

Solutions

EXERCISES [PAGES 44 - 46]

Exercises | Q 1.01 | Page 44

Choose the most correct option.

The vapour pressure of a solution containing 2 moles of a solute in 2 moles of water (vapour pressure of pure water = 24 mm Hg) is _____.

1. 24 mm Hg
2. 32 mm Hg
3. 48 mm Hg
4. **12 mm Hg**

Solution: The vapour pressure of a solution containing 2 moles of a solute in 2 moles of water (vapour pressure of pure water = 24 mm Hg) is **12 mm Hg**.

Exercises | Q 1.02 | Page 44

Choose the most correct option.

The colligative property of a solution is _____.

1. vapour pressure
2. boiling point
3. **osmotic pressure**
4. freezing point

Solution: The colligative property of a solution is **osmotic pressure**.

Exercises | Q 1.03 | Page 44

Choose the most correct option.

In calculating osmotic pressure the concentration of solute is expressed in _____.

1. **molarity**
2. molality
3. mole fraction
4. mass percent

Solution: In calculating osmotic pressure the concentration of solute is expressed in **molarity**.

Exercises | Q 1.04 | Page 44

Choose the most correct option.

Ebullioscopic constant is the boiling point elevation when the concentration of a solution is _____.

1. **1 m**
2. 1 M
3. 1 mass %
4. 1-mole fraction of solute.

Solution: Ebullioscopic constant is the boiling point elevation when the concentration of solution is **1 m**.

Exercises | Q 1.05 | Page 44

Choose the most correct option.

Cryoscopic constant depends on _____.

1. nature of solvent
2. nature of solute
3. nature of solution
4. **number of solvent molecules**

Solution: Cryoscopic constant depends on **number of solvent molecules**.

Exercises | Q 1.06 | Page 45

Choose the most correct option.

Identify the CORRECT statement.

1. Vapour pressure of solution is higher than that of pure solvent.
2. **Boiling point of solvent is lower than that of solution.**
3. Osmotic pressure of solution is lower than that of solvent.
4. Osmosis is a colligative property.

Solution: Boiling point of solvent is lower than that of solution.

Exercises | Q 1.07 | Page 45

Choose the most correct option.

A living cell contains a solution which is isotonic with 0.3 M sugar solution. What osmotic pressure develops when the cell is placed in 0.1 M KCl solution at body temperature?

1. 5.08 atm
2. **2.54 atm**
3. 4.92 atm

4. 2.46 atm

Solution: 2.54 atm.

Exercises | Q 1.08 | Page 45

Choose the most correct option.

The osmotic pressure of blood is 7.65 atm at 310 K. An aqueous solution of glucose isotonic with blood has the percentage (by volume)_____.

1. **5.41 %**
2. 3.54 %
3. 4.53 %
4. 53.4 %

Solution: The osmotic pressure of blood is 7.65 atm at 310 K. An aqueous solution of glucose isotonic with blood has the percentage (by volume) **5.41%**.

Explanation:

$$\begin{aligned}M_2 &= \frac{W_2 RT}{\pi V} \\ \frac{W_2}{V} &= \frac{\pi M_2}{RT} \\ &= \frac{7.65 \text{ atm} \times 180 \text{ g mol}^{-1}}{0.08205 \text{ atm dm}^3 \text{ K}^{-1} \text{ mol}^{-1} \times 310 \text{ K}} \\ &= 54.1 \text{ g dm}^{-3} = 5.41 \text{ g cm}^{-3} = 5.41\%\end{aligned}$$

Exercises | Q 1.09 | Page 45

Choose the most correct option.

Vapour pressure of a solution is _____.

1. directly proportional to the mole fraction of the solute
2. **inversely proportional to the mole fraction of the solute**
3. inversely proportional to the mole fraction of the solvent
4. directly proportional to the mole fraction of the solvent

Solution:

Vapour pressure of a solution is **inversely proportional to the mole fraction of the solute.**

Exercises | Q 1.1 | Page 45

Choose the most correct option.

Pressure cooker reduces cooking time for food because _____.

1. **boiling point of water involved in cooking is increased**
2. heat is more evenly distributed in the cooking space
3. the higher pressure inside the cooker crushes the food material
4. cooking involves chemical changes helped by a rise temperature

Solution:

Pressure cooker reduces cooking time for food because **boiling point of water involved in cooking is increased**.

Exercises | Q 1.11 | Page 45

Choose the most correct option.

Henry's law constant for a gas CH_3Br is $0.159 \text{ mol dm}^{-3} \text{ atm}^{-1}$ at 25°C . What is the solubility of CH_3Br in water at 25°C and partial pressure of 0.164 atm ?

1. $0.0159 \text{ mol L}^{-1}$
2. 0.164 mol L^{-1}
3. **0.026 M**
4. 0.042 M

Solution: 0.026 M

Explanation:

$$\begin{aligned} S &= K_{\text{HP}} = 0.159 \text{ mol dm}^{-3} \text{ atm}^{-1} \times 0.164 \text{ atm} \\ &= 0.026 \text{ M} \end{aligned}$$

Exercises | Q 1.12 | Page 45

Choose the most correct option.

Which of the following statement is NOT correct for 0.1 M urea solution and 0.05 M sucrose solution?

1. Osmotic pressure exhibited by urea solution is higher than that exhibited by sucrose solution
2. Urea solution is hypertonic to sucrose solution
3. **They are isotonic solutions**
4. Sucrose solution is hypotonic to urea solution

Solution: They are isotonic solutions.

