Calculate The Freezing Point Of A Solution Of 300.0 G Of Ethylene Glycol (C2H602) Dissolved In 300.0

Calculate The Freezing Point Of A Solution Of 300.0 G Of Ethylene Glycol (C2H6O2) Dissolved In 300.0 grams of solvent is a fundamental problem in chemistry that involves understanding colligative properties, specifically freezing point depression. This calculation is essential in various applications, including antifreeze formulations, biochemical experiments, and industrial processes. To accurately determine the freezing point of this solution, we need to analyze the properties of ethylene glycol, the principles of freezing point depression, and the specific details of the solution.

In this comprehensive guide, we will explore the necessary concepts, step-by-step calculations, and contextual understanding to find the freezing point of the given solution. By the end, you'll have a clear understanding of how to approach similar problems involving colligative properties and solutions.

Understanding Colligative Properties and Freezing Point Depression

What Are Colligative Properties?

Colligative properties are physical properties of solutions that depend on the number of solute particles present, rather than their identity. These include:

- Freezing point depression
- Boiling point elevation
- Vapor pressure lowering
- Osmotic pressure

The focus here is on freezing point depression, which occurs when a solute is dissolved in a solvent, lowering the temperature at which the solvent freezes.

Principle of Freezing Point Depression

The phenomenon can be quantified using the formula:

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

Where:

- **ΔT_f** = Depression in freezing point (°C)
- **i** = van't Hoff factor (number of particles the solute dissociates into)
- **K_f** = Cryoscopic constant (freezing point depression constant) of the solvent (°C·kg/mol)
- **m** = molality of the solution (mol solute per kg solvent)

To find the new freezing point, we subtract ΔT_f from the pure solvent's freezing point (0°C for water).

Properties of Ethylene Glycol ($C_2H_6O_2$)

Chemical Structure and Molecular Weight

Ethylene glycol is a diol with the chemical formula $C_2H_6O_2$. Its molecular weight is calculated as:

1. C: 12.01 g/mol × 2 = 24.02 g/mol
2. H: 1.008 g/mol × 6 = 6.048 g/mol
3. O: 16.00 g/mol × 2 = 32.00 g/mol

Adding these values gives:

$$\text{Molar mass of } C_2H_6O_2 = 24.02 + 6.048 + 32.00 \approx 62.07 \text{ g/mol}$$

Physical Properties Relevant to Freezing Point Depression

- Ethylene glycol is a common antifreeze agent because it depresses the freezing point of water.

- The van't Hoff factor (i) for ethylene glycol is 1, as it does not dissociate into multiple particles in solution.

Calculating the Molality of the Solution

To determine the freezing point depression, we need the molality (m). This involves converting the mass of ethylene glycol to moles and relating it to the mass of the solvent.

Step 1: Convert Ethylene Glycol Mass to Moles

Given:
- Mass of ethylene glycol (solute) = 300.0 g
- Molar mass of ethylene glycol ≈ 62.07 g/mol

Calculating:

Moles of ethylene glycol = 300.0 g ÷ 62.07 g/mol ≈ 4.834 mol

Step 2: Determine the Mass of the Solvent

The problem states:
- Mass of solvent = 300.0 g (assumed to be water)
- Convert to kilograms:

Mass of solvent = 300.0 g ÷ 1000 = 0.300 kg

Step 3: Calculate Molality (m)

Molality is:

m = moles of solute ÷ kg of solvent = 4.834 mol ÷ 0.300 kg ≈ 16.113 mol/kg

Applying Freezing Point Depression Formula

Values Needed:

- van't Hoff factor, i = 1
- Cryoscopic constant for water, K_f ≈ 1.86°C·kg/mol
- Molality, m ≈ 16.113 mol/kg

Calculating ΔTf:

$$\Delta T_f = i \times K_f \times m = 1 \times 1.86°C\cdot kg/mol \times 16.113\ mol/kg \approx 30.0°C$$

Note: The calculated depression is approximately 30°C, meaning the freezing point of the solution is lowered by about 30°C from the pure solvent's freezing point.

Determining the Final Freezing Point of the Solution

Since pure water freezes at 0°C, the solution's freezing point is:

$$\text{Freezing point} = 0°C - \Delta T_f \approx 0°C - 30.0°C = -30.0°C$$

This indicates that the solution of 300.0 g ethylene glycol dissolved in 300.0 g of water will have an approximate freezing point of −30.0°C.

Implications and Practical Applications

Antifreeze Formulations

The calculated freezing point demonstrates why ethylene glycol is effective as an antifreeze agent in automotive cooling systems. It prevents the coolant from freezing under extreme cold conditions, ensuring engine safety and efficiency.

