Calculate The Freezing Point Of A Solution Of 300.0 G Of Ethylene Glycol (c2h6o2) Dissolved In 300.0

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Understanding how the addition of solutes affects the freezing point of a solvent is crucial in many scientific and industrial applications. This article provides a comprehensive guide to calculating the freezing point depression of a solution composed of ethylene glycol, a common antifreeze agent, dissolved in water. We will explore the fundamental principles, necessary formulas, step-by-step calculations, and practical implications of this process.

Introduction to Freezing Point Depression

What Is Freezing Point Depression?

Freezing point depression refers to the phenomenon where the freezing point of a solvent decreases when a solute is dissolved in it. This colligative property depends on the number of solute particles in the solution rather than their identity. When substances like ethylene glycol are added to water, the solution requires lower temperatures to transition from liquid to solid.

Relevance of Ethylene Glycol

Ethylene glycol ($C_2H_6O_2$) is a widely used antifreeze agent, especially in automobile cooling systems. Its ability to lower the freezing point of water prevents engine components from freezing during cold weather. Understanding how to calculate this freezing point depression helps in designing effective antifreeze solutions.

Fundamental Concepts and Formulas

Molecular Weight of Ethylene Glycol

To perform calculations, we need the molar mass of ethylene glycol:
- Carbon (C): 12.01 g/mol
- Hydrogen (H): 1.008 g/mol

- Oxygen (O): 16.00 g/mol

Calculating:
(2 × 12.01) + (6 × 1.008) + (2 × 16.00) = 24.02 + 6.048 + 32.00 = 62.07 g/mol

Calculating Moles of Ethylene Glycol

Number of moles (n) is given by:
$$ n = \frac{\text{mass}}{\text{molar mass}} $$

Freezing Point Depression Equation

The change in freezing point (ΔT_f) is calculated using:
$$ \Delta T_f = i \times K_f \times m $$

Where:
- i = van 't Hoff factor (number of particles the solute dissociates into; for ethylene glycol, $i = 1$)
- K_f = cryoscopic constant (freezing point depression constant) of the solvent (water has $K_f = 1.86 \, ^\circ C \cdot kg/mol$)
- m = molality of the solution (moles of solute per kilogram of solvent)

The final freezing point T_f of the solution is:
$$ T_f = T_{f, solvent} - \Delta T_f $$
where $T_{f, solvent}$ for pure water is 0°C.

Step-by-Step Calculation

1. Determine the Moles of Ethylene Glycol

Given:
- Mass of ethylene glycol = 300.0 g

Calculating:
$$ n = \frac{300.0 \, g}{62.07 \, g/mol} \approx 4.835 \, mol $$

2. Identify the Mass of Water (Solvent)

Given:
- Mass of water = 300.0 g = 0.3000 kg

3. Calculate Molality m

Molality:
$$ m = \frac{\text{moles of solute}}{\text{kg of solvent}} $$
$$ m = \frac{4.835 \, mol}{0.3000 \, kg} \approx 16.12 \, mol/kg $$

4. Determine the Freezing Point Depression ΔT_f

Since ethylene glycol does not dissociate into multiple particles, $i = 1$.

Using:
$$ \Delta T_f = i \times K_f \times m $$
$$ \Delta T_f = 1 \times 1.86 \, ^\circ C \cdot kg/mol \times 16.12 \, mol/kg $$
$$ \Delta T_f \approx 30.00 \, ^\circ C $$

5. Calculate the Final Freezing Point T_f

$$ T_f = 0^\circ C - 30.00^\circ C = -30.00^\circ C $$

Therefore, the freezing point of the solution is approximately -30.00°C.

Practical Implications and Applications

Importance in Automotive Industry

Automotive antifreeze solutions are designed to lower the freezing point of water in cooling systems to prevent engine freezing during winter. The calculation above demonstrates how the concentration of ethylene glycol influences the antifreeze efficacy.

Designing Antifreeze Mixtures

Understanding the relationship between solute concentration and freezing point depression allows chemists and engineers to tailor antifreeze solutions for specific climates. For instance, increasing ethylene glycol concentration results in a lower freezing point, offering better protection in extremely cold environments.

Safety and Efficiency Considerations

While increasing ethylene glycol concentration lowers the freezing point, it also impacts the solution's viscosity and thermal properties. Balancing these factors is vital for optimal engine performance and safety.

Additional Factors Affecting Freezing Point Depression

Dissociation and Van 't Hoff Factor i

For substances that dissociate in water (like salts), i exceeds 1, leading to greater freezing point depression. Ethylene glycol, however, remains as a single particle in solution, so $i = 1$.