Exercises | Q 2.01 | Page 45

Answer the following in one or two sentences.

What is osmotic pressure?

Solution:

The hydrostatic pressure (on the side of solution) that stops osmosis is called an osmotic pressure of the solution.

OR

The excess of pressure on the side of the solution that stops the net flow of solvent into the solution through a semipermeable membrane is called osmotic pressure.

Exercises | Q 2.02 | Page 45

Answer the following in one or two sentences.

A solution concentration is expressed in molarity and not in molality while considering osmotic pressure. Why?

Solution:

1. The osmotic pressure measurements are made at a specific constant temperature. Molarity remains constant at a specific temperature.
2. It is not necessary to express concentration in a temperature-independent unit like molality.

Hence, the solute concentration is expressed in molarity while calculating osmotic pressure rather than molality.

Exercises | Q 2.03 | Page 45

Answer the following in one or two sentences.

Write the equation relating boiling point elevation to the concentration of the solution.

Solution:

The boiling point elevation is directly proportional to the molality of the solution. Thus,

$$\Delta T_b \propto m$$

$$\therefore \Delta T_b \propto K_b m$$

where, m is the molality of solution. The proportionality constant K_b is called boiling point elevation constant or molal elevation constant or ebullioscopic constant.

Exercises | Q 2.04 | Page 45

Answer the following in one or two sentences.

A 0.1 m solution of K_2SO_4 in water has a freezing point of $-4.3\text{ }^{\circ}\text{C}$. What is the value of van't Hoff factor if K_f for water is $1.86\text{ K kg mol}^{-1}$?

Solution:

Given: Molality of K_2SO_4 solution = $m = 0.1\text{ m}$

Freezing point of solution = $T_f = -4.3\text{ }^{\circ}\text{C}$

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

To find: van't Hoff factor

Formula: $\Delta T_f = i K_f m$

Calculation:

$$\Delta T_f = T_f^0 - T_f$$

$$= 0\text{ }^{\circ}\text{C} - (-4.3\text{ }^{\circ}\text{C}) = 4.3\text{ }^{\circ}\text{C} = 4.3\text{ K}$$

Now, using formula,

$$\Delta T_f = i K_f m$$

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

$$= \frac{4.3\text{K}}{1.86\text{K kg mol}^{-1} \times 0.1\text{mol kg}^{-1}}$$

$$= 23.1$$

The value of van't Hoff factor is 23.1.

Exercises | Q 2.05 | Page 45

Answer the following in one or two sentences.

What is van't Hoff factor?

Solution:

van't Hoff factor (i) is defined as the ratio of colligative property of a solution of electrolyte divided by the colligative property of nonelectrolyte solution of the same concentration.

Thus,

$$i = \frac{\text{colligative property of electrolyte solution}}{\text{colligative property of nonelectrolyte solution of the same concentration}}$$

$$= \frac{\Delta T_f}{(\Delta T_f)_0} = \frac{\Delta T_b}{(\Delta T_b)_0} = \frac{\Delta P}{(\Delta P)_0} = \frac{\pi}{(\pi)_0}$$

where quantities without subscript refer to electrolytes and those with subscript to nonelectrolytes.

Exercises | Q 2.06 | Page 45

Answer the following in one or two sentences.

How is van't Hoff factor related to degree of ionization?

Solution:

The van't Hoff factor is related to degree of ionization as follows:

$$i = 1 + \alpha (n - 1)$$

or

$$\alpha = i - 1 / n - 1$$

where, α = Degree of ionization/dissociation

i = van't Hoff factor

n = Moles of ions obtained from ionization of 1 mole of electrolyte.

Exercises | Q 2.07 | Page 45

Answer the following in one or two sentences.

Which of the following solution will have higher freezing point depression and why?

i. 0.1 m NaCl

ii. 0.05 m $\text{Al}_2(\text{SO}_4)_3$

Solution:

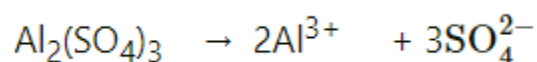
For 0.1 m NaCl:



0.1 m 0.1 m 0.1 m

Total particles in solution = 0.2 mol

For 0.05 m $\text{Al}_2(\text{SO}_4)_3$:



0.05 m 0.1 m 0.15 m

Total particles in solution = 0.25 mol

$\text{Al}_2(\text{SO}_4)_3$ solution contains more number of particles than NaCl solution. Hence, $\text{Al}_2(\text{SO}_4)_3$ solution has maximum ΔT_f .

Therefore, the freezing point depression of 0.05 m $\text{Al}_2(\text{SO}_4)_3$ solution will be higher than 0.1 m NaCl solution.

Exercises | Q 2.08 | Page 45

Answer the following in one or two sentences.

State Raoult's law for a solution containing a nonvolatile solute.

Solution:

The Raoult's law states that, "the vapour pressure of solvent over the solution is equal to the vapour pressure of pure solvent multiplied by its mole fraction in the solution."

Exercises | Q 2.09 | Page 45

Answer the following in one or two sentences.

What is the effect on the boiling point of water if 1 mole of methyl alcohol is added to 1 dm^3 of water? Why?

Solution:

- i. When 1 mole of methyl alcohol is added to 1 dm^3 of water, the boiling point of water decreases.
- ii. Methyl alcohol is a volatile liquid. Therefore, it increases the vapour pressure of a solution at a given temperature. Hence, the solution boils at lower temperature.

Exercises | Q 2.1 | Page 45

Answer the following in one or two sentences.