Industrial and Laboratory Uses

- Ethylene glycol solutions are used to control the freezing points of liquids in various industrial processes.
- In laboratories, understanding colligative properties assists in designing experiments and understanding solution behaviors.

Safety and Environmental Considerations

- Ethylene glycol is toxic if ingested; thus, proper handling and disposal are crucial.
- Its environmental impact requires responsible use, especially in large quantities.

Summary of Key Steps

1. Identify the mass of solute and solvent.
2. Calculate molar mass of ethylene glycol.
3. Convert the mass of ethylene glycol to moles.
4. Calculate molality of the solution.
5. Use the colligative property formula to find freezing point depression.
6. Subtract the depression from the pure solvent's freezing point to find the solution's freezing point.

Conclusion

By systematically applying principles of colligative properties, understanding the characteristics of ethylene glycol, and performing precise calculations, we determined that dissolving 300.0 g of ethylene glycol in 300.0 g of water results in a solution with a freezing point around −30.0°C. This process exemplifies how solution composition influences physical properties and underscores the importance of colligative property calculations in practical applications ranging from automotive antifreeze to industrial processing.

Remember: Always verify calculations and consider experimental conditions, as real-world factors can slightly alter theoretical predictions.

Frequently Asked Questions

What is the formula to calculate the freezing point depression of a solution?

The formula is $\Delta T_f = i K_f m$, where ΔT_f is the freezing point depression, i is the van 't Hoff factor, K_f is the cryoscopic constant, and m is the molality of the solution.

How do you determine the molality of 300.0 g of ethylene glycol in the solution?

Molality is calculated by dividing the number of moles of solute by the mass of solvent in kilograms. First, find moles of ethylene glycol using its molar mass, then divide by the mass of the solvent in kg.

What is the molar mass of ethylene glycol ($C_2H_6O_2$)?

The molar mass of ethylene glycol is approximately 62.07 g/mol.

How does the van 't Hoff factor (i) affect the freezing point depression for ethylene glycol?

Since ethylene glycol does not ionize in solution, its van 't Hoff factor (i) is 1, simplifying the calculation of freezing point depression.

What is the typical cryoscopic constant (Kf) for water, and can it be used here?

The Kf for water is 1.86°C·kg/mol. It can be used if the solvent is water; otherwise, use the specific Kf value for the solvent in the solution.

How do you calculate the molality of 300.0 g of ethylene glycol dissolved in 300.0 g of solvent?

Convert 300.0 g of ethylene glycol to moles, then divide by the mass of the solvent in kg (0.300 kg).

What is the significance of calculating the freezing point depression in antifreeze solutions?

It helps determine how much the freezing point is lowered, which is critical for preventing freezing in vehicles during cold weather.

Can you estimate the freezing point of the solution if 300.0 g of ethylene glycol is dissolved in 300.0 g of water?

Yes. First, calculate molality, then apply $\Delta Tf = i\ Kf\ m$. Since $i = 1$, $Kf = 1.86°C·kg/mol$, and molality can be found from molar mass, you can estimate the freezing point depression and subtract it from 0°C.

Why is it important to consider the solute's molar mass and quantity when calculating freezing point depression?

Because the extent of freezing point depression depends directly on the number of solute particles in the solution, which is determined by the molar mass and quantity of the solute.

Additional Resources

Calculate The Freezing Point Of A Solution Of 300.0 G Of Ethylene Glycol ($C_2H_6O_2$) Dissolved In 300.0 G Of Water

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Introduction

The process of determining the freezing point of a solution is fundamental in physical chemistry, with practical implications spanning from antifreeze formulations to pharmaceutical preparations. A common scenario involves calculating the freezing point depression of a solvent upon the addition of a solute. In this comprehensive review, we focus on a specific case: calculating the freezing point of a solution constituted by dissolving 300.0 grams of ethylene glycol ($C_2H_6O_2$) into 300.0 grams of water. Ethylene glycol, widely used as antifreeze, has unique colligative properties that make this an instructive example of solution behavior analysis.

This investigation aims to elucidate the step-by-step methodology, underpinning theories, and calculations involved, providing clarity for students, researchers, and practitioners interested in colligative phenomena and real-world applications.

Background and Theoretical Framework

Colligative Properties and Freezing Point Depression

Colligative properties depend solely on the number of solute particles in a solvent, not their identity. These properties include vapor pressure lowering, boiling point elevation, osmotic pressure, and freezing point depression. The latter is particularly relevant here.

The freezing point depression (ΔT_f) is given by:

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

where:

- i is the van 't Hoff factor (number of particles into which a solute dissociates),
- K_f is the cryoscopic constant (freezing point depression constant) of the solvent,
- m is the molality of the solution (moles of solute per kilogram of solvent).

