6H_6}{\text{Number of moles of } C_6H_6 + \text{Number of moles of } CCl_4}$$

$$= \frac{0.3846}{0.3846 + 0.4545}$$

$= 0.458$ [½]

TOPIC-2

Vapour Pressure, Raoult's Law, Ideal and Non-ideal Solutions

Revision Notes

- Vapour pressure is the pressure exerted by vapours over a liquid at equilibrium state at constant temperature.
- **Vapour pressure depends on the following factors :**
  (i) Nature of the liquid.
  (ii) Temperature : Vapour pressure of a liquid increases with increase in temperature.
- **Raoult's law for a solution of volatile liquids :** It states that for a solution of volatile liquids, the partial vapour pressure of each component of the solution is directly proportional to its mole fraction in solution.

  Suppose a solution is prepared by mixing two volatile liquids A and B. Let χ_A and χ_B respectively be their mole fractions, and let p_A and p_B be their partial vapour pressures respectively in the solution at a particular temperature. If $p_A{}^0$ and $p_B{}^0$ are respectively their vapour pressures in the pure state, then according to Raoult's law:

  $$p_A = p_A{}^0\,\chi_A$$
  $$p_B = p_B{}^0\,\chi_B$$

  Considering Dalton's law of partial pressure,

  $$p_{total} = p_A + p_B$$

  Substituting values of p_A and p_B,

  $$\begin{aligned} p_{total} &= \chi_A p_A{}^0 + \chi_B p_B{}^0 \\ &= (1-\chi_B)\,p_A{}^0 + \chi_B\,p_B{}^0 \\ &= p_A{}^0 + (p_B{}^0 - p_A{}^0)\chi_B \end{aligned}$$

  The composition of the vapour phase in equilibrium with the solution can be determined from the partial pressure of the two components. If Υ_A and Υ_B are the mole fractions of components A and B respectively in the vapour phase, then

  $$p_A = \gamma_A p_{total}$$

  and
  $$p_B = \gamma_B p_{total}$$

  In general $p_i = \gamma_i\, p_{total}$
- **Raoult's law as a special case of Henry's law :** According to Raoult's law, the vapour pressure of volatile component (A) in a given solution is given as :

  $$p_A = p_A{}^0\chi_A$$

  According to Henry's law, in the solution of a gas in a liquid, the gaseous component is normally so volatile that it exists as a gas and solubility depends upon Henry's law to which :

  $$p_A = K_H\chi_A$$

  On comparing both expressions $p_A{}^0$ is equal to K_H.
- **Raoult's law for non-volatile solute :** For a solution containing non-volatile solute present in a volatile solvent, Raoult's law may be stated as the relative lowering of vapour pressure for a solution is equal to the mole fraction of solute.

  $$\chi_B = \frac{p_A^0 - p_A}{p_A^0},$$

  where, χ_B = mole fraction of solute,
  $p_A{}^0 - p_A$ = relative lowering of vapour pressure.
- **Ideal solution :** A solution is called an ideal solution if it obeys Raoult's law over a wide range of concentration at specific temperature.
  (i) Raoult's law is obeyed. $p_A = p_A{}^0\chi_A,\ p_B = p_B{}^0\chi_B$
  (ii) $\Delta_{mix}H = 0$,
  (iii) $\Delta_{mix}V = 0$,
  (iv) The force of attraction between A-A and B-B is nearly equal to A-B.

  Some examples of ideal solutions are :
  (i) *n*-hexane and *n*-heptane,
  (ii) Ethyl bromide and ethyl chloride,
  (iii) Benzene and toluene,
  (iv) Chlorobenzene and bromobenzene.
- **Non-ideal solutions :** A solution which does not obey Raoult's law for all the concentrations is called a non-ideal solution.

(i) Raoult's law is not obeyed, *i.e.*, $p_A \neq p_A^0 \chi_A$ and $p_B \neq p_B^0 \chi_B$

(ii) $\Delta_{mix}H \neq 0$,

(iii) $\Delta_{mix}V \neq 0$,

(iv) The force of attraction between A-A and B-B is not equal to A-B.

Some examples of non-ideal solutions are :

(i) Water and ethanol (ii) Chloroform and acetone

(iii) Ethanol and cyclohexane

A non-ideal solution can show either positive or negative deviation from Raoult's law.

- **Positive deviation from Raoult's law :** In this type of deviation, A-B interactions are weaker than the interaction between A-A or B-B and leads to increase in vapour pressure.

  Some examples are :

  (i) Water and ethanol, (ii) Chloroform and water,

  (iii) Ethanol and CCl_4, (iv) Methanol and chloroform,

  (v) Benzene and methanol, (vi) Acetic acid and toluene.

- **Negative deviation from Raoult's law :** In this type of deviation in non-ideal solutions, the intermolecular attractive forces between A-A and B-B are weaker than those between A-B and leads to decrease in vapour pressure.

  Some examples are :

  (i) Chloroform and acetone, (ii) Chloroform and methyl acetate,

  (iii) H_2O and HCl, (iv) H_2O and HNO_3,

  (v) Acetic acid and pyridine, (vi) Chloroform and benzene.

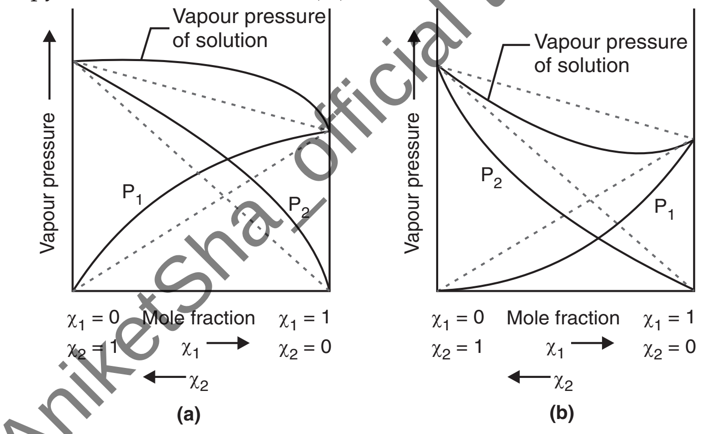


Fig. 2 : The vapour pressures of two component systems as a function of composition :
(a) A solution that shows positive deviation from Raoult's law, and
(b) A solution that shows negative deviation from Raoult's law.

- **Azeotropes :** Liquid mixtures which distil over without change in composition are called constant boiling mixtures or azeotropes or azeotropic mixtures.
- **Minimum boiling azeotropes :** Non-ideal solutions showing large positive deviation from Raoult's law form minimum boiling azeotropes, at a specific composition. *e.g,* water and benzene, chloroform and methanol.
- **Maximum boiling azeotropes :** Non-ideal solutions showing large negative deviation from Raoult's law form maximum boiling azeotropes which boil at temperature higher than the boiling points of its components. *e.g.* mixture of HNO_3 and H_2O.

Know the Formulae

- Raoult's law for a solution of volatile solute in volatile solvent:

$$p_A = p_A^0 \chi_A$$
$$p_B = p_B^0 \chi_B$$

- Raoult's law for a solution of non-volatile solute and volatile solvent:

$$\frac{p_A^o - p_A}{p_A^o} = i\chi_B = i\frac{n_B}{n_A} = i\frac{W_B \times M_A}{W_A \times M_B} \text{ (for dilute solution)}$$

Know the Terms

- **Boiling point :** The temperature at which the vapour pressure of solution becomes equal to the atmospheric pressure.
- **Dalton's Law of Partial Pressure :** When two or more volatile compounds are enclosed in a vessel, the total pressure is equal to the sum of partial pressure of each component.

$$p_{\text{total}} = p_A + p_B$$

Very Short Answer-Objective Type Questions (1 marks each)

A. Multiple choice Questions:

Q. 1. Considering the formation, breaking and strength of hydrogen bond, predict which of the following mixtures will show a positive deviation from Raoult's law?

(a) Methanol and acetone.

(b) Chloroform and acetone.

(c) Nitric acid and water.

(d) Phenol and aniline.

C **[NCERT Exemp. Q. 7, Page 18]**

Ans. Correct option : (a)

Explanation : Mixture of methanol and acetone exhibits positive deviation because methanol-methanol and acetone-acetone interaction is more than methanol-acetone. The more number of hydrogen bonds are broken, the less number of new hydrogen bonds are formed.

Q. 2. On the basis of information given below mark the correct option. Information:

(A) In bromoethane and chloroethane mixture intermolecular interactions of A–A and B–B type are nearly same as A–B type interactions.

(B) In ethanol and acetone mixture A–A or B–B type intermolecular interactions are stronger than A–B type interactions.

(C) In chloroform and acetone mixture A–A or B–B type intermolecular interactions are weaker than A–B type interactions.

(a) Solution (B) and (C) will follow Raoult's law.

(b) Solution (A) will follow Raoult's law.

(c) Solution (B) will show negative deviation from Raoult's law.

(d) Solution (C) will show positive deviation from Raoult's law.

A&E **[NCERT Exemp. Q. 21, Page 21]**

Ans. Correct option : (b)

Explanation : Solution A will follow Raoult's law solution due to nearly same interactions between A-A, B-B, and A-B. The solution formed will be nearly ideal.

B. Match the following :

Q. 1. Match the species given in Column I with those mentioned in Column II.

Column I	Column II
(i) Raoult's law	(a) Ideal solution
(ii) Nitric acid-water	(b) Non-ideal solution
(iii) Obeys Raoult's law	(c) $p = K_H x$
(iv) Ethanol-water	(d) Maximum boiling azeotrope
(v) Does not obey Raoult's law	(e) Minimum boiling azeotrope

Ans. (i) → (c), (ii) → (d), (iii) → (a), (iv) → (e), (v) → (b).

Explanation:

(i) Raoult's law states that for any solution the partial vapour pressure of each volatile component in the solution is directly proportional to its mole fraction.

(ii) The solutions that show large negative deviation from Raoult's law form maximum boiling azeotrope at a specific composition. Nitric acid and water is an example of maximum boiling azeotrope.

(iii) The solutions which obey Raoult's law over the entire range of concentrations are called as ideal solutions.

(iv) The solutions which show a large positive deviation from Raoult's law form minimum boiling azeotrope at a specific composition. Ethanol-water mixture also show a large positive deviation.

(v) The solutions which does not obey Raoult's law over the entire range of concentrations are called as ideal solutions.

C. Answer the following:

Q. 1. Define an ideal solution. R **[CBSE OD 2013, 2012]**

Ans. Solutions which obey Raoult's law over the entire range of concentration at specific temperature. **1**

Q. 2. Some liquids on mixing form 'azeotropes'. What are 'azeotropes' ? U **[CBSE Delhi 2014]**

Ans. **Azeotropes :** Binary mixtures having same composition in liquid and vapour phase and boil at a constant temperature. **[CBSE Marking Scheme 2014] 1**

Q. 3. What type of intermolecular attractive interaction exists in the pair of methanol and acetone ? U **[CBSE Delhi 2014]**

Ans. Hydrogen bonding. **[CBSE Marking Scheme 2014] 1**

Short Answer Type Questions

(2 marks each)

Q. 1. State Raoult's law for a solution containing non-volatile solute. What type of deviation from Raoult's law is shown by a solution of chloroform and acetone and why?

R + U **[CBSE Foreign Set-2 2017]**

Ans. The relative lowering of vapour pressure of a solution is equal to the mole fraction of the solute./ The vapour pressure of a solution of a non-volatile solute is equal to the vapour pressure of the pure solvent at that temperature multiplied by its mole fraction. **1**

Negative deviation due to formation of Hydrogen bond between chloroform and acetone. ½ + ½

[CBSE Marking Scheme 2017]

Commonly Made Error

- Students often re-frame the statement or write only the mathematical expression. Write the law as stated.

Answering Tip

- Read the question carefully. Do not forget to answer the sub-parts.

Q. 2. State Raoult's law for the solution containing volatile components. What is the similarity between Raoult's law and Henry's law ?

R + U **[CBSE Delhi 2014]**

Ans. According to Raoult's law for the solution containing volatile components, the partial vapour pressure of each component is directly proportional to its mole fraction.