Which of the four colligative properties is most often used for molecular mass determination? Why?

Solution:

- i. Among the four colligative properties, osmotic pressure is most often used for molecular mass determination.
- ii. Osmotic pressure is much larger and therefore more precisely measurable property than other colligative properties.

Therefore, it is useful to determine molar masses of very expensive substances and of the substances that can be prepared in small quantities.

Exercises | Q 3.1 | Page 45

Answer the following.

How vapour pressure lowering is related to a rise in the boiling point of solution?

Solution:

- i. At the boiling point of a liquid, its vapour pressure is equal to 1 atm.
- ii. In order to reach boiling point, the solution and solvent must be heated to a temperature at which their respective vapour pressures attain 1 atm.
- iii. At any given temperature the vapour pressure of a solution is lower than that of pure solvent. Hence, the vapour pressure of solution needs a higher temperature to reach 1 atm than that of needed for vapour pressure of solvent.

Therefore, vapour pressure lowering causes a rise in the boiling point of a solution.

Exercises | Q 3.2 | Page 45

Answer the following.

What are isotonic and hypertonic solutions?

Solution:

i. Isotonic solutions:

Two or more solutions having the same osmotic pressure are said to be isotonic solutions.

e.g. For example, 0.1 M urea solution and 0.1 M sucrose solution are isotonic because their osmotic pressures are equal. Such solutions have the same molar concentrations but different concentrations in g/L. If these solutions are separated by a semipermeable membrane, there is no flow of solvent in either direction.

ii. Hypertonic solution:

If two solutions have unequal osmotic pressures, the more concentrated solution with higher osmotic pressure is said to be the hypertonic solution.

e.g. For example, if osmotic pressure of sucrose solution is higher than that of urea solution, the sucrose solution is hypertonic to urea solution.

Exercises | Q 3.3 | Page 46

Answer the following.

A solvent and its solution containing a nonvolatile solute are separated by a semipermeable membrane. Does the flow of solvent occur in both directions? Comment giving a reason.

Solution:

1. When a solution and pure solvent or two solutions of different concentrations are separated by a semipermeable membrane, the solvent molecules pass through the membrane.
2. The passage of solvent molecules through the semipermeable membrane takes place in both directions, since the solvent is on both sides of the membrane.
3. However, the rate of passage of solvent molecules into the solution or from a more dilute solution to more concentrated solution is found to be greater than the rate in the reverse direction.
4. This is favorable since the vapour pressure of solvent is greater than that of solution.

Exercises | Q 3.4 | Page 46

Answer the following.

The osmotic pressure of CaCl_2 and urea solutions of the same concentration at the same temperature are respectively 0.605 atm and 0.245 atm, calculate van't Hoff factor for CaCl_2 .

Solution:

Given: Osmotic pressure of CaCl_2 solution = 0.605 atm

Osmotic pressure of urea solution = 0.245 atm

To find: The value of van't Hoff factor

Formulae: $\pi = MRT$, $\pi = iMRT$

Calculation: For urea solution

$$\pi = MRT$$

$$0.245 \text{ atm} = MRT \quad \dots(i)$$

For CaCl_2 solution

$$\pi = iMRT$$

$$0.602 \text{ atm} = iMRT \quad \dots(ii)$$

From equations (i) and (ii),

$$\frac{0.605}{0.245} = \frac{iMRT}{MRT}$$

$$\therefore i = 2.47$$

The value of van't Hoff factor is 2.47.

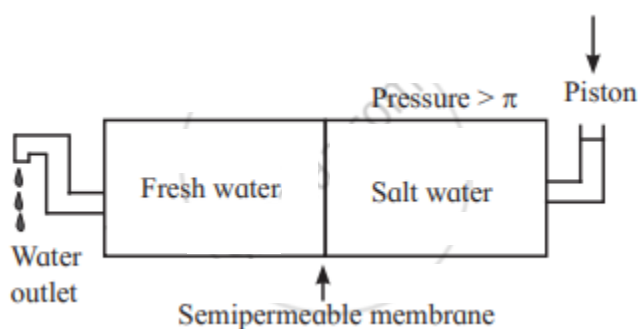
Exercises | Q 3.5 | Page 46

Answer the following.

Explain reverse osmosis.

Solution:

- i. If a pressure larger than the osmotic pressure is applied to the solution side, then pure solvent from the solution passes into pure solvent side through the semipermeable membrane. This phenomenon is called reverse osmosis.
- ii. For example, consider fresh water salt water separated by a semipermeable membrane. When the pressure larger than the osmotic pressure of a solution is applied to solution, pure water from salty water passes into fresh pure water through the membrane. Thus, the direction of osmosis can be reversed by applying a pressure larger than the osmotic pressure.
- iii. The schematic set up for reverse osmosis is as follows:



Exercises | Q 3.6 | Page 46

Answer the following.

How molar mass of a solute is determined by osmotic pressure measurement?

Solution:

1. For very dilute solutions, the osmotic pressure follows the equation,

$$\pi = \frac{n_2 RT}{V} \quad \dots(1)$$

2. If the mass of solute in V litres of a solution is W₂ and its molar mass is

$$M_2, \text{ then } n_2 = \frac{W_2}{M_2}$$

Substituting the value of n₂ in equation (1), we get

$$\pi = \frac{W_2 RT}{M_2 V}$$

$$\therefore M_2 = \frac{W_2 RT}{\pi V}$$

This formula can be used for the calculation of molar mass of a nonionic solute (i.e., nonelectrolyte), by osmotic pressure measurement.