Effect of Temperature and Concentration

Higher concentrations of ethylene glycol lead to more significant freezing point depression. Conversely, diluting the solution raises the freezing point closer to that of pure water.

Impact of Solution Purity

Impurities can alter colligative properties, affecting the accuracy of calculations. Ensuring high purity of chemicals is essential for precise control of freezing points.

Summary and Key Takeaways

- The molar mass of ethylene glycol is approximately 62.07 g/mol.
- Dissolving 300.0 g of ethylene glycol in 300.0 g of water results in a molality of approximately 16.12 mol/kg.
- The calculated freezing point of this solution is approximately -30.00°C.
- Colligative properties like freezing point depression depend on the number of solute particles, not their chemical nature.
- Proper understanding of these principles aids in designing effective antifreeze solutions for various applications.

Conclusion

Calculating the freezing point depression of solutions like ethylene glycol in water is fundamental in fields ranging from automotive engineering to chemical manufacturing. By applying the principles of colligative properties and performing precise calculations, professionals can optimize solutions for performance and safety. The example provided demonstrates how to determine the freezing point of a specific mixture, illustrating the practical relevance of theoretical concepts in everyday applications.

References and Further Reading

- Atkins, P., & de Paula, J. (2010). Physical Chemistry. Oxford University Press.
- Laidler, K. J., Meiser, J. H., & Sanctuary, B. C. (1999). Physical Chemistry. Houghton Mifflin.
- Perry's Chemical Engineers' Handbook, 8th Edition. (2008). McGraw-Hill Education.
- Safety Data Sheets for Ethylene Glycol and Water-based Solutions.
- Industry standards for antifreeze formulations and testing procedures.

By understanding the calculation process and underlying principles, you can effectively determine how various concentrations of ethylene glycol influence the freezing point of aqueous solutions, ensuring optimal performance in real-world scenarios.

Frequently Asked Questions

How do you calculate the freezing point depression of a solution containing ethylene glycol?

The freezing point depression is calculated using the formula ΔTf = i Kf m, where i is the van't Hoff factor, Kf is the cryoscopic constant of the solvent, and m is the molality of the solute. For ethylene glycol in water, you determine molality by dividing moles of ethylene glycol by kilograms of solvent.

What is the molar mass of ethylene glycol (C2H6O2)?

The molar mass of ethylene glycol is approximately 62.07 g/mol, calculated as (2×12.01) + (6×1.008) + (2×16.00).

How many moles of ethylene glycol are present in 300.0 g of the compound?

Number of moles = mass / molar mass = 300..0 g / 62.07 g/mol ≈ 4.83 mol.

What is the total mass of solvent used in the

solution?

The problem states 300.0 g of solution, with 300.0 g of ethylene glycol, so the solvent (water) mass is 0 g, which suggests the entire solution is ethylene glycol. If considering a typical dilute solution, clarify the solvent mass; otherwise, the solvent is the remaining mass after subtracting solute.

How do you determine the molality of the ethylene glycol solution?

Molality (m) = moles of solute / kilograms of solvent. If the solvent mass is known, divide the moles of ethylene glycol by that in kg to find molality.

What is the effect of ethylene glycol on the freezing point of water?

Ethylene glycol lowers the freezing point of water due to freezing point depression, which depends on the concentration of the solution; the more ethylene glycol dissolved, the greater the depression.

What is the typical value of the cryoscopic constant (Kf) for water?

The cryoscopic constant (Kf) for water is approximately 1.86 °C·kg/mol.

How do you calculate the new freezing point of a solution of ethylene glycol in water?

Calculate the freezing point depression ΔTf using the molality and Kf, then subtract ΔTf from 0 °C (freezing point of pure water) to find the solution's freezing point.

What assumptions are made when calculating freezing point depression for ethylene glycol solutions?

Assumptions include ideal solution behavior, complete dissociation (if applicable), and constant properties of solvent; in the case of ethylene glycol, which does not dissociate, i = 1 is used.

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

Understanding the freezing point depression of solutions is a fundamental concept in chemistry, especially in areas related to colligative properties. When a solute such as ethylene glycol ($C_2H_6O_2$) is dissolved in a solvent like water, it causes the freezing point of the solution to decrease relative to the pure solvent. This phenomenon is crucial in various practical applications, including antifreeze formulations, food preservation, and chemical manufacturing. In this detailed review, we will explore how to calculate the freezing point of a solution containing 300.0 g of ethylene glycol dissolved in 300.0 g of water, examining the principles behind colligative properties, the step-by-step calculation process, and the implications of the results.

