colligative properties practice problems

Colligative properties practice problems are essential to understanding the behavior of solutions in chemistry. These properties depend not on the identity of the solute but rather on the number of solute particles in a given quantity of solvent. The four main colligative properties include vapor pressure lowering, boiling point elevation, freezing point depression, and osmotic pressure. This article will delve into these colligative properties, provide practice problems, and offer solutions to enhance your understanding. By engaging with these problems, you will reinforce your knowledge and improve your problem-solving skills in the context of colligative properties.

Understanding Colligative Properties

Colligative properties are critical in various fields such as chemistry, biology, and environmental science. They are influenced by the number of solute particles, which can be ions or molecules, dissolved in a solvent. The four primary colligative properties are:

1. Vapor Pressure Lowering

When a non-volatile solute is added to a solvent, the vapor pressure of the solution is lower than that of the pure solvent. This occurs because the solute particles occupy space at the surface of the liquid, reducing the number of solvent molecules that can escape into the vapor phase.

2. Boiling Point Elevation

The presence of a solute raises the boiling point of a solvent. The increase in boiling point can be calculated using the formula:

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

Where:
- ΔT_b = change in boiling point
- i = van 't Hoff factor (number of ions/particles the solute dissociates into)
- K_b = ebullioscopic constant (depends on the solvent)
- m = molality of the solution

3. Freezing Point Depression

Similar to boiling point elevation, the freezing point of a solvent decreases when a solute is added. This can be calculated using the formula:

$$ \Delta T_f = i \cdot K_f \cdot m $$

Where:
- ΔT_f = change in freezing point
- i = van 't Hoff factor
- K_f = cryoscopic constant (depends on the solvent)
- m = molality of the solution

4. Osmotic Pressure

Osmotic pressure is the pressure required to prevent the flow of solvent into a solution through a semipermeable membrane. It can be calculated using the formula:

$$ \Pi = i \cdot C \cdot R \cdot T $$

Where:
- Π = osmotic pressure
- i = van 't Hoff factor
- C = molar concentration of the solution
- R = ideal gas constant (0.0821 L·atm/(K·mol))
- T = temperature in Kelvin

Practice Problems

Now that we have a solid understanding of the colligative properties, let’s dive into some practice problems.

Problem 1: Vapor Pressure Lowering

A solution is prepared by dissolving 10 g of urea (molar mass = 60 g/mol) in 200 g of water. Calculate the vapor pressure lowering of the solution if the vapor pressure of pure water is 23.8 mmHg at the given temperature.

Solution Steps:

1. Calculate the number of moles of urea:
\[
\text{moles of urea} = \frac{10 \, \text{g}}{60 \, \text{g/mol}} = 0.167 \,

\text{mol}
\]

2. Calculate the number of moles of water:
\[
\text{moles of water} = \frac{200 \, \text{g}}{18 \, \text{g/mol}} = 11.11 \, \text{mol}
\]

3. Calculate the mole fraction of water:
\[
\chi_{\text{water}} = \frac{11.11}{11.11 + 0.167} \approx 0.985
\]

4. Calculate the vapor pressure of the solution:
\[
P_{\text{solution}} = \chi_{\text{water}} \cdot P^0_{\text{water}} = 0.985 \cdot 23.8 \, \text{mmHg} \approx 23.5 \, \text{mmHg}
\]

5. Calculate the vapor pressure lowering:
\[
\Delta P = P^0_{\text{water}} - P_{\text{solution}} = 23.8 \, \text{mmHg} - 23.5 \, \text{mmHg} = 0.3 \, \text{mmHg}
\]

Problem 2: Boiling Point Elevation

Calculate the boiling point elevation when 5.0 g of sodium chloride (NaCl) is dissolved in 100 g of water. The ebullioscopic constant \(K_b \) for water is 0.512 °C·kg/mol.

Solution Steps:

1. Calculate the number of moles of NaCl:
\[
\text{moles of NaCl} = \frac{5.0 \, \text{g}}{58.5 \, \text{g/mol}} \approx 0.086 \, \text{mol}
\]

2. Determine the van 't Hoff factor \(i \) for NaCl, which dissociates into two ions (Na\(^+\) and Cl\(^-\)):
\[
i = 2
\]

3. Calculate the molality of the solution:
\[
m = \frac{0.086 \, \text{mol}}{0.1 \, \text{kg}} = 0.86 \, \text{mol/kg}

\]

4. Calculate the boiling point elevation:
$$
\Delta T_b = i \cdot K_b \cdot m = 2 \cdot 0.512 \cdot 0.86 \approx 0.88 \, \text{°C}
$$

5. The new boiling point of the solution:
$$
T_b = 100 \, \text{°C} + 0.88 \, \text{°C} = 100.88 \, \text{°C}
$$

Problem 3: Freezing Point Depression

If 10 g of glucose ($C_6H_{12}O_6$) is dissolved in 200 g of water, find the freezing point depression. The cryoscopic constant K_f for water is 1.86 °C·kg/mol.