In both case, $p \propto \chi$ / Henry's law is a special case of Raoult's law. **[CBSE Marking Scheme 2014] 2**

Q. 3. State Raoult's law. How is it formulated for solutions of non-volatile solutes ?

R + U **[CBSE Comptt. Delhi 2012]**

OR

Derive expression for Raoult's law when the solute is non-volatile. R **[CBSE Comptt. Delhi 2013]**

Ans. Raoult's law for solution of non-volatile solution : The relative lowering of vapour pressure for a solution is equal to the mole fraction of solute when solvent alone is volatile.

$$\frac{p_A^\circ - p_A}{p_A^\circ} = \chi_B$$

where, $p_A^\circ \rightarrow$ Vapour pressure of pure component 'A'.

$p_A \rightarrow$ Partial vapour pressure of component 'A'

$\chi_B \rightarrow$ Mole fraction of solute

$p_A^\circ - p_A \rightarrow$ Lowering of vapour pressure

$\frac{p_A^\circ - p_A}{p_A^\circ} \rightarrow$ Relative lowering of vapour pressure. **2**

Q. 4. Define an ideal solution and write one of its characteristics. R + U **[CBSE Delhi 2014]**

Ans. Solution which obey Raoult's law over the entire range of concentration at specific temperature is known as an ideal solution.

Characteristics : **1**

(i) $\Delta H_{mix} = 0$

(ii) $\Delta V_{mix} = 0$ **(Any one)1**

[CBSE Marking Scheme 2014]

Answering Tip

- Read the question carefully before answering. Be specific.

Q. 5. What is meant by positive deviations from Raoult's law ? Give an example. What is the sign of $\Delta_{mix}H$ for positive deviation ?

OR

Define azeotropes. What type of azeotrope is formed by positive deviation from Raoult's law ? Give an example. R **[CBSE Delhi 2015]**

Ans. In case of positive deviation from Raoult's law, the intermolecular attractive forces between the solute-solvent molecules are weaker than those between the solute-solute and solvent-solvent molecules.

Example: Mixture of ethanol and acetone.

Sign for $\Delta_{mix}H$ is positive **1+½+½**

OR

Azeotropes—A liquid mixture which distills at constant temperature without undergoing any change in composition is called azeotropes. **1**

Minimum boiling azeotropes is formed by positive deviation from Raoult's law. ½

Example : (i) Water and benzene

(ii) Chloroform and methanol ½

Q. 6. Why a mixture of Carbon disulphide and acetone shows positive deviation from Raoult's law? What type of azeotrope is formed by this mixture?

A&E **[CBSE Comptt. Delhi/OD 2018]**

Ans. Intermolecular forces of attraction between carbon disulphide and acetone are weaker than the pure components. **1**

Minimum boiling azeotrope at a specific composition. **1**

[CBSE Marking Scheme 2018]

Detailed Answer:

When carbon disulphide is added to the acetone, the dipolar interaction between molecule of solute solvent (A – B) than the respective interaction between solute-solute (A – B) and solvent – solvent (B – B) weakens, which leads to increase in vapour pressure. Hence, shows positive deviation in vapour pressure from Raoult's Law. **1**

Minimum boiling azeotrope at a specific composition is formed by this mixture. **1**

Q. 7. (i) Gas (A) is more soluble in water than Gas (B) at the same temperature. Which one of the two gases will have the higher value of K_H (Henry's constant) and why ?

(ii) In non-ideal solution, what type of deviation shows the formation of maximum boiling azeotropes ?

A&E [CBSE OD 2016]

Ans. (i) Gas B will have the higher value of K_H (Henry's constant) as lower is the solubility of the gas in the liquid higher is the value of K_H. 1

(ii) In non-ideal solution, negative deviation shows the formation of maximum boiling azeotropes. **1**

[CBSE Marking Scheme 2016]

Q. 8. Explain why on addition of 1 mol of NaCl to 1 litre of water, the boiling point of water increases, while addition of 1 mol of methyl alcohol to one litre of water decreases its boiling point.

A&E [NCERT Exemp. Q 37, Page 24]

Ans. Sodium Chloride (NaCl) is a non-volatile solute, therefore, addition of NaCl to water lowers the vapour pressure of water. As a result, boiling point of water increases. Methyl alcohol on the other hand is more volatile than water, hence, its addition increases, the total vapour pressure over the solution and a decrease in boiling point of water results. **2**

Long Answer Type Questions-I

(3 marks each)

Q 1. Components of a binary mixture of two liquids A and B were being separated by distillation. After sometimes separation of components stopped and composition of vapour phase became same as that of liquid phase. Both the components started coming in the distillate. Explain why this happened. A&E [NCERT Exemp. Q. 36, Page 24]

Ans. Both components are appearing in the distillate and composition of liquid and vapour is same, this shows that liquids have formed azeotropic mixture. Therefore, it cannot be separated at this stage by distillation.

Azeotropes are binary mixtures having the same composition in fluid, vapour phase and boils at a constant temperature. The components of azeotropic mixtures are separated by fractional distillation. **3**

AI Q. 2. The vapour pressure of pure liquids A and B at 400 K are 450 and 700 mm Hg respectively. Find out the composition of liquid mixture if total pressure at this temperature is 600 mm Hg.

A [CBSE Comptt. Delhi 2017]

Ans. $p_{\text{total}} = p_1{}^o + (p_2{}^o - p_1{}^o)x_2$ **1**

$600 = 450 + (700 - 450)\, x_2$ **1**

$x_2 = 0.6$ **½**

$x_2 = 1 - 0.6 = 0.4$ **½**

[CBSE Marking Scheme 2017]

OR

Detailed Answer:

$p_A{}^0 = 450$ mm Hg, $p^0{}_B = 450$ mm Hg

$p_{\text{Total}} = 600$ mm Hg

According to Raoult's law,

$$p_A = \chi_A \times p_A{}^0$$
$$p_B = \chi_B \times p_B{}^0$$
$$p_{\text{Total}} = p_A + p_B$$
$$= (1 - \chi_B)\, p_A{}^{\mathbf{0}} + \chi_B\, p_B{}^{\mathbf{0}} = p_A{}^{\mathbf{0}} + (p_B{}^0 - p_A{}^0)\, \chi_B$$
$$600 = 450 + (700 - 450)\chi_B$$
$$600 - 450 = 250\chi_B$$
$$150 = 250\chi_B$$
$$\chi_B = \frac{150}{250} = 0.6 \Rightarrow \chi_A = 1 - 0.6 = 0.4$$ **3**

Q. 3. Using Raoult's law explain how the total vapour pressure over the solution is related to mole fraction of components in the following solutions.

(a) $CHCl_3(l)$ and $CH_2Cl_2(l)$

(b) NaCl(s) and $H_2O(l)$

C [NCERT Exemp. Q. 56, Page 27]

Ans. (a) $p = p^0_A x_A + p^0_B x_B$; Where p^0_A , p^0_B are the vapour pressure of pure components (A) and (B) while x_A and x_B are the mole fractions of the components in the solution. **1½**

(b) NaCl(s) is a non-volatile solute. When it is dissolved in water, the vapour pressure is lowered. Vapour pressure of solution can be calculated using the following relations :

$p = p^0 x_a$

Where, x_a = mole fraction of solvent **(i)**

p^0 = vapour pressure of pure solvent

p = vapour pressure of solution

Similarly,

$$\frac{\Delta p}{p^0} = x_b$$

$\Delta p = (p^0 - p)$ x_b = mole fraction of solute **(ii) 1½**

Long Answer Type Questions-II

(5 marks each)

Q. 1. (a) 30 g of urea (M = 60 g mol^{-1}) is dissolved in 846 g of water. Calculate the vapour pressure of water for this solution if vapour pressure of pure water at 298 K is 23.8 mm Hg.

(b) Write two differences between ideal solutions and non-ideal solutions.

A + U [CBSE OD Set-1, 2, 3 2017]

Ans. (a) $(P_A^0 - P_A)/P_A^0 = (w_B \times M_A)/(M_B \times w_A)$ ½

$$\frac{23.8 - P_A}{23.8} = (30 \times 18)/60 \times 846$$ 1

$23.8 - P_A = 23.8 \times [(30 \times 18)/60 \times 846]$ ½

$23.8 - P_A = 0.2532$

$P_A = 23.55\ mm\ Hg$ 1

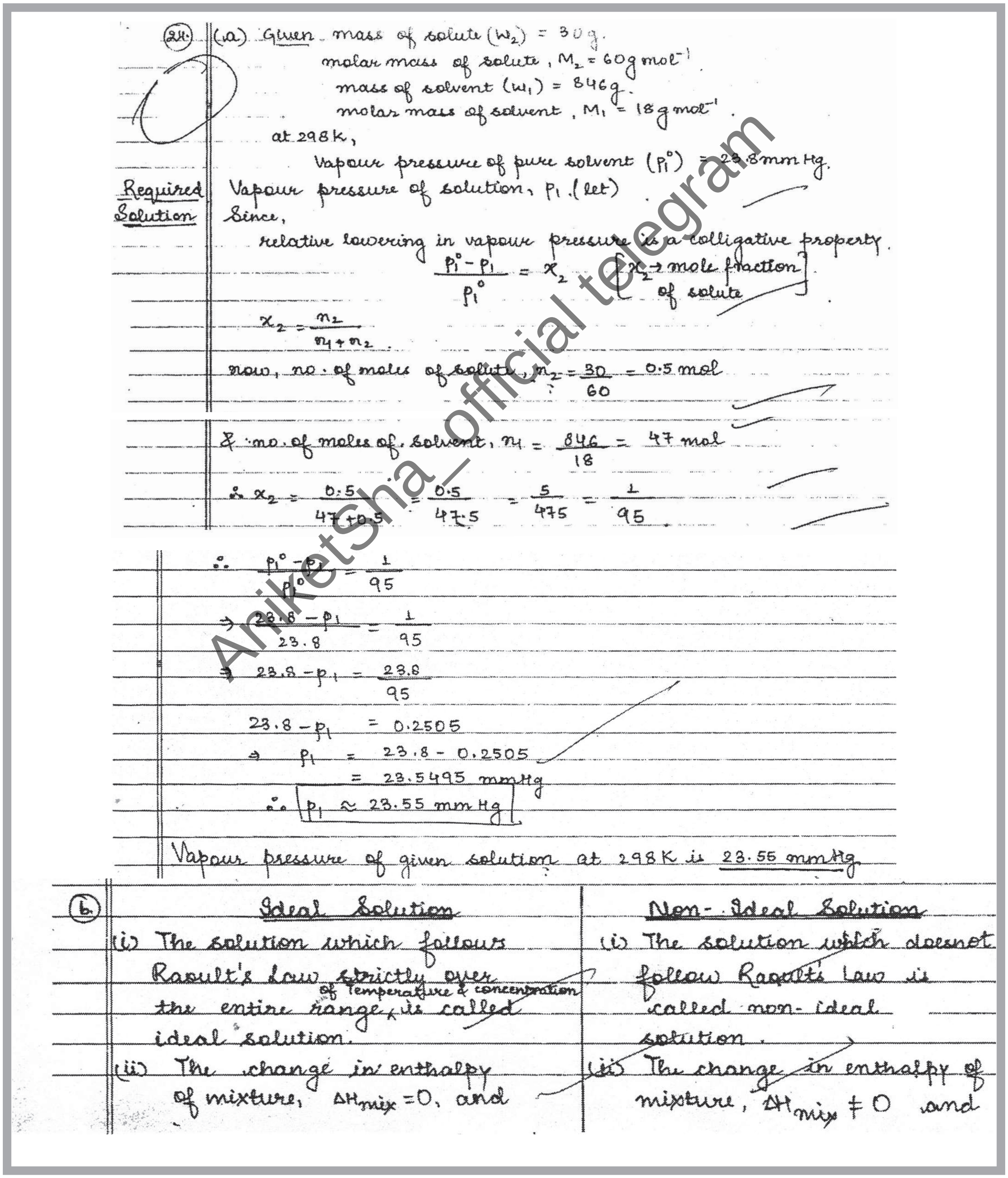
(b)

Ideal solution	Non-ideal solution
(a) It obeys Raoult's law over the entire range of concentration.	**(a)** Does not obey Raoult's law over the entire range of concentration.
(b) $\Delta_{mix} H = 0$	**(b)** $\Delta_{mix} H$ is not equal to 0.
(c) $\Delta_{mix} V = 0$	(c) $\Delta_{mix} V$ is not equal to 0.

