Calculate The Vapor Pressure (in Torr) At 298 K In A Solution Prepared By Dissolving 23.8 G Of The Non-volatile

Calculate The Vapor Pressure (in Torr) At 298 K In A Solution Prepared By Dissolving 23.8 G Of The Non-volatile substance to understand the effect of solute addition on the vapor pressure of a solvent is a fundamental concept in chemistry, particularly in the study of solutions and colligative properties. This article provides a comprehensive guide to calculating the vapor pressure in such a scenario, including the necessary formulas, step-by-step procedures, and relevant explanations to ensure clarity for students and professionals alike.

Understanding Vapor Pressure and Its Significance

What Is Vapor Pressure?

Vapor pressure is the pressure exerted by a vapor in equilibrium with its condensed phases (liquid or solid) at a given temperature in a closed system. It reflects the tendency of molecules to escape from the liquid phase into the vapor phase. The higher the vapor pressure, the more volatile the substance.

Why Does Vapor Pressure Change with Solute Addition?

When a non-volatile solute is dissolved in a solvent, it causes a decrease in the vapor pressure of the solvent. This phenomenon is explained by Raoult's Law, which states that the vapor pressure of a solvent over a solution is proportional to the mole fraction of the solvent present.

Raoult’s Law and Its Application

Raoult’s Law Formula

The law is mathematically expressed as:

$$
P_{solution} = X_{solvent} \times P_{pure \, solvent}
$$

where:

- $P_{solution}$ is the vapor pressure of the solution,
- $X_{solvent}$ is the mole fraction of the solvent in the solution,
- $P_{pure \, solvent}$ is the vapor pressure of the pure solvent at the same temperature.

Implication for Non-volatile Solutes

Since the solute is non-volatile, it does not contribute to the vapor pressure. Its presence reduces the mole fraction of the solvent, thus lowering the vapor pressure compared to pure solvent.

Step-by-Step Calculation Procedure

To accurately calculate the vapor pressure, follow these steps:

1. Identify the Relevant Data

- Mass of non-volatile solute: 23.8 g
- Temperature: 298 K
- Vapor pressure of pure solvent at 298 K ($P_{pure \, solvent}$)
- Molar mass of the solute
- Molar mass of the solvent

Note: For this example, assume the solvent is water, which is common in such calculations. The vapor pressure of water at 298 K is approximately 23.8 Torr.

2. Calculate Moles of Solute

Determine the molar mass of the solute. Since it's unspecified, let's assume the solute is a typical non-volatile substance, such as sodium chloride (NaCl), with a molar mass of approximately 58.44 g/mol.

$$
n_{solute} = \frac{\text{mass of solute}}{\text{molar mass of solute}} = \frac{23.8\, \text{g}}{58.44\, \text{g/mol}} \approx 0.407\, \text{mol}
$$

3. Calculate Moles of Solvent

Assuming the solvent is water:
- Molar mass of water: 18.015 g/mol
- Mass of water in the solution: Since the total mass isn't specified, assume the solution is just the solute and enough water to make calculations straightforward. For simplicity, suppose the total solution mass is the sum of solute and solvent. Alternatively, specify the mass of water if known.

Suppose the solution contains 100 g of water:

$$
n_{water} = \frac{100\, \text{g}}{18.015\, \text{g/mol}} \approx 5.55\, \text{mol}
$$

4. Calculate Mole Fractions

- Mole fraction of water:

$$
X_{water} = \frac{n_{water}}{n_{water} + n_{solute}} = \frac{5.55}{5.55 + 0.407} \approx \frac{5.55}{5.957} \approx 0.931
$$

- Mole fraction of solute:

$$
X_{solute} = 1 - X_{water} \approx 0.069
$$

5. Calculate the Vapor Pressure of the Solution

Applying Raoult’s Law:

$$
P_{solution} = X_{water} \times P_{water\, pure}
$$

Using the vapor pressure of pure water at 298 K:

$$
P_{water\, pure} = 23.8\, \text{Torr}
$$

Thus,

$$
P_{solution} = 0.931 \times 23.8\, \text{Torr} \approx 22.2\, \text{Torr}
$$

The vapor pressure of the solution at 298 K is approximately 22.2 Torr, reflecting the decrease caused by the non-volatile solute.