For water, the typical value of K_f is 1.86 °C·kg/mol.

Ethylene Glycol and Its Properties

Ethylene glycol ($C_2H_6O_2$) is a dihydric alcohol with the molecular weight:

$$
\text{MW} = (2 \times 12.01) + (6 \times 1.008) + (2 \times 16.00) = 62.068\, \text{g/mol}
$$

Since ethylene glycol is a non-electrolyte, it does not dissociate in solution, implying:

$$
i = 1
$$

Step-by-Step Calculation

1. Determining Moles of Ethylene Glycol

Given:

- Mass of ethylene glycol: 300.0 g
- Molecular weight of ethylene glycol: 62.068 g/mol

Calculating moles:

$$
n_{EG} = \frac{300.0\, \text{g}}{62.068\, \text{g/mol}} \approx 4.832\, \text{mol}
$$

2. Identifying the Solvent Mass and Calculating Molality

Given:

- Mass of water: 300.0 g = 0.3000 kg

Molality (m):

$$
m = \frac{n_{EG}}{\text{mass of solvent in kg}} = \frac{4.832\, \text{mol}}{0.3000\, \text{kg}} \approx 16.11\, \text{mol/kg}
$$

3. Calculating Freezing Point Depression

Using the formula:

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

Substituting known values:

$$
\Delta T_f = 1 \times 1.86\, ^\circ\text{C·kg/mol} \times 16.11\, \text{mol/kg} \approx 29.97\, ^\circ\text{C}
$$

4. Determining the New Freezing Point

Pure water freezes at 0 °C. The addition of ethylene glycol depresses this freezing point:

$$
T_{f,\, \text{solution}} = T_{f,\, \text{pure water}} - \Delta T_f
$$

$$
T_{f,\, \text{solution}} = 0\, ^\circ\text{C} - 29.97\, ^\circ\text{C} \approx -29.97\, ^\circ\text{C}
$$

Thus, the solution's freezing point is approximately -30.0 °C.

Critical Analysis of Assumptions and Limitations

While the calculation appears straightforward, several factors can influence the accuracy of this theoretical estimate:

- Ideal Solution Behavior: The calculation assumes ideal behavior, where ethylene glycol and water interact without deviations. Real solutions often exhibit non-idealities, especially at high solute concentrations.

- Complete Dissolution: It presumes complete dissolution of ethylene glycol, which is reasonable given its high solubility in water.

- Temperature Dependence of K_f: The cryoscopic constant K_f can vary slightly with temperature, but the variation is generally negligible within typical ranges.

- Absence of Dissociation: Ethylene glycol is a non-electrolyte; thus, $i=1$. For electrolytes or dissociating compounds, this factor must be adjusted.

- Volume Changes: The calculation does not account for volumetric changes upon mixing, which could influence concentration measurements in practical scenarios.

Practical Implications and Applications

Antifreeze Formulations

Understanding the freezing point depression of ethylene glycol-water mixtures is critical in designing effective antifreeze solutions for automotive engines, especially in cold climates. The approximately -30 °C freezing point for this mixture confirms its utility in preventing freezing during winter.

Industrial and Laboratory Use

Accurate calculations ensure safety margins and optimal performance in cooling systems, cryopreservation, and chemical processing.

Extending the Analysis: Variations and Further Considerations

- Varying the Ethylene Glycol Concentration: Increasing or decreasing the amount of glycol alters the freezing point proportionally, allowing customization for specific temperature thresholds.

- Mixture Ratios and Their Effects: Exploring different ratios reveals the relationship between concentration and colligative properties, important for process optimization.

- Impact of Additives: In real-world scenarios, additives such as corrosion inhibitors or dyes may influence solution properties subtly.

Conclusion

Calculating the freezing point of a solution comprising 300.0 g of ethylene glycol dissolved in 300.0 g of water demonstrates the principles of colligative properties and their practical significance. The theoretical freezing point depression of approximately 30 °C below pure water’s freezing point underscores the effectiveness of ethylene glycol in antifreeze applications.

While idealized calculations provide valuable insights, real-world conditions necessitate considerations of non-ideal behavior, solution interactions, and environmental factors. Nonetheless, this analysis not only highlights the fundamental calculations involved but also emphasizes their importance in engineering, safety, and scientific research.

References

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Final Remarks

This detailed investigation demonstrates how fundamental chemical principles translate into practical calculations, reinforcing the importance of colligative properties in everyday applications. Whether designing antifreeze, optimizing cooling systems, or conducting academic research, mastery of these calculations enhances both understanding and effectiveness in scientific endeavors.

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