(any two correct difference) **1+1**

[CBSE Marking Scheme 2017]

OR



㉔ (a) Given mass of solute (w_2) = 30 g.
molar mass of solute, $M_2 = 60 g mol^{-1}$.
mass of solvent (w_1) = 846 g.
molar mass of solvent, $M_1 = 18 g mol^{-1}$.
at 298 K,
Vapour pressure of pure solvent (p_1°) = 23.8 mm Hg.

Required Solution

Vapour pressure of solution, p_1 (let).
Since,
relative lowering in vapour pressure is a colligative property.

$$\frac{p_1^\circ - p_1}{p_1^\circ} = x_2 \quad \left[\begin{array}{l} x_2 \to \text{mole fraction} \\ \text{of solute} \end{array}\right].$$

$$x_2 = \frac{n_2}{n_1 + n_2}.$$

now, no. of moles of solute, $n_2 = \frac{30}{60} = 0.5$ mol

& no. of moles of solvent, $n_1 = \frac{846}{18} = 47$ mol

$$\therefore x_2 = \frac{0.5}{47 + 0.5} = \frac{0.5}{47.5} = \frac{5}{475} = \frac{1}{95}.$$

$$\therefore \frac{p_1^\circ - p_1}{p_1^\circ} = \frac{1}{95}$$

$$\Rightarrow \frac{23.8 - p_1}{23.8} = \frac{1}{95}$$

$$\Rightarrow 23.8 - p_1 = \frac{23.8}{95}$$

$$23.8 - p_1 = 0.2505$$

$$\Rightarrow p_1 = 23.8 - 0.2505$$

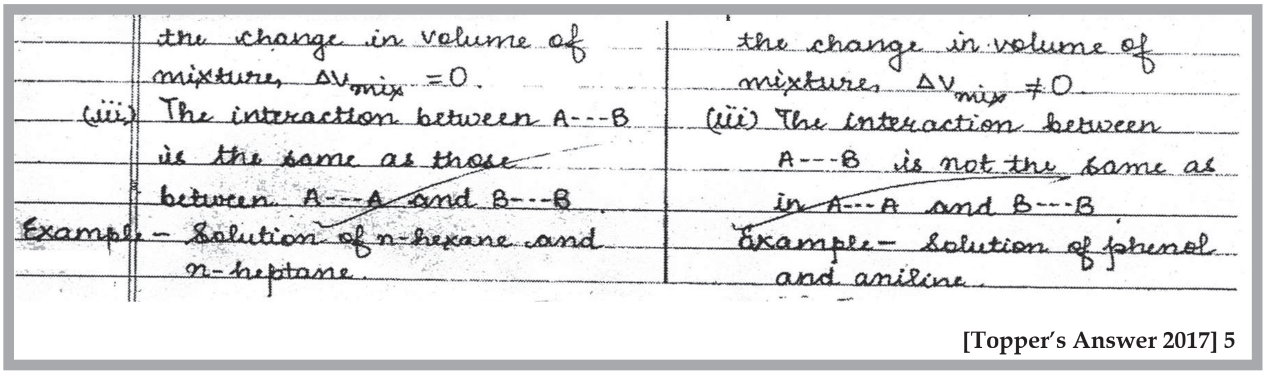
$$= 23.5495 \text{ mmHg}$$

$$\therefore \boxed{p_1 \approx 23.55 \text{ mm Hg}}$$

Vapour pressure of given solution at 298 K is 23.55 mmHg.

ⓑ

Ideal Solution	Non-Ideal Solution
(i) The solution which follows Raoult's law strictly over the entire range of temperature & concentration is called ideal solution.	(i) The solution which doesnot follow Raoult's law is called non-ideal solution.
(ii) The change in enthalpy of mixture, $\Delta H_{mix} = 0$, and	(ii) The change in enthalpy of mixture, $\Delta H_{mix} \neq 0$ and



the change in volume of mixture, $\Delta V_{mix} = 0$.	the change in volume of mixture, $\Delta V_{mix} \neq 0$.
(iii) The interaction between A---B is the same as those between A---A and B---B.	(iii) The interaction between A---B is not the same as in A---A and B---B.
Example – Solution of n-hexane and n-heptane.	Example– Solution of phenol and aniline.

[Topper's Answer 2017] 5

TOPIC-3

Colligative Properties, Determination of Molecular Mass, Abnormal Molecular Mass, Van't Hoff Factor

Revision Notes

- **Colligative properties :** Certain properties of solutions depend only on the number of particles of the solute (molecule or ions) and do not depend on the nature of solute, such properties are called colligative properties. These are :
  - **(i)** Relative lowering of vapour pressure,
  - **(ii)** Depression in freezing point,
  - **(iii)** Elevation of boiling point,
  - **(iv)** Osmotic pressure of the solution.
- **Relative lowering of vapour pressure :** The relative lowering of vapour pressure is the ratio of lowering of vapour pressure and vapour pressure of pure solvent which is equal to the mole fraction of solute.

  Vapour pressure of pure solvent → $p_A{}^\circ$

  Lowering of vapour pressure → $p_A{}^\circ - p_A$

  Relative lowering of vapour pressure

  $$\frac{p_A{}^\circ - p_A}{p_A{}^\circ} = \chi_{\text{solute}} = \frac{n}{N+n}$$

  where n and N are the number of moles of solute and solvent respectively.
- **Elevation of the boiling point :** The difference in boiling point of solution and pure solvent is called elevation of the boiling point.

  Boiling point of pure solvent → $T_b{}^0$

  Boiling point of solution → T_b

  Increase in boiling point $\Delta T_b = T_b - T_b{}^0$ is known as elevation of boiling point for dilute solution.

  $$\Delta T_b \propto \frac{\Delta p}{p^\circ} = x_B$$

  $$\Delta T_b = K\chi_B$$

  $$\Delta T_b = K \times \frac{W_B}{M_B} \times \frac{M_A}{W_A}$$

  $$\Delta T_b = K_b m$$

  K_b → Boiling point elevation constant or molal elevation constant or Ebullioscopic constant.

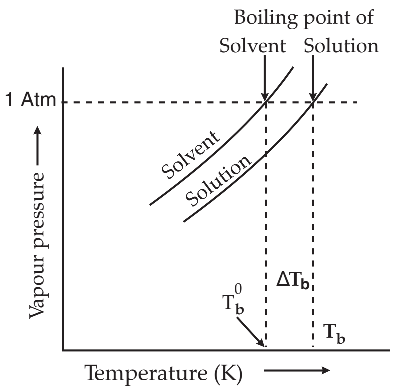


Fig. 3 : The vapour pressure curve for solution lies below the curve for pure water. The diagram shows that ΔT_b denotes the elevation of boiling point of a solvent in solution.

- **Depression of freezing point :** According to Raoult's law, when a non-volatile solid is added to the solvent its vapour pressure decreases and it would become equal to that of solid solvent at lower temperature. Thus, the difference in the freezing point of pure solvent and that of the solution is known as depression in freezing point.

  The freezing point of pure solvent → T_f^0
  The freezing point when non-volatile solute is dissolved in it → T_f (Freezing point of solution)
  The decrease in freezing point $\Delta T_f = T_f^0 - T_f$ is known as depression in freezing point.
  For dilute solutions,

$$\Delta T_f = K\chi_B$$

$$\Delta T_f = K\frac{W_B}{M_B} \times \frac{M_A}{W_A}$$

$$\Delta T_f = K_f m.$$

We know

(i) $$\frac{W_B \times 1000}{M_B \times W_A} = \text{molality}$$

(ii) $$K \times M_A = K_f$$

K_f = Freezing point depression constant or molal depression constant or Cryoscopic constant.

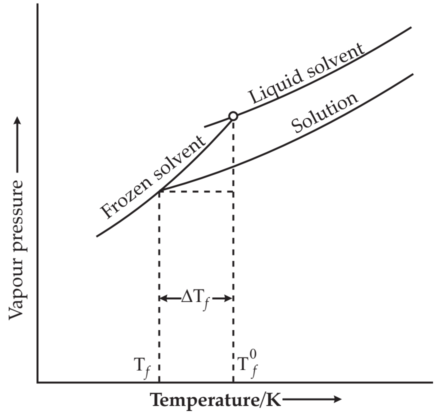


Fig. 4 : Diagram showing ΔT_f, depression of the freezing point of a solvent in a solution.

- **Osmosis :** The process in which there is net flow of solvent to the solution by a semipermeable membrane is called osmosis.
- **Osmotic pressure :** The extra pressure that is applied to stop the flow of solvent to solution across a semipermeable membrane is called osmotic pressure of the solution.

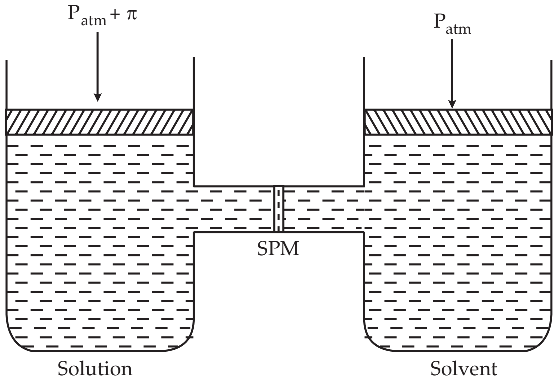


Fig. 5 : The excess pressure equal to the osmotic pressure must be applied on the solution side to prevent osmosis.

For dilute solutions, osmotic pressure is proportional to the molar concentration (C) of the solution at a given temperature T.

Thus π = CRT as π is the osmotic pressure and R is the gas constant.

$\pi = \frac{n}{VRT}$ (n is the number of moles, V is the volume of solution)

- **Reverse osmosis :** The direction of osmosis can be reversed, if a pressure larger than the osmotic pressure is applied to the solution side. Now the pure solvent flows out of the solution through the semipermeable membrane. This phenomenon is called reverse osmosis.

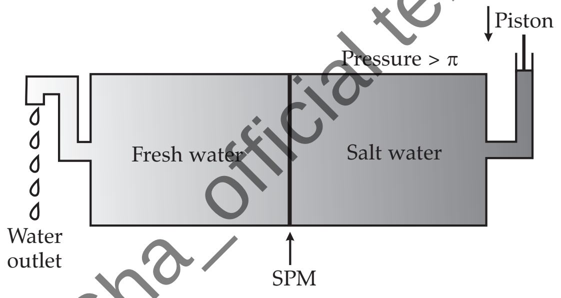


Fig. 6 : Reverse osmosis occurs when a pressure larger than the osmotic pressure is applied to the solution.

- **Abnormal molecular mass :** When the molecular mass calculated with the help of colligative property is different from theoretical molecular mass, it is called abnormal molecular mass.
- **Van't Hoff factor (i) :** The ratio of the observed (experimental) value of a colligative property to the normal (calculated) value of the same property is called as van't Hoff factor.

Mathematically,

$$i = \frac{\text{Observed (experimental) value of a colligative property}}{\text{Normal (calculated) value of the same colligative property}}$$

Or, $$i = \frac{\Delta_{obs}}{\Delta_{cal}},$$

where Δ_{obs} and Δ_{cal} respectively represent the observed and calculated value of a colligative property.

Thus,

(i) for lowering of vapour pressure, $i = \frac{(\Delta p)_{obs}}{(\Delta p)_{cal}}$;

(ii) for elevation of boiling point, $i = \frac{(\Delta T_b)_{obs}}{(\Delta T_b)_{cal}}$;

(iii) for depression of freezing point, $i = \frac{(\Delta T_f)_{obs}}{(\Delta T_f)_{cal}}$;

(iv) for osmotic pressure, $i = \frac{\pi_{obs}}{\pi_{cal}}$;

Since a colligative property is proportional to number of particles of solute.

$$i = \frac{\text{Normal molecular mass}}{\text{Obesrved molecular mass}}$$

Normal molecular mass = i × Calculated molecular mass.

$$i = \frac{\text{Total number of moles of particle after association/dissociation}}{\text{Total number of moles of particle before association/dissociation}}$$

- **Hypertonic solution :** A solution is called hypertonic, if its concentration is higher than that of the solution separating it by a semipermeable membrane.
- **Hypotonic solution :** A solution is called hypotonic, if its concentration is lower than that of the solution separating it by a semipermeable membrane.
- **Isotonic solution :** Two solutions are called isotonic, if they exert the same osmotic pressure at a given temperature. Isotonic solutions have same molar concentration. When such solutions are separated by semipermeable membrane no osmosis occurs between them.