Exercises | Q 3.7 | Page 46

Answer the following.

Why vapour pressure of a solvent is lowered by dissolving a nonvolatile solute into it?

Solution:

- i. Vapour pressure of a liquid depends on the ease with which the molecules escape from the surface of the liquid.
- ii. When a nonvolatile solute is dissolved in a solvent, some of the surface molecules of the solvent are replaced by nonvolatile solute molecules. These solute molecules do not contribute to vapour above the solution.
- iii. Thus, the number of solvent molecules available for vaporization per unit surface area of a solution is less than the number at the surface of the pure solvent.
- iv. As a result the solvent molecules at the surface of solution vaporize at a slower rate than pure solvent. This results in lowering of vapour pressure

Exercises | Q 3.8 | Page 46

Answer the following.

Using Raoult's law, how will you show that $\Delta P = P_1^0 x_2$? Where, x₂ is the mole fraction of solute in the solution and P₁⁰ vapour pressure of pure solvent.

Solution:

1. Raoult's law expresses the quantitative relationship between vapour pressure of solution and vapour pressure of the solvent.
2. In solutions of nonvolatile solutes, the law is applicable only to the volatile solvent.
3. The law states that, "the vapour pressure of solvent over the solution is equal to the vapour pressure of pure solvent multiplied by its mole fraction in the solution."
4. Suppose that for a binary solution containing solvent and one nonvolatile solute, P_1 is the vapour pressure of

solvent over the solution, x_1 and x_2 are the mole fractions of solvent and solute, respectively and P_1^0 is the vapour pressure of pure solvent, then, $P_1 = P_1^0 x_1$.

5. Since, $x_1 = 1 - x_2$,

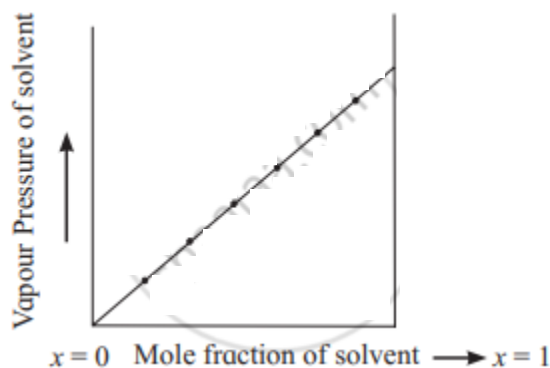
$$P_1 = P_1^0 x_1 = P_1^0 (1 - x_2) = P_1^0 - P_1^0 x_2$$

$$\therefore P_1^0 - P_1 = P_1^0 x_2$$

$$\therefore \Delta P = P_1^0 x_2 \quad (\because \Delta P \text{ is the lowering of vapour pressure})$$

Note: A plot of P_1 versus x_1 is a straight as shown below.

Variation of vapour pressure of solution with mole fraction of solvent



Exercises | Q 3.9 | Page 46

Answer the following.

While considering boiling point elevation and freezing point depression a solution concentration is expressed in molality and not in molarity. Why?

Solution:

1. In boiling point elevation and freezing point depression, we deal with the systems whose temperature is not constant.

2. We cannot express the concentration of the solution in molarity because it changes with temperature whereas molality is temperature independent.

Hence, while considering boiling point elevation and freezing point depression a solution concentration is expressed in molality and not in molarity.

Exercises | Q 4 | Page 46

Derive the relationship between the degree of dissociation of an electrolyte and van't Hoff factor.

Solution:

1. The weak electrolytes involve the concept of degree of dissociation (α) that changes the van't Hoff factor.

2. Consider an electrolyte A_xB_y that dissociates in aqueous solution as

	$A_xB_y \rightleftharpoons xA^{y+} + yB^{x-}$		
Initially	1 mol	0	0
At equilibrium	$(1 - \alpha)$ mol	$(x\alpha)$ mol	$(y\alpha)$ mol

3. If α is the degree of dissociation of electrolyte, then the moles of cations are $x\alpha$ and those of anions are $y\alpha$ equilibrium. We have dissolved just 1 mol of electrolyte initially. α mol of electrolyte dissociates and $(1 - \alpha)$ mol remains undissociated at equilibrium.

Total moles after dissociation = $(1 - \alpha) + (x\alpha) + (y\alpha)$

$$= 1 + \alpha(x + y - 1)$$

$$= 1 + \alpha(n - 1)$$

where, $n = x + y$ = moles of ions obtained from dissociation of 1 mole of electrolyte.

4. The van't Hoff factor given as

$$i = \frac{\text{actual moles of particles in solution after dissociation}}{\text{moles of formula units dissolved in solution}}$$

$$= \frac{1 + \alpha(n - 1)}{1}$$

$$\text{Hence, } i = 1 + \alpha(n - 1) \text{ or } \alpha = \frac{i - 1}{n - 1}$$

Exercises | Q 5 | Page 46

What is the effect of temperature on solubility of solids in water? Give examples.

Solution:

1. The effect of temperature on solubility of a substance depends on enthalpy of solution.

a. When the substance dissolves in water by an endothermic process, that is, with the absorption of heat, its solubility increases with an increase of temperature.

e.g. KCl dissolve in water by endothermic process.

b. On the other hand, when the substance dissolves in water by an exothermic process, that is, with the release of heat, its solubility decreases with an increase of temperature.

e.g. CaCl_2 and $\text{Li}_2\text{SO}_4 \cdot \text{H}_2\text{O}$ dissolve in water releasing heat.