Solution Steps:

1. Calculate the number of moles of glucose:
$$
\text{moles of glucose} = \frac{10 \, \text{g}}{180 \, \text{g/mol}} \approx 0.056 \, \text{mol}
$$

2. Determine the van 't Hoff factor i for glucose, which does not dissociate:
$$
i = 1
$$

3. Calculate the molality of the solution:
$$
m = \frac{0.056 \, \text{mol}}{0.2 \, \text{kg}} = 0.28 \, \text{mol/kg}
$$

4. Calculate the freezing point depression:
$$
\Delta T_f = i \cdot K_f \cdot m = 1 \cdot 1.86 \cdot 0.28 \approx 0.52 \, \text{°C}
$$

5. The new freezing point of the solution:
$$
T_f = 0 \, \text{°C} - 0.52 \, \text{°C} = -0.52 \, \text{°C}
$$

Problem 4: Osmotic Pressure

Calculate the osmotic pressure of a solution containing 0.1 moles of potassium sulfate (K_2SO_4) in 2 liters of water at 25 °C. Assume complete dissociation.

Solution Steps:

1. Determine the van 't Hoff factor i:
$$
i = 3 \quad (\text{K}_2\text{SO}_4 \rightarrow 2 \text{K}^+ + \text{SO}_4^{2-})
$$

2. Calculate the molarity of the solution:
$$
C = \frac{0.1 \, \text{mol}}{2 \, \text{L}} = 0.05 \, \text{mol/L}
$$

3. Convert temperature to Kelvin:
$$
T = 25 + 273.15 = 298.15 \, \text{K}
$$

4. Calculate the osmotic pressure:
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Frequently Asked Questions

What are colligative properties and how do they relate to solute concentration?

Colligative properties are properties of solutions that depend on the number of solute particles in a given amount of solvent, not the identity of the solute. These properties include boiling point elevation, freezing point depression, vapor pressure lowering, and osmotic pressure.

How do you calculate the boiling point elevation of a solution?

The boiling point elevation can be calculated using the formula: $\Delta T_b = i K_b m$, where ΔT_b is the change in boiling point, i is the van 't Hoff factor, K_b is the ebullioscopic constant of the solvent, and m is the molality of the solution.

What is the freezing point depression and how is it calculated?

Freezing point depression is the decrease in the freezing point of a solvent when a solute is added. It can be calculated using the formula: $\Delta T_f = i K_f m$, where ΔT_f is the change in freezing point, i is the van 't Hoff factor, K_f is the cryoscopic constant of the solvent, and m is the molality of the solution.

What is the van 't Hoff factor and why is it important in colligative properties?

The van 't Hoff factor (i) represents the number of particles into which a solute dissociates in solution. It is important because it affects the magnitude of colligative properties; for example, NaCl dissociates into two ions (Na^+ and Cl^-), so i = 2, while glucose does not dissociate, so i = 1.

How does the addition of a non-volatile solute affect the vapor pressure of a solvent?

The addition of a non-volatile solute lowers the vapor pressure of the solvent due to the solute particles occupying space at the surface of the liquid, which reduces the number of solvent molecules that can escape into the vapor phase. This is described by Raoult's Law.

What are some real-world applications of colligative properties?

Real-world applications of colligative properties include using antifreeze in car engines to lower the freezing point of the coolant, using salt on roads to melt ice by depressing the freezing point, and determining molecular weights of solutes through freezing point depression or boiling point elevation.

How does osmotic pressure relate to colligative properties?

Osmotic pressure is the pressure required to stop the flow of solvent into a solution through a semipermeable membrane. It is directly proportional to the molarity of the solute in the solution, and can be calculated using the formula: $\pi = i C R T$, where π is the osmotic pressure, C is the molarity, R is the gas constant, and T is the temperature in Kelvin.

Can colligative properties be used to determine the molar mass of a solute? How?

Yes, colligative properties can be used to determine the molar mass of a solute by measuring the freezing point depression or boiling point elevation and using the formulas for ΔT_f or ΔT_b. By rearranging the formulas, you can solve for the molar mass of the solute based on the measured change in temperature and the known quantities of the solvent.

What factors can affect colligative properties in a solution?

Factors that can affect colligative properties include the concentration of the solute, the nature of the solute (such as whether it dissociates into ions), the type of solvent used, and temperature, as colligative properties can vary with changes in temperature.

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