Know the Formulae

- **Modified equations for colligative properties :**

(i) Relative lowering of vapour pressure of solvent

$$\frac{p_A{}^\circ - p_A}{p_A{}^\circ} = (i)\left(\frac{n}{N+n}\right)$$

(ii) Elevation of boiling point

$$\Delta T_b = iK_b m$$

(iii) Depression of freezing point

$$\Delta T_f = iK_f m$$

(iv) Osmotic pressure of solution

$$\pi = \frac{inRT}{V}$$

or $\pi = i\,CRT$

- **Determination of molecular mass using colligative properties :**

(i) Relative lowering of vapour pressure :

$$\frac{p_A{}^\circ - p_A}{p_A{}^\circ} = \chi_B = \frac{n_B}{n_A + n_B} = \frac{n_B}{n_A}$$

$$\frac{p_A{}^\circ - p_A}{p_A{}^\circ} = \frac{W_B \times M_A}{W_A \times M_B}$$

$$M_B = \frac{p_A{}^\circ}{p_A{}^\circ - p_A} \times \frac{W_B \times M_A}{W_A}$$

(ii) Elevation of boiling point :

$$\Delta T_b = K_b \times m$$

$$\Rightarrow \quad \Delta T_b = K_b \times \frac{W_B}{M_B} \times \frac{1000}{W_A \text{ in gms}}.$$

$$M_B = \frac{K_b \times W_B \times 1000}{\Delta T_b \times W_A}$$

(iii) Depression of freezing point :

$$\Delta T_f = K_f \times m$$

$$\Rightarrow \quad \Delta T_f = K_f \times \frac{W_{\text{solute}}}{M_{\text{solute}}} \times \frac{1000}{W_{\text{solvent}}}$$

$$M_B = \frac{1000 \times W_B \times K_f}{\Delta T_f \times W_A}$$

(iv) Osmotic pressure :

$$\pi = CRT,$$

$$\Rightarrow \quad \pi = \frac{\text{No. of moles}}{\text{Volume of solution}} \times R \times T$$

$$\pi = \frac{W_B}{M_B} \times \frac{RT}{V}$$

$$M_B = \frac{W_B \times RT}{\pi \times V}$$

- Degree of dissociation (α) :

$$\alpha = \frac{i-1}{n-1}$$

$i \rightarrow$ van't Hoff factor

$n \rightarrow$ No. of ions produced per formula of the compound

- Degree of association (α)

$$\alpha = \frac{1-i}{1-\frac{1}{n}}$$

- **Strength** = Molarity × Mol. wt.
  = Normality × Eq. wt.
- $K_b = 0.512$ K kg/mol for water
- $K_f = 1.86$ K kg/mol

Know the Terms

- **Normal boiling point :** Temperature at which the vapour pressure of the liquid equals one atm.
- **Molal boiling point :** Boiling point of a 1 molal solution.
- **Freezing point :** Temperature at which the vapour pressure of liquid solvent is equal to the vapour pressure of solid solvent.
- **Molal depression constant :** It is the depression in freezing point when 1 mole of the solute is dissolved in 1000 g of the solvent.
- **Semipermeable membrane :** Membrane that allows only the selective passage of chemical species. *e.g.* Cellophane.
- **Transition temperature :** This is the temperature at which salt becomes anhydrous and the process becomes exothermic, solubility starts decreasing.
- **Endosmosis :** The inward osmosis of water into the semipermeable membrane is known as endosmosis.
- **Exosmosis :** The outward osmosis of water from the cell membrane is known as exosmosis.
- **Desalination :** Sea water can be converted into potable water fit for drinking purpose by reverse osmosis process known as desalination.
- **Plasmolysis :** When plant cell is placed in hypertonic solution, the fluid from the plant cell comes out and the cell shrinks. This phenomenon is called plasmolysis and is due to osmosis.

Very Short Answer-Objective Type Questions (1 mark each)

A. Multiple choice Questions:

Q. 1. Colligative properties depends on ....

(a) the nature of the solute particles dissolved in solution.

(b) the number of solute particles in solution.

(c) the physical properties of the solute particles dissolved in solution.

(d) the nature of solvent particles.

U [NCERT Exemp. Q. 8, Page 18]

Ans. Correct option : (b)

Explanation : Colligative properties depend upon the number of solute particles in the solution and it is independent of its nature.

Q. 2. Which of the following statements is false?

(a) Units of atmospheric pressure and osmotic pressure are the same.

(b) In reverse osmosis, solvent molecules move through a semipermeable membrane from a region of lower concentration of solute to a region of higher concentration.

(c) The value of molal depression constant depends on nature of solvent.

(d) Relative lowering of vapour pressure, is a dimensionless quantity.

A&E [NCERT Exemp. Q. 16, Page 20]

Ans. Correct option : (b)

Explanation : In reverse osmosis, solvent molecules move through a semipermeable membrane from higher concentration of solute to lower concentration.

Q. 3. Which of the following aqueous solutions should have the highest boiling point?

(a) 1.0 M NaOH **(b) 1.0 M Na_2SO_4**

(c) 1.0 M NH_4NO_3 **(d) 1.0 M KNO_3**

U [NCERT Exemp. Q. 9, Page 18]

Ans. Correct option : (b)

Explanation : 1.0 M Na_2SO_4 since it furnishes maximum number of ions ($2Na^+ + SO_4^{2-}$).

Q. 4. An unripe mango placed in a concentrated salt solution to prepare pickle, shrivels because ....

(a) it gains water due to osmosis.

(b) it loses water due to reverse osmosis.

(c) it gains water due to reverse osmosis.

(d) it loses water due to osmosis.

A&E [NCERT Exemp. Q. 12, Page 19]

Ans. Correct option : (b)

Explanation : Water starts moving out of mango (lower concentration) to the salt solution (higher concentration) due to osmosis.

Q. 5. We have three aqueous solutions of NaCl labelled as 'A', 'B' and 'C' with concentrations 0.1M, 0.01M and 0.001M, respectively. The value of van't Hoff factor for these solutions will be in the order ....

(a) $i_A < i_B < i_C$ **(b) $i_A > i_B > i_C$**

(c) $i_A = i_B = i_C$ **(d) $i_A < i_B > i_C$**

A [NCERT Exemp. Q. 20, Page 20]

Ans. Correct option : (c)

Explanation : The value of van't Hoff's factor will be i. It is due to complete dissociation of strong electrolyte (NaCl) in dilute solutions and on complete dissociation value of i for NaCl is 2.

Q. 6. The values of Van't Hoff factors for KCl, NaCl and K_2SO_4, respectively are:

(a) 2, 2 and 2 **(b) 2, 2 and 3**

(c) 1, 1 and 2 **(d) 1, 1 and 1**

A [NCERT Exemp. Q. 15, Page 19]

Ans. Correct option : (b)

Explanation : KCl ($K^+ + Cl^-$) and NaCl ($Na^+ + Cl^-$) ionize to give 2 ions and K_2SO_4 ($K^+ + SO_4^{2-}$) ionize to form 3 ions so, van't Hoff factors for KCl, NaCl, and K_2SO_4 are 2, 2, and 3, respectively.

B. Match the following :

Q. 1. Match the species given in Column I with those mentioned in Column II.

Column I	Column II
(a) Raoult's law	(i) $\Delta T_f = K_f m$
(b) Henry's law	(ii) $\pi = CRT$
(c) Elevation of boiling point	(iii) $p = x_1p_1^0 + x_2p_2^0$
(d) Depression in freezing point	(iv) $\Delta T_b = K_b m$
(e) Osmotic pressure	(v) $p = K_H.x$

[NCERT Exemp. Q. 49, Page 26]

Ans. Correct option : (a) → (iii), (b) → (v), (c) → (iv), (d) → (i), (e) → (ii)

Raoult's law : Mathematical representation of Raoult's law

$p = x_1p_1^0 + x_2p_2^0$

Herry's law : $p = K_Hx$

Elevation of boiling point : Mathematical representation, $\Delta T_b = K_bm$

Depression in freezing point : Mathematical representation, $\Delta T_f = K_fm$

Osmotic pressure : Mathematical representation, $\pi = CRT$.

C. Answer the following :

Q. 1. What are isotonic solutions ? R [CBSE Delhi 2014]

Ans. The solutions having same osmotic pressure at a given temperature are called isotonic solutions. **1**

[CBSE Marking Scheme 2014]

Q. 2. What is meant by term reverse osmosis ?

R [CBSE OD 2013]

Ans. Reverse Osmosis : (RO) is a water purification technology that uses a semipermeable membrane to remove larger particles from drinking water in reverse osmosis. **1**

Q. 3. Define the following terms :

(i) Isotonic solutions

(ii) Van't Hoff factor R [CBSE Delhi/OD 2012]

Ans. (i) The solutions having same osmotic pressure at a given temperature are called isotonic solutions. ½

(ii) Van't Hoff factor is expressed as :

$$i = \frac{\text{Normal molecular mass}}{\text{Observed molecular mass}}$$

(or any other definition) ½

[CBSE Marking Scheme 2012]

AI Q. 4. Explain boiling point elevation constant for a solvent or ebullioscopic constant.

U [CBSE OD/Foreign 2012]

Ans. We know that,

$$\Delta T_b = K_bm.$$

where $m = 1$, $\Delta T_b = K_b$. Thus, boiling point elevation constant is equal to the elevation in boiling point when 1 mole of a solute is dissolved in 1 kg of solvent. It is also called ebullioscopic constant. **1**

Short Answer Type Questions **(2 marks each)**

Q. 1. Define the following terms:
(i) Colligative properties
(ii) Molality (m) R **[CBSE Delhi Set-1 2017]**

Ans. **(i)** Properties that are independent of nature of solute and depend on number of moles of solute only. **1**

(ii) Number of moles of solute dissolved per kg of the solvent. **[CBSE Marking Scheme 2017] 1**

Q. 2. Define the following terms:
(i) Ideal solution
(ii) Molarity (M) R **[CBSE Delhi Set-2 2017]**

Ans.(i) The solution that obeys Raoults' Law over the entire range of concentration. **1**

(ii) Number of moles of solute dissolved per litre of solution or $M = \frac{W_b \times 1000}{M_b \times V(\text{mL})}$ **1**

[CBSE Marking Scheme 2017]

Q. 3. Define the following terms:
(i) Abnormal molar mass
(ii) van't Hoff factor (i) R **[CBSC Delhi Set-3 2017]**

Ans. **(i)** If the molar mass calculated by using any of the colligative properties to be different than theoretically expected molar mass. **1**

(ii) Extent of dissociation or association or ratio of the observed colligative property to calculated colligative property. **1**

[CBSE Marking Scheme 2017]

Answering Tip
- In all definition based questions use accurate precise definition.

Q. 4. A 1.00 molar aqueous solution of trichloroacetic acid (CCl_3COOH) is heated to its boiling point. The solution has the boiling point of 100.18 °C. Determine the van't Hoff factor for trichloroacetic acid. (K_b for water = 0.512 K kg mol^{-1}). A

OR

Define the following terms :
(i) Mole fraction **(ii) Isotonic solutions**
(iii) Van't Hoff factor **(iv) Ideal solution**
R **[CBSE Delhi 2012]**

Ans. $\Delta T_b = iK_b m$ **1**

$$(373.18 - 373)\text{ K} = i \times 0.512 \text{ K kg mol}^{-1} \times 1 \text{ m}$$
$$0.18 \text{ K} = i \times 0.512 \text{ K kg mol}^{-1} \times 1 \text{ m},$$
$$i = 0.35$$ **1**

OR

(i) Mole fraction is the ratio of number of moles of one component to the total number of moles in a mixture.

$$\chi_A = \frac{n_A}{n_A + n_B}$$

where n_A = number of moles of component A.
n_B = number of moles of component B. ½

(ii) Two solutions having same osmotic pressure at a given temperature are called isotonic solutions. ½

(iii) Van't Hoff factor is the ratio of normal molecular mass and observed molecular mass. ½

(iv) Ideal solution : The solution which follows Raoult's law over entire range of concentrations at specific temperature is called ideal solution. ½

Answering Tip
- As it is a two mark question just write the definition of each.