2. It is important to understand that there is no direct correlation between solubility and exothermicity or endothermicity. For example, dissolution of CaCl_2 in water is exothermic and that of NH_4NO_3 is endothermic. However, the solubility of these substances increases with the temperature

Exercises | Q 6 | Page 46

Obtain the relationship between freezing point depression of a solution containing nonvolatile-nonelectrolyte solute and its molar mass.

Solution:

1. The freezing point depression (ΔT_f) is directly proportional to the molality of solution.

Thus, $\Delta T_f = K_f m$ (1)

2. Suppose we prepare a solution by dissolving W_2 g of solute in W_1 g of solvent.

$$\text{Moles of solute in } W_1 \text{ g of solvent} = \frac{W_2}{M_2}$$

where, M_2 is the molar mass of solute.

$$\text{Mass of solvent} = W_1 \text{ g} = \frac{W_1 \text{ g}}{100 \text{ g/kg}} = \frac{W_1}{1000} \text{ kg}$$

3. The molality is expressed as,

$$m = \frac{\text{Moles of solute}}{\text{Mass of solvent in kg}}$$

$$m = \frac{W_2/M_2 \text{ mol}}{W_1/1000 \text{ kg}}$$

$$m = \frac{1000W_2}{M_2W_1} \text{ mol kg}^{-1} \quad \dots(2)$$

4. Substituting equation (2) in equation (1), we get,

$$\Delta T_f = \frac{1000K_f W_2}{M_2 W_1}$$

Hence,

$$M_2 = \frac{1000K_f W_2}{\Delta T_f W_1}$$

Exercises | Q 7 | Page 46

Explain with diagram the boiling point elevation in terms of vapour pressure lowering.

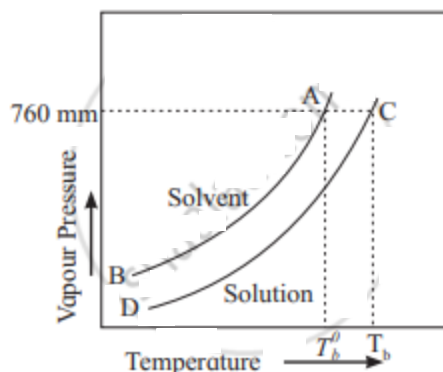
Solution:

1. The vapour pressures of a solution and of pure solvent are plotted as a function of temperature in the given diagram.
2. At any temperature, the vapour pressure of a solution is lower than that of pure solvent. Hence, the vapour pressure-temperature curve of solution (CD) lies below that of solvent (AB).
3. The difference between the two vapour pressures increases as temperature and vapour pressure increase as predicted by the equation,

$$\Delta P = P_1^0 x_2$$

4. The intersection of the curve CD with the line corresponding to 760 mm is the boiling point of solution. The similar intersection of the curve AB is the boiling point of pure solvent. It is clear from the diagram that the boiling point of the solution (T_b) is higher than that of pure solvent (T_b^0).

5. At the boiling point of a liquid, its vapour pressure is equal to 1 atm.
6. In order to reach boiling point, the solution and solvent must be heated to a temperature at which their respective vapour pressures attain 1 atm.
7. At any given temperature the vapour pressure of solution is lower than that of pure solvent. Hence, the vapour pressure of solution needs a higher temperature to reach 1 atm than that needed for vapour pressure of solvent.
8. In other words, the solution must be heated to higher temperature to cause it to boil than the pure solvent.



**Vapour pressure-temperature
of pure solvent and solution**

Exercises | Q 8 | Page 46

Fish generally needs O_2 concentration in water at least 3.8 mg/L for survival. What partial pressure of O_2 above the water is needed for the survival of fish? Given the solubility of O_2 in water at $0^\circ C$ and 1 atm partial pressure is 2.2×10^{-3} mol/L.

Solution:

Given: O_2 concentration in water required for fishes = 3.8 mg/L

Solubility of O_2 in water = 2.2×10^{-3} mol/L

Pressure = 1 atm

To find: Partial pressure of O_2 above the water needed for the survival of fish.

Formula: $S = K_H P$

Calculation: Pressure = 1 atm = 1.013 bar

Now, using formula and rearranging,

$$K_H = \frac{S}{P} = \frac{2.2 \times 10^{-3} \text{ mol / L}}{1.013 \text{ bar}} = 2.17 \times 10^{-3} \text{ mol L}^{-1} \text{ bar}^{-1}$$

O_2 concentration in water required for fishes

$$= 3.8 \text{ mg/L} = \frac{3.8 \times 10^{-3} \text{ g/L}}{32 \text{ g/mol}} = 1.19 \times 10^{-4} \text{ mol L}^{-1}$$

Now, using formula and rearranging,

$$P = \frac{S}{K_H} = \frac{1.19 \times 10^{-4} \text{ mol L}^{-1}}{2.17 \times 10^{-3} \text{ mol L}^{-1} \text{ bar}^{-1}} = 0.0548 \text{ bar}$$

The partial pressure of O₂ above the water needed for the survival of fish is 0.0548 bar.

Exercises | Q 9 | Page 46

The vapour pressure of water at 20 °C is 17 mm Hg. What is the vapour pressure of solution containing 2.8 g urea in 50 g of water?