Factors Affecting Vapor Pressure Calculations

Molecular Nature of Solutes and Solvents

Different solutes have varying impacts on vapor pressure depending on their molar masses and interactions with the solvent. Larger molar mass solutes tend to cause a more significant reduction due to lower mole fractions for the same mass.

Temperature Dependence

Vapor pressure is temperature-dependent, increasing with higher temperatures. Precise calculations require vapor pressure data at the specific temperature of interest.

Solution Composition

The amount of solute and solvent determines the mole fractions and, consequently, the vapor pressure. Accurate measurements of these quantities are crucial for precise calculations.

Real-World Applications of Vapor Pressure Calculations

Boiling Point Elevation and Freezing Point Depression

Understanding vapor pressure is essential in colligative properties, which influence the boiling point and freezing point of solutions—a principle exploited in various industries, including pharmaceuticals and food technology.

Pharmaceutical Formulations

Ensuring proper vapor pressure helps in formulating drugs with desirable evaporation rates and stability.

Environmental Chemistry

Vapor pressure influences the volatility of pollutants and their dispersion in the atmosphere.

Summary and Key Takeaways

- Vapor pressure decreases upon the addition of a non-volatile solute due to the reduction in the mole fraction of the solvent.
- Raoult’s Law provides a straightforward method to estimate the vapor pressure of solutions.

- Accurate calculation requires knowledge of the molar masses, solution composition, and pure solvent vapor pressure at the specified temperature.
- Understanding these principles aids in various scientific and industrial applications, emphasizing the importance of colligative properties.

Conclusion

Calculating the vapor pressure of a solution at a given temperature, such as 298 K, involves understanding the interplay between solute and solvent molecules. By applying Raoult's Law and considering the molecular properties and quantities involved, one can precisely determine how the presence of a non-volatile solute affects vapor pressure. This knowledge is essential in fields ranging from chemical engineering to environmental science, offering insights into solution behavior and properties.

If you have specific data or different solutes and solvents, the calculation steps can be adapted accordingly to yield accurate results tailored to your particular scenario.

Frequently Asked Questions

What is the first step to calculate the vapor pressure of a solution at 298 K when a non-volatile solute is dissolved?

The first step is to determine the molality of the solution by calculating the moles of solute and the mass of solvent, then using Raoult's law to find the vapor pressure depression.

How do you calculate the molar mass of the non-volatile solute if only the mass is given?

The molar mass cannot be determined without knowing the chemical identity of the solute; it must be provided or inferred from additional information.

What is Raoult's law, and how is it used in this calculation?

Raoult's law states that the vapor pressure of the solvent in a solution is proportional to its mole fraction times the vapor pressure of the pure solvent. It is used to determine the vapor pressure depression caused by the solute.

Given 23.8 g of a non-volatile solute, how do you find the molality of the solution?

Molality is calculated by dividing the moles of solute by the kilograms of solvent. You need the molar mass of the solute and the mass of the solvent to do this.

If the vapor pressure of pure water at 298 K is 23.8 Torr, how does dissolving a non-volatile solute affect the vapor pressure?

Dissolving a non-volatile solute lowers the vapor pressure of the solvent proportionally to the mole fraction of the solvent, according to Raoult's law.

What additional information is needed to accurately calculate the vapor pressure in this problem?

The molar mass of the non-volatile solute and the vapor pressure of the pure solvent at 298 K are needed to perform the calculation.

How does the presence of a non-volatile solute influence the boiling point of the solution?

The non-volatile solute increases the boiling point due to boiling point elevation, related to the molality of the solution, but this is separate from vapor pressure calculation.

What is the formula to find the vapor pressure of the solution at 298 K?

Vapor pressure of solution = vapor pressure of pure solvent × mole fraction of solvent; mole fraction is calculated from the moles of solvent and solute.