Q. 5. What are colligative properties? Write the colligative property which is used to find the molecular mass of macromolecules.
R **[CBSE Foreign Set-1 2017]**

Ans. Properties that depend on the number of solute particles irrespective of their nature relative to the total number of particles present in the solution. **1**
Osmotic pressure. **1**

[CBSE Marking Scheme 2017]

Q. 6. What is meant by elevation in boiling point? Why is it a colligative property?
R **[CBSE Foreign Set-3 2017]**

Ans. The increase in boiling point of the solvent in a solution when a non-volatile solute is added. **1**

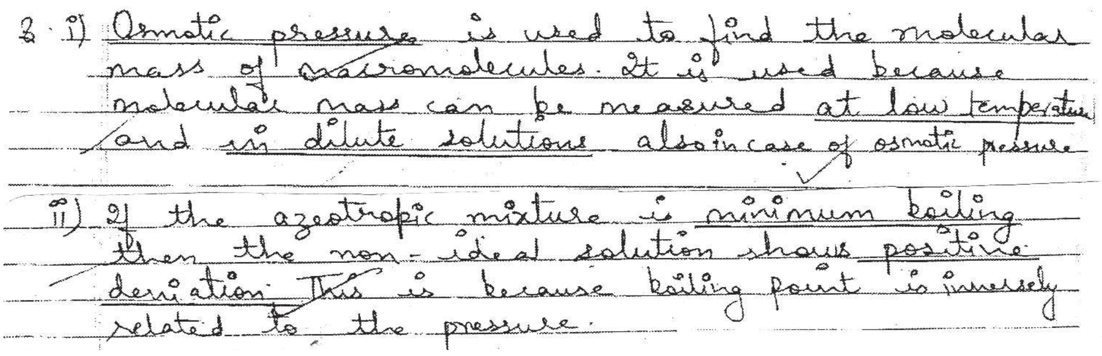
Because it depends upon molality/the number of solute particles rather than their nature/ $\Delta T_B \propto m$ **1**

[CBSE Marking Scheme 2017]

Detailed Answer:
Elevation in boiling point can be defined as an increase in boiling point of the solvent in a solution on addition of a non-volatile solute.
It is considered as a colligative property because it depends upon the number of solute particles dissolved in a definite amount of the solvent and not on the nature of the solute. **1+1**

Q. 7. (i) Write the colligative property which is used to find the molecular mass of macromolecules.
(ii) In non-ideal solution, what type of deviation shows the formation of minimum boiling azeotropes?
U **[CBSE OD Set-2 2016]**

Ans.



2. i) Osmotic pressure is used to find the molecular mass of macromolecules. It is used because molecular mass can be measured at low temperature and in dilute solutions also in case of osmotic pressure.

ii) If the azeotropic mixture is minimum boiling then the non-ideal solution shows positive deviation. This is because boiling point is inversely related to the pressure.

1 + 1

[Topper's Answer 2016]

Detailed Answer:

(i) Osmotic pressure is the colligative property which is used to find the molecular mass of macromolecules. **1**

(ii) In non-ideal solution, positive deviation shows the formation of minimum boiling azeotropes. **1**

Q. 8. Define osmotic pressure. How is the osmotic pressure related to the concentration of a solute in a solution?

R + U **[CBSE Comptt. OD 2016; Delhi 2015]**

Ans. The external pressure applied on the solution side to stop the flow of solvent across the semipermeable membrane *i.e.*, osmosis is known as osmotic pressure. **1**

The osmotic pressure is directly proportional to the concentration of the solution *i.e.*, $\pi = CRT$. **1**

[CBSE Marking Scheme 2016]

Q. 9. Which of the following solutions has higher freezing point?
0.05 M $Al_2(SO_4)_3$, 0.1 M $K_3[Fe(CN)_6]$ Justify.

A **[CBSE SQP 2017]**

Ans. 0.05 M $Al_2(SO_4)_3$ has higher freezing point. **1**

0.05 M $Al_2(SO_4)_3$: $i = 5$, $\Delta T_f \propto$ No. of particles; $\Delta T_f = i \times$ concentration $= 5 \times 0.05 = 0.25$ moles of ions

0.1 M $K_3[Fe(CN)_6]$: $i = 4$, ½

$= 4 \times 0.1 = 0.4$ moles of ions ½

[CBSE Marking Scheme 2017]

Q. 10. Calculate the mass of compound (molar mass = 256 g mol^{-1}) to be dissolved in 75 g of benzene to lower its freezing point by 0.48 K(K_f = 5.12 K kg mol^{-1}).

A **[CBSE Delhi 2014]**

Ans. Given :
$$\Delta T_f = \frac{K_f \times W_2 \times 1000}{W_1 \times M_2} \quad ½$$

$$= 5.12 \text{ K kg mol}^{-1} \times \frac{W_2 \times 1000 \text{ g Kg}^{-1}}{75 \text{ g} \times 256 \text{ g mol}^{-1}} \quad 1$$

$$W_2 = \frac{0.48 \times 75 \times 256}{5.12 \times 1000} \text{ g}$$

$$W_2 = 1.8 \text{ g} \quad ½$$

[CBSE Marking Scheme 2014]

Answering Tips

- Mention correct formula before starting the numerical. Carefully note the marking scheme in above answer where it is clear that formula has separate marks.
- Be careful while substituting the values in the formula.

Q. 11. Will the elevation in boiling point be same if 0.1 mol of sodium chloride or 0.1 mol of sugar is dissolved in 1L of water ? Explain.

C **[CBSE SQP 2016]**

Ans. No, the elevation in boiling point is not the same. ½
Elevation in boiling point is a colligative property which depends on the number of particles. NaCl is an ionic compound which dissociates in solution to give more number of particles whereas sugar is made up of covalent molecules and thus does not dissociate. **1½**

Q. 12. Explain why on addition of 1 mol glucose to 1 litre water the boiling point of water increases.

C **[CBSE Delhi Set-1, 2, 3 2017]**

Ans. Vapour pressure of the solvent decreases in the presence of non-volatile solute (glucose) hence boiling point increases. **2**

[CBSE Marking Scheme 2017]

Q. 13. Calculate the freezing point of a solution containing 8.1 g of HBr in 100 g of water, assuming the acid to be 90% ionized.
[Given: Molar mass Br = 80 g/mol, K_f water = 1.86 K kg/mol]

A **[CBSE SQP 2018-2019]**

Ans.
$$HBr \rightarrow H^+ + Br^-$$
$$i = 1 - \alpha + n\alpha$$
$$n = 2$$
$$i = 1 + \alpha \quad ½$$
$$\Delta T_f = iK_f m \quad ½$$
$$\Delta T_f = (1+\alpha) 1{\cdot}86 \text{ K Kg mol}^{-1} \times \frac{8{\cdot}1 \text{ g} \times 1000 \text{ g Kg}^{-1}}{81 \text{ g mol}^{-1} \times 100 \text{ g}}$$
$$\Delta T_f = 3.53 \text{ °C}$$

$T_{f°} = 0°C$

$\Delta T_f = T_{f°} - T_{f'}$ ½

$T_{f'} = -3.534°C$ ½

[CBSE Marking Scheme 2018]

Commonly Made Error

- Students often make mistakes in calculation of number of moles (n) and degree of dissociation (i).

Q. 14. 18 g of glucose, $C_6H_{12}O_6$ (Molar Mass = 180 g mol^{-1}) is dissolved in 1 kg of water in a sauce pan. At what temperature will this solution boil ?

(K_b for water = 0.52 K kg mol^{-1}, boiling point of pure water = 373.15 K)

$\boxed{\text{A}}$ **[CBSE Delhi 2013; NCERT]**

Ans. $\Delta T_b = K_b \times m$ ½

$$T_b - T_b° = 0.52 \text{ K kg mol}^{-1} \times \frac{18 \text{ g}}{180 \text{ g mol}^{-1}} \times \frac{1}{1\text{kg}} \quad ½$$

$$\Rightarrow \quad T_b - 373.15 = \frac{0.52}{10}$$

$$\Rightarrow \quad T_b - 373.15 = 0.052 \text{ K} \quad ½$$

$$\Rightarrow \quad T_b = 0.052 + 373.15$$

$$\therefore \quad T_b = 373.202 \text{ K} \quad ½$$

Commonly Made Error

- Students do not write applied formula or sometimes miss the next step of value assignment to all the entities in it.

Long Answer Type Questions-I

(3 marks each)

Q. 1. A solution of glucose (molar mass = 180 g mol^{-1}) in water has a boiling point of 100.20°C. Calculate the freezing point of the same solution. Molal constants for water K_f and K_b are 1.86 K kg mol^{-1} and 0.512 K kg mol^{-1} respectively.

$\boxed{\text{A}}$ **[CBSE Foreign Set-1, 2, 3 2017]**

Ans. Given: T_b of glucose solution = 100.20°C

$\Delta T_b = K_b . m$

$m = 0.20/0.512$

$m = 0.390$ mol/kg 1

$\Delta T_f = K_f . m$ ½

$\Delta T_f = 1.86$ K kg/mol × 0.390 mol/kg ½

$\Delta T_f = 0.725$ K

Freezing point of solution = 273.15 – 0.725

= 272.425 K 1

[CBSE Marking Scheme 2017]

Q. 2. 45 g of ethylene glycol ($C_2H_4O_2$) is mixed with 600 g of water. Calculate

(i) the freezing point depression and

(ii) the freezing point of the solution

(Given : K_f of water = 1.86 K kg mol^{-1})

$\boxed{\text{A}}$ **[CBSE Comptt. Delhi 2015]**

Ans. (i) $\Delta T_f = K_f m$ ½

$$\Rightarrow \quad \Delta T_f = K_f \frac{W_B \times 1000}{M_B \times W_A} \quad ½$$

$$\Rightarrow \quad \Delta T_f = \frac{1.86 \text{K kg mol}^{-1} \times 45\text{g} \times 1000 \text{ g kg}^{-1}}{62 \text{ g mol}^{-1} \times 600 \text{ g}}$$

$\Delta T_f = 2.325$ K or 2.325 °C 1

(ii) $T_f° - T_f = 2.325$ °C

$\Rightarrow$ 0 °C $- T_f = 2.325$ °C

$\Rightarrow$ $T_f = -2.325$ °C or 270.675 K 1

[CBSE Marking Scheme 2015]

Answering Tip

- Write working formula followed by data in the working formula.

Q. 3. Calculate the freezing point of an aqueous solution containing 10.5 g of Magnesium bromide in 200 g of water, assuming complete dissociation of Magnesium bromide. (Molar mass of Magnesium bromide = 184 g mol^{-1}, K_f for water = 1.86 K kg mol^{-1}). $\boxed{\text{A}}$ **[CBSE Comptt. Delhi/OD 2018]**

Ans.

$$\text{Moles for MgBr}_2 = \frac{10.5}{184} = 0.0571 \text{ mol}$$

$$\text{Molality} = \frac{0.0571 \text{ g mol}}{200 \text{ g}} \times 1000 \text{ g Kg}^{-1}$$

$= 0.2855$ mol kg^{-1}

$i = 3$ ½

$\Delta T_f = i K_f m$ ½

$= 3\times 1.86$ K Kg mol^{-1} × 0.2855 mol Kg^{-1}

= 1.59 K 1

Freezing point = 273 – 1.59

= 271.41K or –1.59 °C 1

[CBSE Marking Scheme 2018]

Q. 4. 3.9 g of benzoic acid dissolved in 49 g of benzene shows a depression in freezing point of 1.62 K. Calculate the van't Hoff factor and predict the nature of solute (associated or dissociated).