Solution:

Given: Vapour pressure of pure water = $P_1^0 = 17 \text{ mm Hg}$

Mass of urea (W_2) = 2.8 g

Mass of water (W_1) = 50 g

To find: Vapour pressure of the solution (P_1)

Formula:
$$\frac{P_1^0 - P_1}{P_1^0} = \frac{W_2 M_1}{M_2 W_1}$$

Calculation:

Molar mass of urea (NH_2CONH_2) = 14 + 2 + 12 + 16 + 14 + 2 = 60 g mol⁻¹

Molar mass of water = 18 g mol⁻¹

Now, using formula,

$$\begin{aligned} \frac{P_1^0 - P_1}{P_1^0} &= \frac{W_2 M_1}{M_2 W_1} \\ &= \frac{17 \text{ mm Hg} - P_1}{17 \text{ mm Hg}} = \frac{2.8 \text{ g} \times 18 \text{ g mol}^{-1}}{50 \text{ g} \times 60 \text{ g mol}^{-1}} \\ \therefore \frac{17 \text{ mm Hg} - P_1}{17 \text{ mm Hg}} &= 0.0168 \end{aligned}$$

$$\therefore 17 \text{ mm Hg} - P_1 = 0.0168 \times 17 \text{ mm Hg}$$

$$\therefore 17 \text{ mm Hg} - P_1 = 0.2856 \text{ mm Hg}$$

$$\therefore P_1 = 17 \text{ mm Hg} - 0.2856 \text{ mm Hg} = 16.71 \text{ mm Hg}$$

Vapour pressure of the given solution is 16.71 mm Hg.

Exercises | Q 10 | Page 46

A 5% aqueous solution (by mass) of cane sugar (molar mass 342 g/mol) has a freezing point of 271 K. Calculate the freezing point of 5% aqueous glucose solution.

Solution:

Given: Percentage by mass of cane sugar solution = 5 %

Percentage by mass of glucose solution = 5 %,

Freezing point of cane sugar solution = 271 K

Molar mass of cane sugar = 342 g mol⁻¹

To find: Freezing point of glucose solution

Formula: $M_2 = \frac{1000 \times K_f \times W_2}{\Delta T_f W_1}$

Calculation: 5 % solution (by mass) of cane sugar means that mass of cane sugar (W_2) = 5 g, and mass of solvent (W_1) = 95 g.

5 % glucose solution means that mass of glucose = W'_2 = 5g, and mass of solvent = W'_1 = 95 g

Molar mass of glucose ($C_6H_{12}O_6$) = (M'_2) = 180 g mol⁻¹

ΔT_f for cane sugar solution = $\Delta T_f = T_f^0 - T_f = 273.15 \text{ K} - 271 \text{ K} = 2.15 \text{ K}$

Now, using the formula,

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

Rearranging the formula, we get

$$1000K_f = \frac{M_2 \times \Delta T_f \times W_1}{W_2} \quad \text{.....(1)}$$

$$1000K_f = \frac{M'_2 \times \Delta T'_f \times W'_1}{W'_2} \quad \text{.....(2)}$$

From equations (1) and (2),

$$\frac{M_2 \times \Delta T_f \times W_1}{W_2} = \frac{M'_2 \times \Delta T'_f \times W'_1}{W'_2}$$

$$\therefore \frac{342 \text{ mol}^{-1} \times 2.15 \text{ K} \times 95 \text{ g}}{5 \text{ g}} = \frac{180 \text{ g mol}^{-1} \times \Delta T'_f \times 95 \text{ g}}{5 \text{ g}}$$

$$\Delta T'_f = \frac{342 \text{ mol}^{-1} \times 2.15 \text{ K}}{180 \text{ g mol}^{-1}} = 4.085 \text{ K}$$

$$\therefore \text{Freezing point of glucose solution } (T_f) = T_f^0 - \Delta T'_f$$

$$= 273.15 \text{ K} - 4.085 \text{ K}$$

$$= 269.065 \text{ K}$$

Freezing point of glucose solution is 269.065 K.

Alternate method:

Formulae: 1. $m = \frac{1000W_2}{M_2W_1}$

2. $\Delta T_f = K_f m$

Calculation: 5 % solution (by mass) of cane sugar means that mass of cane sugar (W_2) = 5 g, and mass of solvent (W_1) = 95 g.

Now, using formula (i),

$$\text{Molality of cane sugar solution} = m = \frac{1000W_2}{M_2W_1}$$

$$= \frac{1000 \text{ g kg}^{-1} \times 5 \text{ g}}{342 \text{ g mol}^{-1} \times 95 \text{ g}} = 0.1539 \text{ m}$$

$$\text{Now, } \Delta T_f \text{ for cane sugar solution} = \Delta T_f = \Delta T_f^0 - T_f = 273.15 \text{ K} - 271 \text{ K} = 2.15 \text{ K}$$

From formula (ii),

$$\Delta T_f (\text{cane sugar}) = K_f \times m$$

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

$$\therefore K_f = \frac{2.15}{0.1539} = 13.97 \text{ K kg mol}^{-1}$$

5 % glucose solution means that mass of glucose = $W'_2 = 5 \text{ g}$,

and mass of solvent = $W'_1 = 95 \text{ g}$

Molar mass of glucose ($\text{C}_6\text{H}_{12}\text{O}_6$) = $(M'_2) = 180 \text{ g mol}^{-1}$

Using formula (i),

Molality of glucose solution =

$$m = \frac{1000W_2}{M_2W_1}$$
$$= \frac{1000\text{g kg}^{-1} \times 5\text{g}}{180\text{g mol}^{-1} \times 95\text{g}} = 0.2924 \text{ m}$$

From formula (ii),

$$\Delta T'_f(\text{glucose}) = K_f \times m$$

(\because Since solvent is same, K_f is same for cane sugar and glucose solutions.)

$$\therefore \Delta T'_f(\text{glucose}) = 13.97 \times 0.2924 = 4.085\text{K}$$

$$\therefore \text{Freezing point of glucose solution } (T_f) = T_f^0 - \Delta T'_f$$

$$= 273.15 \text{ K} - 4.085 \text{ K}$$

$$= 269.065 \text{ K}$$

Exercises | Q 11 | Page 46

A solution of citric acid $\text{C}_6\text{H}_8\text{O}_7$ in 50 g of acetic acid has a boiling point elevation of 1.76 K. If K_b for acetic acid is $3.07 \text{ K kg mol}^{-1}$, what is the molality of solution?