Why is it important to convert the solute mass to moles when calculating vapor pressure?

Because vapor pressure depression depends on the mole fraction of the solvent, which requires knowing the number of moles of solute and solvent for accurate calculation.

Can you directly calculate vapor pressure without knowing the molar mass of the solute?

No, because the calculation requires the mole fraction of the solvent, which depends on the number of moles of solute; without molar mass, you cannot determine the moles of solute.

Additional Resources

Calculate The Vapor Pressure (in Torr) At 298 K In A Solution Prepared By Dissolving 23.8 G Of The Non-volatile Substance

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Introduction

Understanding vapor pressure is fundamental in physical chemistry, especially when analyzing solutions and their behaviors. Vapor pressure signifies the pressure exerted by a vapor in equilibrium with its liquid or solid phase at a specific temperature. When a non-volatile solute is dissolved in a solvent, the vapor pressure of the solvent is affected, leading to phenomena such as boiling point elevation and freezing point depression.

This detailed analysis aims to provide a comprehensive approach to calculating the vapor pressure of a solution at 298 K, given the dissolution of 23.8 grams of a non-volatile substance. We will explore the principles underpinning vapor pressure, the impact of non-volatile solutes, and the step-by-step methodology to arrive at an accurate value in Torr.

Fundamental Concepts of Vapor Pressure

What Is Vapor Pressure?

Vapor pressure (P_v) is the pressure exerted by the vapor of a liquid in equilibrium with its condensed phases at a given temperature. It depends on:

- The temperature (T)
- The nature of the liquid (intermolecular forces)
- The surface area (less significant in pure liquids)

For pure solvents, vapor pressure increases with temperature, following the Clausius-Clapeyron relation.

Raoult’s Law and Its Significance

Raoult’s law states that:

> The vapor pressure of a solvent over a solution ($P_{solution}$) is proportional to the mole fraction of the solvent in the solution ($X_{solvent}$) and the vapor pressure of the pure solvent ($P°_{solvent}$):

$$P_{\text{solution}} = X_{\text{solvent}} \times P^{\circ}_{\text{solvent}}$$

In essence, the presence of solutes affects the vapor pressure by decreasing the mole fraction of the solvent, thus lowering the vapor pressure relative to the pure solvent.

Impact of Non-volatile Solutes on Vapor Pressure

Why Non-volatile Substances Reduce Vapor Pressure

A non-volatile substance does not contribute to vapor phase pressure directly because it has negligible vapor pressure at the temperature of interest. When dissolved, it causes the total vapor pressure of the solution to decrease, as the solvent molecules are “diluted,” reducing their mole fraction.

Key Principles

- Raoult’s Law applies to solutions with volatile solvents and solutes.
- Adding a non-volatile solute decreases the solvent’s vapor pressure proportionally to its mole fraction.

Mathematical Expression

Given the mole fraction of the solvent ($X_{solvent}$) and the vapor pressure of pure solvent ($P°_{solvent}$):

$$ P_{\text{solution}} = X_{\text{solvent}} \times P^{\circ}_{\text{solvent}} $$

Since the solute is non-volatile, it does not contribute to vapor pressure, and the total vapor pressure depends solely on the solvent’s mole fraction in the solution.

Step-by-Step Calculation Methodology

Step 1: Identify the Solvent and Its Pure Vapor Pressure

- Determine the solvent involved in the solution, which is typically provided or implied.
- Obtain the vapor pressure of the pure solvent at 298 K from standard tables.

For example purposes, assume water as the solvent:

$$ P^{\circ}_{\text{water}} (298 K) \approx 23.8\, \text{Torr} $$

(Values vary slightly depending on the source, but this is a common approximation.)

Step 2: Calculate Moles of Solute and Solvent

- Given data:

- Mass of non-volatile solute: 23.8 g
- Molar mass of solute: unknown (we will denote as M_s)

- Assumptions:

- The solvent is water (molar mass: 18.015 g/mol).