(Given : Molar mass of benzoic acid = 122 g mol^{-1}, K_f for benzene = 4.9 K kg mol^{-1})

$\boxed{\text{A}}$ **[CBSE Delhi 2015]**

Ans. $\Delta T_f = i K_f m$

$$m = \frac{W_B \times 1000}{M_B \times W_B}$$

ΔT_f = Depression in freezing point = 1.62

i = van't Hoff factor

K_f = constant = 4.9

$$m = \frac{3.9 \times 1000}{122 \times 49} = 0.65$$

$$i = \frac{\Delta T_f}{K_f m}$$

$$= \frac{1.62}{4.9 \times 0.65} = 0.50$$

$\therefore$ $i = 0.50$

As the value of $i < 1$, the solute is associated. 3

Q. 5. The freezing point of benzene decreases by 2.12 K when 2.5 g of benzoic acid (C_6H_5COOH) is dissolved in 25 g of benzene. If benzoic acid forms a dimer in benzene, calculate the van't Hoff factor and the percentage association of benzoic acid. (K_f for benzene = 5.12 K kg mol^{-1})

A **[CBSE SQP 2017]**

Ans. $\Delta T_f = i\, K_f\, m$ ½

$$2.12\text{ K} = i \times \frac{5.12\text{ K kg mol}^{-1} \times 2.5\text{ g} \times 1000\text{ g Kg}^{-1}}{122\text{ g mol}^{-1} \times 25\text{ g}}$$ 1

$i = 0.505$ ½

for association

$$i = 1 - \frac{\alpha}{2}$$ ½

$\alpha = 0.99$

Percentage association of benzoic acid is 99.0% ½

[CBSE Marking Scheme 2017]

Commonly Made Errors

- Students forget to put the value of i in ionic solids.

Answering Tip

- Remember to put the value of i in questions where complete dissociation is mentioned for ionic solids.

Q. 6. 1.00 g of a non electrolyte solute when dissolved in 50 g of benzene lowered the freezing point of benzene by 0.40 K. Find the molar mass of the solute. (K_f for benzene = 5.12 K kg mol^{-1})

A **[CBSE OD 2013]**

Ans. Given,

$$W_2 = 1.00\text{ g}, W_1 = 50\text{ g}$$
$$K_f = 5.12\text{ K kg mol}^{-1}$$
$$\Delta T_f = 0.40\text{ K}$$

$$0.40\text{ K} = \frac{5.12\text{ K Kg mol}^{-1} \times 1\text{ g} \times 1000\text{ g Kg}^{-1}}{M_2 \times 50\text{ g}}$$ ½

$$\Rightarrow \quad M_2 = \frac{K_f \times W_2 \times 1000}{W_1 \times \Delta T_f}$$ ½

$$= \frac{5.12 \times 1 \times 1000}{50 \times 0.40}\text{ g mol}^{-1}$$ 1

$\therefore$ $M_2 = 256\text{ g mol}^{-1}$ 1

Answering Tip

- Remember to put the value of kg in question correctly.

Q. 7. Calculate the amount of KCl which must be added to 1 kg of water so that the freezing point is depressed by 2 K. (K_f for water = 1.86 K kg mol^{-1})

A **[CBSE Delhi 2012]**

Ans. Since one mole of KCl gives 2 mole particles, the value of

$i = 2$ 1

$\Delta T_f = 2\text{K}$

$K_f = 1.86\text{K kg mol}^{-1}$

Applying equation, $T_f = iK_f m$

$$m = \frac{\Delta T_f}{iK_f} = \frac{2}{2 \times 1.86}$$

≈ 0.5376

$= 0.54\text{ mol kg}^{-1}$ 1

Therefore, 0.54 mole of KCl should be added to one kg of water. 1

Q. 8. Calculate the boiling point of a 1M aqueous solution (density 1.04 g mL^{-1}) of Potassium chloride (K_b for water = 0.52 K kg mol^{-1}, Atomic masses : K = 39 u, Cl = 35.5 u). Assume, Potassium chloride is completely dissociated in solution.

A **[CBSE SQP 2016]**

Ans. Molar mass of KCl = 39 + 35.5 = 74.5 g mol^{-1}

As KCl dissociates completely, number of ions produced are 2.

Therefore, van't Hoff factor, $i = 2$ ½

Mass of KCl solution = 1000 × 1.04 = 1040 g

Mass of solvent = 1040 – 74.5 = 965.5 g = 0.9655 kg ½

Molality of the solution :

$$\frac{\text{No. of moles of solute}}{\text{Mass of solvent in kg}} = \frac{1\text{ mol}}{0.9655\text{ kg}} = 1.0357\text{ m}$$ ½

$\Delta T_b = i \times K_b \times m$ ½

$= 2 \times 0.52 \times 1.0357 = 1.078°\text{ C}$ ½

Therefore, boiling point of solution

= 100 + 1.078 = 101.078°C ½

Commonly Made Error

- Few students subtract the value obtained from boiling point of water instead of adding T_b to the boiling point of water to obtain the correct boiling point of solution.

Answering Tip

- Students should remember that boiling point is elevated in a solution. Hence, T_b will be greater. So, addition of value has to be done.

Q. 9. At 25°C, the saturated vapour pressure of water is 3.165 k Pa (23.75 mm Hg) Find the saturated vapour pressure of a 5% aqueous solution of urea (carbamide) at the same temperature. (Molar mass of urea = 60.05 g mol^{-1})

A **[CBSE Foreign 2012]**

Ans.
$$\frac{p° - p_s}{p°} = n_2 = \frac{n_2}{n_1}$$

(for dilute solution $n_2 << n_1$)

$$\frac{p° - p_s}{p°} = \frac{W_2 \times M_1}{W_1 \times M_2}$$ 1

Given $p° = 3.165$ k Pa, $W_2 = 5$ g, $W_1 = 95$ g

$M_2 = 60.05$ g mol^{-1}, $M_1 = 18$ g mol^{-1}

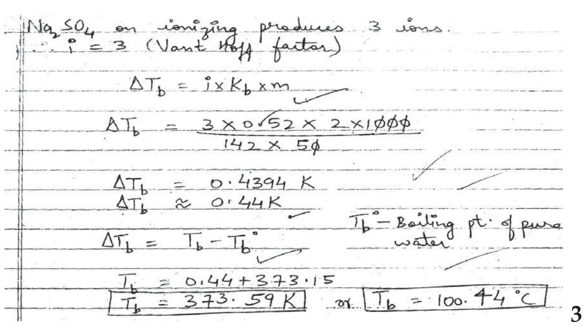
$$\frac{3.165 - p_S}{3.165} = \frac{5\times18}{60.05\times95} = 0.0158 \quad \mathbf{1}$$

$$\Rightarrow \quad 3.165 - p_S = 0.049$$

$$\Rightarrow \quad p_S = 3.116 \text{ k Pa} \quad \mathbf{1}$$

Q. 10. Calculate the boiling point of solution when 2g of Na_2SO_4 (M = 142 g mol^{-1}) was dissolved in 50 g of water, assuming Na_2SO_4 undergoes complete ionization. A **[CBSE OD Set-2 2017]**

Ans.



Na_2SO_4 on ionizing produces 3 ions.

$\therefore i = 3$ (Vant Hoff factor)

$\Delta T_b = i \times K_b \times m$

$\Delta T_b = \frac{3 \times 0.52 \times 2 \times 100\cancel{0}}{142 \times 5\cancel{0}}$

$\Delta T_b = 0.4394$ K

$\Delta T_b \approx 0.44$K

$\Delta T_b = T_b - T_b^\circ$ $\quad T_b^\circ$ – Boiling pt. of pure water

$T_b = 0.44 + 373.15$

$\boxed{T_b = 373.59 \text{ K}}$ or $\boxed{T_b = 100.44\ ^\circ C}$ **3**

[Topper's Answer 2017]

Detailed Answer:

van't Hoff Factor $i = 3$

$$\Delta T_b = iK_b m$$

$$\Delta T_b = \frac{3\times0.52 \text{ K Kg mol}^{-1}\times2\text{g}\times1000 \text{ g Kg}^{-1}}{142 \text{ g mol}^{-1}\times50 \text{ g}}$$

$$\Delta T_b = iK_b m$$

$$\Delta T_b = 0.439 \text{ K} \approx 0.44 \text{ K}$$

$$\Delta T_b = T_b - T_b^0$$

$$T_b = 0.44 + 373.15$$

$$= 373.59 \text{ K}$$

$$\text{or} \quad \Delta T_b = 100.44°\text{C} \quad \mathbf{3}$$

Q. 11. A 5 percent solution (by mass) of cane-sugar (M.W. 342) is isotonic with 0.877% solution of substance X. Find the molecular weight of X.

A **[CBSE Comptt. OD 2015]**

Ans. Since,

$$\frac{W_{\text{cane sugar}}}{M_{\text{cane sugar}}} = \frac{W_X}{M_X} \quad \mathbf{1}$$

$$\frac{5 \text{ g}}{342 \text{ g mol}^{-1}} = \frac{0.877}{M_X} \quad \mathbf{1}$$

$$\Rightarrow \quad M_X = \frac{0.877\times342}{5} \text{ g mol}^{-1}$$

$$\Rightarrow \quad M_X = 59.9 \text{ or } 60 \text{ g mol}^{-1} \quad \mathbf{1}$$

Q. 12. Determine the osmotic pressure of a solution prepared by dissolving 2.5 × 10^{-2} g of K_2SO_4 in 2L of water at 25°C, assuming that it is completely dissociated.

(R = 0.0821 L atm K^{-1} mol^{-1}, molar mass of K_2SO_4 = 174 g mol^{-1}) A **[CBSE Delhi 2013]**

Ans. When K_2SO_4 is dissolved in water, ions are produced.

Total number of ions produced = 3

$$i = 3 \quad \tfrac{1}{2}$$

$$\pi = i\text{CRT} = \frac{i\times n\times \text{R}\times\text{T}}{\text{V}} \quad \tfrac{1}{2}$$

$$\Rightarrow \pi = 3 \times \frac{2.5\times10^{-2}\text{g}}{174 \text{ g mol}^{-1}}\times\frac{0.0821 \text{ L atm K}^{-1}\text{mol}^{-1}}{2 \text{ L}} \times 298 \text{ K} \quad \mathbf{1}$$

$$= 5.27 \times 10^{-3} \text{ atm} \quad \mathbf{1}$$

Q. 13. A solution is prepared by dissolving 10 g of non-volatile solute in 200 g of water. It has a vapour pressure of 31.84 mm Hg at 308 K. Calculate the molar mass of the solute.

(Vapour pressure of pure water at 308 K = 32 mm Hg) A **[CBSE OD 2015]**

Ans. $\frac{p^0 - p}{p^0} = \frac{W_s \times M_{\text{solvent}}}{M_s \times W_{\text{solvent}}}$, s = solute **1**

$\Rightarrow(32 - 31.84)/32 = 10 \times 18/M_s \times 200$ **1**

$M_s = 180$ g/mol **1**

[CBSE Marking Scheme 2015]

Q. 14. Give reasons for the following:

(a) When 2g of benzoic acid is dissolved in 25 g of benzene, the experimentally determined molar mass is always greater than the true value.

(b) Mixture of ethanol and acetone shows positive deviation from Raoult's Law.

(c) The preservation of fruits by adding concentrated sugar solution protects against bacterial action.

A&E **[CBSE SQP 2018-2019]**

Ans. (a) Molecules of benzoic acid dimerise in benzene, the number of particles are reduced. **1**

(b) The intermolecular interactions between ethanol and acetone are weaker/ the escaping tendency of ethanol and acetone molecules increases on mixing / the vapour pressure increases. **1**

(c) Due to osmosis, a bacterium on fruit loses water, shrivels and dies. **1**

[CBSE Marking Scheme 2018]

Detailed Answer:

(a) As benzoic acid on dissolving in benzene has molecular mass double of its normal molecular mass. This is caused due to number of particles. Thus, the experimentally determined molar mass is always greater than the true value. **1**

(b) Hydrogen bonding is present in the molecules of ethanol. When acetone is added to ethanol, molecules of acetone enter between the molecules of ethanol breaking the bonds. This weakens the intermolecular attractive forces resulting in increase in vapour pressure of mixture than that in pure state. **1**

(c) Sugar has an osmotic effect i.e., when fruits are placed in a concentrated sugar solution, water is drawn out of the cells of micro-organisms so that they no longer survive. **1**

Q. 15. Give reasons for the following :

(a) Measurement of osmotic pressure method is preferred for the determination of molar masses of macromolecules such as proteins and polymers.