Solution:

Given: Boiling point elevation $= \Delta T_b = 1.76 \text{ K}$

$$K_b \text{ of acetic acid} = 3.07 \text{ K kg mol}^{-1}$$

$$\text{Mass of acetic acid} = 50 \text{ g}$$

To find: Molality of the solution

$$\text{Formula: } \Delta T_b = K_b m$$

Calculation: Using formula and rearranging, we get,

$$m = \frac{\Delta T_b}{K_b} = \frac{1.76\text{K}}{3.07\text{K kg mol}^{-1}} = 0.573 \text{ mol kg}^{-1} = 0.573 \text{ m}$$

The molality of the solution is 0.573 m.

Exercises | Q 12 | Page 46

An aqueous solution of a certain organic compound has a density of 1.063 g mL^{-1} , osmotic pressure of 12.16 atm at 25°C and a freezing point of -1.03°C . What is the molar mass of the compound?

Solution:

Given: Density of a solution = $d = 1.063 \text{ g mL}^{-1}$

Osmotic pressure of solution = $\pi = 12.16 \text{ atm}$

Temperature = $T = 25^\circ\text{C} = 298.15 \text{ K}$

Freezing point of solution = $T_f = -1.03^\circ\text{C}$

To find: Molar mass of a compound

Formulae: 1. $\Delta T_f = K_f m$

2. $\pi = MRT$

$$3. m = \frac{1000W_2}{M_2W_1}$$

Calculation: $R = 0.08205 \text{ dm}^3 \text{ atm K}^{-1} \text{ mol}^{-1}$

$$\Delta T_f = T_f^0 - T_f = 0^\circ\text{C} - (-1.03^\circ\text{C}) = 1.03^\circ\text{C} = 1.03 \text{ K}$$

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

Using formula (i),

$$\Delta T_f = K_f m$$

$$m = \frac{\Delta T_f}{K_f} = \frac{1.03 \text{ K}}{1.86\text{K kg mol}^{-1}} = 0.554 \text{ mol kg}^{-1} = 0.554 \text{ m}$$

Using formula (ii),

$$\pi = MRT$$

$$M = \frac{\pi}{RT} = \frac{12.16 \text{ atm}}{0.08205 \text{ dm}^3 \text{ atm K}^{-1} \text{ mol}^{-1} \times 298.15 \text{ K}} = 0.497 \text{ mol dm}^{-3} = 0.497 \text{ M}$$

$$\text{Mass of solvent} = \frac{0.497 \text{ mol dm}^{-3}}{0.554 \text{ mol kg}^{-1}} \times 1 \text{ dm}^3 = 0.897 \text{ kg} = 897 \text{ g units}$$

$$\text{Mass of solution} = 1.063 \text{ g mL}^{-1} \times 1000 \text{ mL} = 1063 \text{ g}$$

$$\text{Mass of solute} = 1063 \text{ g} - 897 \text{ g} = 166 \text{ g}$$

Now, using formula (iii),

$$m = \frac{1000W_2}{M_2W_1}$$

$$\therefore M_2 = \frac{1000W_2}{mW_1} = \frac{1000 \text{ g kg}^{-1} \times 166 \text{ g}}{0.554 \text{ mol kg}^{-1} \times 897 \text{ g}}$$

$$= 334 \text{ g mol}^{-1}$$

The molar mass of the compound is 334 g mol^{-1} .

Exercises | Q 13 | Page 46

A mixture of benzene and toluene contains 30% by mass of toluene. At 30°C , vapour pressure of pure toluene is 36.7 mm Hg and that of pure benzene is 118.2 mm Hg. Assuming that the two liquids form ideal solutions, calculate the total pressure and partial pressure of each constituent above the solution at 30°C .

Solution:

Given:

Mass percentage of toluene = 30 %W/W

Vapour pressure of liquid toluene (P_1^0) = 36.7 mm Hg

Vapour pressure of liquid benzene (P_2^0) = 118.2 mm Hg

To find:

1. Partial pressures of each constituent
2. Total pressure

Formulae:

$$1. P_1 = P_1^0 x_1 \text{ and } P_2 = P_2^0 x_2,$$

$$2. P = P_1 + P_2$$

Calculation:

Molar mass of toluene, $C_7H_8 = (7 \times 12) + (8 \times 1) = 92 \text{ g mol}^{-1}$

Molar mass of benzene, $C_6H_6 = (6 \times 12) + (6 \times 1) = 78 \text{ g mol}^{-1}$

Now, 30 % W/W toluene means 30 g toluene in 100 g solution.