- Calculations:

1. Moles of solute:

$$ n_{\text{solute}} = \frac{23.8\, \text{g}}{M_s} $$

2. Mass of solvent:

- To proceed, assume a known volume or mass of solvent used, or specify the total solution mass. If not specified, assume a standard volume for illustrative purposes (e.g., 1 L of water).

- For 1 liter of water:

$$ \text{Mass of water} = 1000\, \text{g} $$

- Moles of solvent:

$$ n_{\text{water}} = \frac{1000\, \text{g}}{18.015\, \text{g/mol}} \approx 55.5\, \text{mol} $$

(The total moles depend on the actual amount of solvent used, which must be specified.)

Step 3: Determine Mole Fraction of the Solvent

$$ X_{\text{water}} = \frac{n_{\text{water}}}{n_{\text{water}} + n_{\text{solute}}} $$

- Example with an assumed molar mass:

Suppose the solute is a compound with $M_s = 58$ g/mol.

$$ n_{\text{solute}} = \frac{23.8\, \text{g}}{58\, \text{g/mol}} \approx 0.41\, \text{mol} $$

- Calculate mole fraction:

$$ X_{\text{water}} = \frac{55.5}{55.5 + 0.41} \approx \frac{55.5}{55.91} \approx 0.993 $$

Step 4: Apply Raoult’s Law

$$ P_{\text{solution}} = X_{\text{water}} \times P^{\circ}_{\text{water}} $$

$$ P_{\text{solution}} \approx 0.993 \times 23.8\, \text{Torr} \approx 23.66\, \text{Torr} $$

This indicates a slight reduction in vapor pressure due to the non-volatile solute.

Factors Affecting the Calculation and Real-World Considerations

Temperature Dependence

Vapor pressure is highly temperature-sensitive. The calculation is valid at 298 K, but deviations can occur if temperature varies. Use the Clausius-Clapeyron equation for more precise calculations across temperatures.

Non-ideal Solutions

Raoult’s law assumes ideal behavior, which may not hold for all solutions:

- Intermolecular interactions between solute and solvent can cause deviations.
- Positive deviations occur when interactions are weaker than in pure substances, increasing vapor pressure.
- Negative deviations occur when interactions are stronger, decreasing vapor pressure further than predicted.

Purity and Measurement Accuracy

Experimental vapor pressure measurements can be influenced by impurities, measurement errors, and solution homogeneity.

Practical Applications and Implications

Boiling Point Elevation and Freezing Point Depression

The vapor pressure reduction influences other colligative properties:

- Boiling point elevation:

$$ \Delta T_b = \frac{K_b \times m \times i}{\text{molar mass of solvent}} $$

- Freezing point depression:

$$ \Delta T_f = \frac{K_f \times m \times i}{\text{molar mass of solvent}} $$

Where:

- K_b, K_f are solvent-specific constants.
- m is molality.
- i is the van 't Hoff factor (for non-electrolytes, i=1).

Chemical Engineering and Industrial Relevance

Understanding vapor pressure alterations is crucial in designing distillation processes, solvent recovery, and formulation stability.

Summary of Key Equations

Step	Equation	Description

|---------|-----------------------------|--|
Moles of solute	\(n_{\text{solute}} = \frac{m_{\text{solute}}}{M_s} \)	Converts mass to mols
Mole fraction of solvent	\(X_{\text{solvent}} = \frac{n_{\text{solvent}}}{n_{\text{solvent}} + n_{\text{solute}}} \)	Determines solvent's molar contribution
Vapor pressure of solution	\(P_{\text{solution}} = X_{\text{solvent}} \times P^{\circ}_{\text{solvent}} \)	Raoult’s law application

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Final Remarks

Calculating vapor pressure in a solution with a non-volatile solute at 298 K involves a detailed understanding of solution chemistry, molar calculations, and thermodynamic principles. The key is accurately determining the mole fractions and applying Raoult’s law, considering solution ideality. Such calculations inform not only academic understanding but also practical applications in industry, environmental science, and material engineering.

Given the assumptions in this discussion, precise results depend on exact solution composition, molar masses, and the solvent’s vapor pressure data. Always verify data with experimental measurements when possible for critical applications.

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