(b) Aquatic animals are more comfortable in cold water than in warm water.

(c) Elevation of boiling point of 1 M KCl solution is nearly double than that of 1 M sugar solution.

A&E [CBSE Delhi/OD 2018]

Ans. (a) As compared to other colligative properties, its magnitude is large even for very dilute solutions / macromolecules are generally not stable at higher temperatures and polymers have poor solubility / pressure measurement is around the room temperature and the molarity of the solution is used instead of molality. **1**

(b) Because oxygen is more soluble in cold water or at low temperature. **1**

(c) Due to dissociation of KCl / KCl (aq) $\rightarrow$ $K^+ + Cl^-$, i is nearly equal to 2. **1**

[CBSE Marking Scheme 2018]

Detailed Answer:

(a) In osmotic pressure method, pressure is measured at room temperature and instead of molality, molarity of the solution is used. It is preferred for the macromolecules like proteins as they are unstable at high temperature and polymers have poor solubility. Also, due to their high molecular mass, the only colligative property which has a measurable magnitude is osmotic pressure. Therefore, osmotic pressure method is preferred.

(b) In cold water, the solubility of oxygen is more. The amount of dissolved oxygen in water decreases with increase in the temperature of water. Therefore, aquatic animals are more comfortable in cold water than in warm water.

(c) 1M KCl solution dissociates into 1M K^+ and 1M Cl^- whereas 1M sugar solution does not dissociates to give ions. So, the van't Hoff factor for KCl solution is 2 whereas that for sugar solution is 1. As we know, greater is the van't Hoff factor, greater would be the colligative property. Hence, elevation of boiling point of 1M KCl solution is nearly double than that of 1M sugar solution. **1+1+1**

Q. 16. Calculate the freezing point of a solution containing 60 g of glucose (Molar mass = 180 g mol^{-1}) in 250 g of water. (K$_f$ of water = 1.86 K kg mol^{-1})] **A [CBSE Delhi/OD 2018]**

Ans.

$$\Delta T_f = K_f m$$

$$= K_f \frac{w_2 \times 1000}{M_2 \times w_1} \qquad \frac{1}{2}$$

$$= \frac{1.86 \text{ K Kg mol}^{-1} \times 60 \text{ g} \times 1000 \text{ g Kg}^{-1}}{180 \text{ g mol}^{-1} \times 250 \text{ g}} \qquad \frac{1}{2}$$

$$= \frac{1.86 \times 60 \times 1000}{180 \times 250} \text{ K} \qquad \frac{1}{2}$$

$$= 2.48 \text{ K} \qquad \frac{1}{2}$$

$$\Delta T_f = T_{f^\circ} - T_f \qquad \frac{1}{2}$$

$$2.48 \text{ K} = 273.15 \text{ K} - T_f$$

$$T_f = 270.67 \text{ K}/270.52 \text{ K}/ - 2.48^\circ\text{C} \qquad \frac{1}{2}$$

[CBSE Marking Scheme 2018]

Long Answer Type Questions-II

(5 marks each)

Q. 1. (i) Define the following terms :

(a) Molarity

(b) Molal elevation constant (K$_b$)

(ii) A solution containing 15 g urea (molar mass = 60 g mol^{-1}) per litre of solution in water has the same osmotic pressure (isotonic) as a solution of glucose (molar mass = 180 g mol^{-1}) in water. Calculate the mass of glucose present in one litre of its solution.

R + A [CBSE OD 2014]

Ans. (i) (a) Molarity : Molarity of a substance in a solution is equal to the number of moles of the substance present in one litre of the solution.

i.e. $\text{Molarity} = \frac{\text{No. of moles of substance}}{\text{Volume of solution in L}}$ **1**

(b) Molal elevation constant : It is also called ebullioscopic constant. It is equal to the change in boiling point of one molar solution.

$$\Delta T_b = K_b . m$$ **1**

(ii) Given; Mass of urea, $W_B = 15$ g

Molar mass of urea, $M_B = 60$ g

The solution of urea in water is isotonic to that of glucose solution.

So, $\pi_{urea} = \pi_{Glucose}$

$$C_{urea} RT = C_{Glucose} RT$$

$$\frac{n_{urea}}{V} RT = \frac{n_{Glucose}}{V} RT$$

or, $$\frac{15}{60} = \frac{W_{Glucose}}{180}$$

or, $$W_{Glucose} = \frac{15 \times 180}{60}$$

$$W_{Glucose} = 45 \text{ g}$$

So, 45 g of glucose is present in 1 L of solution. **3**

Commonly Made Error

- Calculation errors are commonly seen. In many answers, no unit is written with the final answer.

Answering Tip

- Write essential steps and express the final answer alongwith a proper unit.

Q. 2. (i) Define the following terms :

(a) Ideal solution

(b) Azeotrope

(c) Osmotic pressure

(ii) A solution of glucose ($C_6H_{12}O_6$) in water is labelled as 10% by weight. What would be the molality of the solution ?

(Molar mass of glucose = 180 g mol^{-1})

R + A **[CBSE OD 2013]**

Ans. (i) (a) Ideal solution : Those solutions which follow Raoult's law at specific temperature over the entire range of concentration are called ideal solution. **1**

(b) Azeotrope : A liquid mixture which distills at constant temperature without under going any changes in composition is called azeotrope. **1**

(c) Osmotic pressure : The minimum excess pressure that has to be applied on the solution side to prevent the entry of the solvent into the solution through the semipermeable membrane is called osmotic pressure. **1**

(ii) Given : Mass of solute, $w = 10$ g

Mass of solvent, W = 90 g

Molar mass of solute, M = 180

$$\text{Molality} = \frac{w \times 1000}{M \times W} \quad \mathbf{1}$$

$$= \frac{10 \times 1000}{90 \times 180}$$

$$= 0.6172 \approx 0.62 \text{ mol kg}^{-1} \quad \mathbf{1}$$

AI Q. 3. (i) Define the following terms :

(a) Mole fraction,

(b) Ideal solution.

(ii) 15.0 g of an unknown molecular material is dissolved in 450 g of water. The resulting solution freezes at – 0.34 °C. What is the molar mass of the material ? [K_f for water = 1.86 K kg mol^{-1}]

R + A **[CBSE OD 2012]**

Ans. (i) (a) The ratio of number of moles of one component to the total number of moles of solution is known as mole fraction. **1**

(b) The solution which follows Raoult's law over entire range of concentration at specific temperature is called ideal solution. **1**

(ii) $W_B = 15$ g, $W_A = 450$ g, $\Delta T_f = 0.34$ K, M_B = ?

$$M_B = \frac{1000 \times K_f \times W_B}{\Delta T_f \times W_A} \quad \mathbf{1}$$

$$= \frac{1000 \text{ K kg}^{-1} \times 1.86 \text{ K kg mol}^{-1} \times 15 \text{ g}}{0.34\text{K} \times 450 \text{ g}} \quad \mathbf{1}$$

$$= 182.35 \text{ g/mol} \quad \mathbf{1}$$

Q. 4. (i) Explain the following :

(a) Henry's law about dissolution of a gas in a liquid,

(b) Boiling point elevation constant for a solvent.

(ii) A solution of glycerol ($C_3H_8O_3$) in water was prepared by dissolving some glycerol in 500 g of water. This solution has a boiling point of 100.42°C. What mass of glycerol was dissolved to make this solution ? [K_b for water = 0.512 K kg mol^{-1}]

U + A **[CBSE Delhi & OD 2012]**

Ans. (i) (a) The partial pressure of the gas above the liquid (vapour phase) is directly proportional to the mole fraction of the gas dissolved in the liquid. **1**

(b) Boiling Point Elevation Constant : It is equal to elevation in boiling point of 1 molal solution, *i.e.*, mole of solute is dissolved in 1 kg of solvent. (or mathematical expression) **1**

(ii) W_B = ? W_A = 500 g ΔT_b = 100.42°C – 100°C = 0.42°C or 0.42K

K_b = 0.512 Kkg/mol M_B = 92g/mol

$$\Delta T_b = K_b \frac{W_B \times 1000}{M_B \times W_A (\text{in grams})}$$

$$W_B = \frac{\Delta T_b \times M_B \times W_A (\text{in grams})}{1000 \times K_B} \quad \mathbf{1}$$

$$= \frac{0.42 \text{ K} \times 92\text{g mol}^{-1} \times 500}{1000 \text{ g Kg}^{-1} \times 0.512 \text{ K kg mol}^{-1}} \quad \mathbf{1}$$

$$= 37.73 \text{ g} \quad \mathbf{1}$$

[CBSE Marking Scheme 2012]

Q. 5. (i) A 10% solution (by mass) of sucrose in water has a freezing point of 269.15 K. Calculate the freezing point of 10% glucose in water if the freezing point of pure water is 273.15 K. Given:

(Molar mass of sucrose = 342 g mol^{-1})

(Molar mass of glucose = 180 g mol^{-1})

[CBSE Delhi Set-1, 2, 3 2017]

(ii) Define the following terms:

(a) Molality (m)

(b) Abnormal molar mass

A + R **[CBSE OD Set-1, 2, 3 2017]**

Ans. (i) $\Delta T_f = K_f m$ ½

Here, $m = w_2 \times 1000/M_2 \times M_2$

$273.15 - 269.15 = K_f \times 10 \times 1000/342 \times 90$ **1**

K_f = 12.3 K kg/mol ½

$\Delta T_f = K_f m$

= 12.3× 10 × 1000/180 × 90

= 7.6 K

T_f = 273.15 – 7.6 = 265.55 K

(or any other correct method) 1

(ii) (a) Number of moles of solute dissolved in per kilo gram of the solvent. **1**

(b) Abnormal molar mass: If the molar mass calculated by using any of the colligative properties to be different than theoretically expected molar mass. **1**

[CBSE Marking Scheme 2017]

AI Q. 6. (i) What type of deviation is shown by a mixture of ethanol and acetone ? Give reason.

(ii) A solution of glucose (molar mass = 180 g mol^{-1}) in water is labelled as 10% (by mass). What would be the molality and molarity of the solution ?

(Density of solution = 1.2 g mL^{-1})

R + A **[CBSE OD 2014]**

Ans. **(i)** It shows positive deviation. **1**

It is due to weaker interaction between acetone and ethanol than ethanol-ethanol interactions. **1**

(ii) Given : $W_B = 10$ g, $W_S = 100$ g, $W_A = 90$ g, $M_B = 180$ g/mol and d = 1.2 g/mL

$$M = \frac{\text{Wt \%} \times \text{density} \times 10}{\text{Mol.wt.}} \quad ½$$

$$M = \frac{10 \times 1.2 \times 10}{180} \quad ½$$

$$= 0.66 \text{ M or } 0.66 \text{ mol/L} \quad ½$$

$$m = \frac{W_B \times 1000}{M_B \times W_A (\text{in g})} \quad ½$$

$$m = \frac{10 \times 1000}{180 \times 90}$$

$$= 0.61 \text{ m or } 0.61 \text{ mol/kg}$$

(or any other suitable method) 1

[CBSE Marking Scheme 2014]

Commonly Made Error

- Calculation errors are commonly seen. In many answers, no unit is written with the final answer.

Answering Tip

- Write essential steps and express the final answer alongwith a proper unit.

Q. 7. (i) The vapour pressure of benzene and toluene at 293 K are 75 mm Hg and 22 mm Hg respectively. 23.4 g of benzene and 64.4 g of toluene are mixed. If the two form an ideal solution, calculate the mole fraction of benzene in the vapour phase assuming that the vapour pressures are in equilibrium with the liquid mixture at this temperature.