Thus, mass of benzene = $100 - 30 = 70 \text{ g}$

$$\text{Number of moles of toluene, } C_7H_8 = n_A = \frac{30\text{g}}{92 \text{ mol}} = 0.326 \text{ mol}$$

$$\text{Number of moles of benzene, } C_6H_6 = n_B = \frac{70 \text{ g}}{78 \text{ mol}} = 0.897 \text{ mol}$$

$$\text{Total number of moles } (n_A + n_B) = 0.326 \text{ mol} + 0.897 \text{ mol} = 1.223 \text{ mol}$$

$$\text{Mole fraction of toluene } (x_{C_7H_8}) = \frac{n_A}{n_A + n_B} = \frac{0.326}{1.223} = 0.2666$$

$$\text{Mole fraction of benzene } (x_{C_6H_6}) = 1.0 - 0.2666 = 0.7334$$

Now, using formula (i),

$$P_{C_7H_8} = P_{C_7H_8}^0 \times x_{C_7H_8} = 36.7 \text{ mm Hg} \times 0.2666 = 9.78 \text{ mm Hg}$$

$$P_{C_6H_6} = P_{C_6H_6}^0 \times x_{C_6H_6} = 118.2 \text{ mm Hg} \times 0.7334 = 86.7 \text{ mm Hg}$$

Now, using formula (ii),

Vapour pressure of the solution,

$$P = P_{C_7H_8} + P_{C_6H_6} = 9.78 + 86.7 = 96.48 = 96.5 \text{ mm Hg}$$

\therefore Partial pressures of toluene and benzene are 9.78 mm Hg and 86.7 mm Hg, respectively.

\therefore Total pressure above the solution is 96.5 mm Hg.

At 25 °C, a 0.1 molal solution of CH₃COOH is 1.35 % dissociated in an aqueous solution. Calculate the freezing point and osmotic pressure of the solution assuming molality and molarity to be identical.

Solution:

Given:

Molality of solution (m) = 0.1 m = 0.1 mol kg⁻¹

Degree of dissociation (α) = 1.35% = 0.0135

Temperature = 25 °C = 25 °C + 273.15 = 298.15 K

Molarity of solution (M) = 0.1 M

To find:

1. Freezing point of solution
2. Osmotic pressure of solution

Formulae:

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

$$2. \Delta T_f = i K_f m$$

$$3. \pi = i MRT$$

Calculation:

Using formula (i),

$$\alpha = \frac{i - 1}{n - 1} = i - 1 \text{ because } n = 2$$

$$\therefore i = 1 + \alpha = 1 + 0.0135 = 1.0135$$

Now, using formula (ii),

$$\Delta T_f = i K_f m = 1.0135 \times 1.86 \text{ K kg mol}^{-1} \times 0.1 \text{ mol kg}^{-1} \\ = 0.189 \text{ K} = 0.189 \text{ } ^\circ\text{C}$$

$$\text{Now, } \Delta T_f = T_f^0 - T_f$$

$$\therefore T_f = T_f^0 - \Delta T_f = 0^\circ\text{C} - (0.189^\circ\text{C}) = -0.189^\circ\text{C}$$

Now, using formula (iii),

$$\pi = i MRT = 1.0135 \times 0.1 \text{ mol dm}^{-3} \times 0.08205 \text{ dm}^3 \text{ atm K}^{-1} \text{ mol}^{-1} \times 298.15 \text{ K} = 2.48 \text{ atm}$$

∴ The freezing point of the solution is – 0.189 °C

∴ The osmotic pressure of solution at 25 °C is 2.48 atm

Exercises | Q 15 | Page 46

A 0.15 m aqueous solution of KCl freezes at - 0.510 °C. Calculate i and osmotic pressure at 0 °C. Assume the volume of solution equal to that of water.

Solution:

Given:

Molality of solution = $m = 0.15 \text{ m}$

Freezing point of solution = $T_f = - 0.510 \text{ °C}$

Temperature = $0 \text{ °C} = 273 \text{ K}$

To find:

1. The value of van't Hoff factor (i)
2. Osmotic pressure of solution

Formulae:

$$1. \Delta T_f = K_f m$$

$$2. i = \frac{\Delta T_f}{(\Delta T_f)_0}$$

$$3. \pi = MRT = \frac{n_2 RT}{V}$$

$$4. i = \frac{\pi}{\pi_0}$$

Calculation:

$$\Delta T_f = T_f^0 - T_f$$

$$= 0^\circ\text{C} - (-0.510^\circ\text{C}) = 0.510^\circ\text{C} = 0.510 \text{ K}$$

$$m = 0.15 \text{ m} = 0.15 \text{ mol kg}^{-1}$$

Now, using formula (i),

$$\Delta T_f = K_f m$$

$$(\Delta T_f)_0 = 1.86 \text{ K kg mol}^{-1} \times 0.15 \text{ mol kg}^{-1} = 0.279 \text{ K}$$

Now, using formula (ii),

$$i = \frac{\Delta T_f}{(\Delta T_f)_0} = \frac{0.510 \text{ K}}{0.279 \text{ K}} = 1.83$$

Now, using formula (iii),

$$(\pi)_0 = MRT$$

$$= \frac{n_2}{V} RT$$

$$= \frac{0.15 \text{ mol} \times 0.08205 \text{ dm}^3 \text{ atm} \cdot \text{mol}^{-1} \text{ K}^{-1} \times 273 \text{ K}}{1 \text{ dm}^3}$$

$$= 3.36 \text{ atm}$$

Now, using formula (iv),

$$i = \frac{\pi}{\pi_0} = 1.83$$

$$\pi = 1.83 \times 3.36 \text{ atm}$$

$$\pi = 6.15 \text{ atm}$$

∴ The van't Hoff factor is 1.83.

∴ The osmotic pressure of solution at 0 °C is 6.15 atm.