(ii) What is meant by + ve and – ve deviations from Raoult's law and how is the sign of ΔH solution related to + ve and – ve deviations from Raoult's law ? A&C **[CBSE Comptt. OD 2013]**

Ans. (i) Calculation of the total vapour pressure

Moles of benzene (n_A)

$$= \frac{\text{Mass of benzene}}{\text{Molar mass of benzene } (C_6H_6)}$$

$$= \frac{(23.4\text{g})}{(78 \text{ g mol}^{-1})} = 0.3 \text{ mol}$$

Moles of toluene (n_B)

$$= \frac{\text{Mass of toluene}}{\text{Molar mass of toluene } (C_7H_8)}$$

$$= \frac{(64.4 \text{ g})}{(92 \text{g mol}^{-1})} = 0.7 \text{ mole}$$

Mole fraction of benzene (χ_A)

$$= \frac{n_A}{n_A + n_B}$$

$$= \frac{(0.3 \text{ mole})}{(0.3 \text{ mole} + 0.7 \text{ mole})} = 0.3$$

Mole fraction of toluene (χ_B)

$$= \frac{n_B}{n_A + n_B}$$

$$= \frac{(0.7 \text{ mole})}{(0.3 \text{ mole} + 0.7 \text{ mole})} = 0.7$$

Vapour pressure of toluene in solution (p_A)

$= p°_A \times \chi_A = (75 \text{ mm}) \times 0.3$

$= 22.5$ mm

Vapour pressure of toluene in solution (p_B)

$= p°_B \times \chi_B$

$= (22 \text{ mm}) \times 0.7$

$= 15.4$ mm

Total vapour pressure of solution

$= p_A + p_B$

$= 22.5 + 15.4$

$= 37.9$ mm

Calculation of mole fraction of benzene in the vapour phase:

Mole fraction of benzene in vapour phase

$$= \frac{\text{Partial vapour pressure of benzene}}{\text{Total vapour pressure}}$$

$$= \frac{(22.5 \text{ mm})}{(37.9 \text{ mm})} = 0.59 \quad 3$$

(ii) Solutions showing positive deviations, the partial vapour pressure of each component of solution is greater than the vapour pressure as expected according to Raoult's law.

Solutions showing negative deviations, the partial vapour pressure of each component of solution is less than vapour pressure as expected according to Raoult's law. **1**

For positive deviation $\Delta_{mix}H = + \text{ve}$ ½

For negative deviation $\Delta_{mix}H = - \text{ve}$ ½

Answering Tips

- Write essential steps while solving numerical.
- Be specific to what is asked in the question. Avoid unnecessary explanations.

Q. 8. (i) A 5% solution (by mass) of cane – sugar in water has freezing point of 271 K. Calculate the freezing point of 5% solution (by mass) of glucose in water if the freezing point of pure water is 273.15 K. [Molecular masses : Glucose $C_6H_{12}O_6$: 180 amu; Cane – sugar $C_{12}H_{12}O_{11}$: 342 amu]

(ii) State Henry's law and mention two of its important applications. A + R **[CBSE Comptt. OD 2013]**

Ans. (i) 5% by mass cane sugar = 5 g cane sugar (Mol. wt = 342 amu in 100 g solution)

$$n_B = \frac{5}{342} \text{ and } w_A = 95 \text{ g}$$

$$\Delta T_f = 273.15 - 271 = 2.15 \text{ K}$$

$$K_f = \frac{\Delta T_f \times w_A}{n_B \times 1000} = \frac{2.15 \times 95}{\frac{5}{342} \times 1000}$$

$$= 13.97 \text{ K kg mol}^{-1}$$

5% by mass glucose = 5 g glucose (Mol. wt = 180 amu)in 100 g solution

$$\Delta T_f = K_f \times \frac{n_B 1000}{w_A} = 13.97 \times \frac{5}{180} \times \frac{1000}{95}$$

$$= 4.085 \text{ K}$$

$$T_f = 273.15 - 4.085$$

Freezing point of glucose solution,

$$T_f = 269.065 \text{ K}$$ **3**

(ii) According to Henry's law, the partial pressure of a gas in vapour phase (p) is directly proportional to the mole fraction (x) of the gas in the solution. **1**

Henry's law is applied in the production of carbonated beverages and for the deep-sea-divers. **1**

Commonly Made Error

- Students often forget to subtract the value obtained with freezing point of pure water.

Answering Tip

- Students should remember that freezing point is decreased on addition of a non volatile solute in a solution. So, T_p will be greater. Hence, subtraction needs to be done.

AI **Q. 9. (i) State Raoult's law for a solution containing volatile components. How does Raoult's law becomes a special case of Henry's law ?**

(ii) 1.00 g of a non-electrolyte solute dissolved in 50 g of benzene lowered the freezing point of benzene by 0.40 K. Find the molar mass of the solute. (K_f for benzene = 5.12 K kg mol^{-1}).

R + U + A **[CBSE OD 2013]**

Ans. (i) Partial vapour pressure of a liquid component is directly proportional to its mole fraction in its solution. **1**

The partial pressure of the volatile component or gas is directly proportional to its mole fraction in solution. Only the proportionality constant K_H differs from $p_A°$. Thus, Raoult's law becomes a special case of Henry's law in which K_H becomes equal to $p_A°$. **1**

(ii) Given, $W_B = 1.00$ g, $W_A = 50$ g, $K_f = 5.12$ K kg mol^{-1}; $\Delta T_f = 0.40$ K

$$\Delta T_f = K_f \frac{W_B \times 1000}{M_B \times W_A (\text{in grams})}$$ **1**

$$M_B = K_f \frac{W_B \times 1000}{\Delta T_f \times W_A}$$ **1**

$$= \frac{5.12 \times 1 \times 1000}{0.40 \times 50} \text{ g mol}^{-1}$$

$$= 256 \text{ g mol}^{-1}$$ **1**

Q.10. (i) Explain why on addition of 1 mol glucose to 1 litre water the boiling point of water increases.

(ii) Henry's law constant for CO_2 in water is 1.67×10^8 Pa at 298 K. Calculate the number of moles of CO_2 in 500 ml of soda water when packed under 2.53×10^5 Pa at the same temperature.

A&E **[CBSE Comptt. OD Set-1, 2, 3 2017]**

Ans.(i) Vapour pressure of the solvent decreases in the presence of non-volatile solute (glucose) hence boiling point increases. **2**

(ii) $\rho_{Co_2} = K_H \chi_{Co_2}$ ½

$\chi_{Co_2} = \rho_{Co_2}/K_H$

$= 2.53 \times 10^5 \text{ Pa}/1.67 \times 10^8 \text{ Pa} = 1.51 \times 10^{-3}$

$n_{H_2o} = 500 \text{ g}/18 \text{ g/mol} = 27.77 \text{ mol}$ **1**

Let $n_{Co_2} = n$ mol

$\chi_{Co_2} = n/(27.77 + n) = 1.51 \times 10^{-3}$ ½

$n_{Co_2} = 1.51 \times 10^{-3} \times 27.77 \text{ mol} = 0.042 \text{ mol}$ **1**

[CBSE Marking Scheme 2017]

Q. 11. (i) Define the following terms:

(a) Ideal solution

(b) Osmotic pressure.

(ii) Calculate the boiling point elevation for a solution prepared by adding 10 g $CaCl_2$ to 200 g of water, assuming that $CaCl_2$ is completely dissociated. (K_b for water = 0.512 K kgmol^{-1}; Molar mass of $CaCl_2$ = 111 g mol^{-1})

R + A **[CBSE Comptt. OD Set-1, 2, 3 2017]**

Ans.(i) (a) The solution which obey Raoult's law over the entire range of concentration. **1**

(b) It is the excess pressure that must be applied to a solution to prevent osmosis. **1**

(ii) $\Delta T_b = iK_b m$

Here, $m = w_B \times 1000/M_B \times w_A$ **1**

$\Delta T_b = [3 \times 0.512 \text{ K kg mol}^{-1} \times 1000 \times 10 \text{ g}/$

$[111 \text{ g mol}^{-1} \times 200 \text{ g}]$ **1**

$= 0.69$ K **1**

[CBSE Marking Scheme 2017]

Q. 12. (i) Calculate the freezing point of solution when 1.9 g of $MgCl_2$ (M = 95 g mol^{-1}) was dissolved in 50 g of water, assuming $MgCl_2$ undergoes complete ionization. (K_f for water = 1.86 K kg mol^{-1})

(ii) (a) Out of 1 M glucose and 2 M glucose, which one has a higher boiling point and why?

(b) What happens when the external pressure applied becomes more than the osmotic pressure of solution ?

OR

(i) When 2.56 g of sulphur was dissolved in 100 g of CS_2, the freezing point lowered by 0.383 K. Calculate the formula of sulphur (S_X). (K_f for CS_2 = 3.83 K kg mol^{-1}, Atomic mass of Sulphur = 32 g mol^{-1}).

(ii) Blood cells are isotonic with 0.9% sodium chloride solution. What happens if we place blood cells in a solution containing;

(a) 1.2% sodium chloride solution ?

(b) 0.4% sodium chloride solution ?

A + U **[CBSE Delhi 2016]**

Ans.(i)

$$\Delta T_f = i \frac{K_f W_b \times 1000}{M_b \times W_a}$$ **1**

$$\Delta T_f = 3 \times \left(\frac{1.86 \times 1.9}{95 \times 50}\right) \times 1000$$ **1**

$$= 2.23 \text{ K}$$

$$\Delta T_f - \Delta T_f' = 273.15 - 2.23$$

$$T_f' = 270.92 \text{ K} \qquad \mathbf{1}$$

(ii) (a) 2 M glucose has a higher boiling point because higher the number of particles lesser is the vapour pressure. ½ + ½

(b) Reverse osmosis. **1**

OR

(i)
$$\Delta T_f = \frac{K_f W_b \times 1000}{M_b \times W_a} \qquad \mathbf{1}$$

$$0.383 = \left(\frac{3.83 \times 2.56}{M \times 100}\right) \times 1000 \qquad \mathbf{1}$$

$$M = 256$$

$$S \times x = 256$$

$$32 \times x = 256$$

$$x = 8 \qquad \mathbf{1}$$

(ii) (a) If we place blood cells in solution containing 1.2% sodium chloride solution, they shrink. **1**

(b) It we place blood cells in solution containing 0.4% sodium chloride solution, they swell. **1**

[CBSE Marking Scheme 2016]

Q. 13. How can you remove the hard calcium carbonate layer of the egg without damaging its semipermeable membrane? Can this egg be inserted into a bottle with a narrow neck without distorting its shape? Explain the process involved.

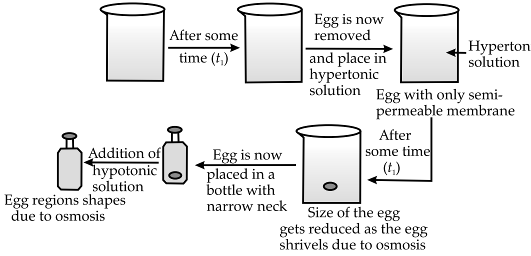
C [NCERT Exemp. Q. 61, Page 28]

Ans. This can be achieved as under :

(i) Place the egg in a mineral acid solution for about 2 hours. The outershell of the egg dissolves. Remove any portion left with your fingers.

(ii) Place the egg in a saturated solution (hypertonic) of sodium chloride for about 3 hours. Size of the egg is reduced as the egg shrivels due to osmosis.

(iii) Insert the egg in a bottle with a narrow neck. Add water to the bottle. Water will act as hypotonic solution. Egg regains shape due to osmosis. This is shown diagrammatically as under :



5

Q. 14. Why is the mass determined by measuring a colligative property in case of some solutes abnormal? Discuss it with the help of Van't Hoff factor. **C [NCERT Exemp. Q. 62, Page 28]**

Ans. Certain compounds when dissolved in suitable solvents either dissociate or associate.

For example, ethanoic acid dimerizes in benzene due to hydrogen bonding, while in water, it dissociates and forms ions. As a result, the number of chemical species in solution increases or decreases as compared to the number of chemical species of solute added to form the solution. Since, the magnitude of colligative property depends on the number of solute particles, it is expected that the molar mass determined on the basis of colligative properties will be either higher or lower than the expected value or the normal value and is called abnormal molar mass.

In order to account for the extent of dissociation or association of molecules in solution, Van't Hoff introduced a factor, i, known as the Van't Hoff factor. **5**

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