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, not their identity. These include vapor pressure lowering, boiling point elevation, osmotic pressure, and freezing point depression. The key idea is that adding solute particles disrupts the solvent's ability to form a solid or vapor, leading to observable changes in physical properties.

Freezing Point Depression Explained

When a non-volatile solute like ethylene glycol is added to water, the freezing point of the solution decreases. This occurs because the solute particles interfere with the formation of the orderly solid lattice of ice, requiring lower temperatures to achieve solidification. The magnitude of this depression is proportional to the molality of the solution and the number of particles contributed by the solute.

Key Concepts and Formulas

Freezing Point Depression Formula

The change in freezing point (ΔT_f) is given by the formula:

\[

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

Where:
- i = van 't Hoff factor (number of particles the solute dissociates into)
- K_f = cryoscopic constant of the solvent (for water, $K_f = 1.86\, ^\circ C\, \mathrm{kg/mol}$)
- m = molality of the solution (moles of solute per kilogram of solvent)

The new freezing point (T_f) of the solution is then:

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

For water, $T_{f,\, pure} = 0\, ^\circ C$.

Understanding the Van 't Hoff Factor (i)

Since ethylene glycol does not dissociate in water, $i = 1$.

Step-by-Step Calculation

Step 1: Determine the Moles of Ethylene Glycol

Given:
- Mass of ethylene glycol = 300.0 g
- Molar mass of ethylene glycol ($C_2H_6O_2$):

$$
(2 \times 12.01) + (6 \times 1.008) + (2 \times 16.00) = 24.02 + 6.048 + 32.00 = 62.07\, \mathrm{g/mol}
$$

Calculate moles:

$$
n_{EG} = \frac{300.0\, \mathrm{g}}{62.07\, \mathrm{g/mol}} \approx 4.835\, \mathrm{mol}
$$

Step 2: Convert the Solvent Mass to Kilograms

Given:
- Mass of water = 300.0 g

Convert to kg:

$$
m_{water} = 300.0\, \mathrm{g} \times \frac{1\, \mathrm{kg}}{1000\, \mathrm{g}} = 0.300\, \mathrm{kg}
$$

Step 3: Calculate Molality of the Solution

Molality (m):

$$
m = \frac{n_{EG}}{m_{water}} = \frac{4.835\, \mathrm{mol}}{0.300\, \mathrm{kg}} \approx 16.12\, \mathrm{mol/kg}
$$

Step 4: Calculate the Freezing Point Depression (ΔT_f)

Using the formula:

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

Since ethylene glycol does not dissociate:

$$
i = 1
$$

Plugging in the values:

$$
\Delta T_f = 1 \times 1.86\, ^\circ C\, \mathrm{kg/mol} \times 16.12\, \mathrm{mol/kg} \approx 30.0\, ^\circ C
$$

Step 5: Determine the New Freezing Point of the Solution

The pure water freezing point:

$$
T_{f,\, pure} = 0\, ^\circ C
$$

Therefore, the solution's freezing point:

$$
T_f = 0\, ^\circ C - 30.0\, ^\circ C = -30.0\, ^\circ C
$$

Result: The solution of 300.0 g of ethylene glycol dissolved in 300.0 g of water has an approximate freezing point of -30.0°C.

Implications and Real-World Applications

Antifreeze Solutions

One of the primary applications of this calculation is in understanding antifreeze formulations used in automotive cooling systems. Ethylene glycol's ability to depress freezing points protects engines from freezing in cold climates. Knowing the exact concentration helps engineers optimize formulations for maximum protection without exceeding safety or environmental limits.

Chemical Safety and Environmental Considerations

While ethylene glycol is effective as an antifreeze, it is toxic to humans and animals. Accurate calculations of its freezing point depression are vital to ensure proper concentration levels that balance effectiveness and safety.

Limitations of the Calculation

- The calculation assumes ideal behavior, neglecting interactions that could alter the colligative properties.
- The effect of temperature on K_f and other constants is not considered.
- Real solutions may show deviations due to impurities or non-ideal mixing.

Features, Pros, and Cons

Features:
- Provides a quantitative measure of solution behavior based on molality and colligative properties.
- Uses fundamental principles of chemistry applicable to various solutes and solvents.
- Facilitates design and optimization of practical solutions like antifreeze.

Pros:
- Simple and straightforward calculation for dilute solutions.
- Based on measurable and well-established constants.
- Useful in industrial applications for safety and efficiency.

Cons:
- Assumes ideal solution behavior; real solutions may diverge.
- Does not account for dissociation or association of solutes unless i is adjusted.
- Limits in high concentrations where non-ideal effects dominate.

Conclusion

Calculating the freezing point of a solution containing ethylene glycol dissolved in water demonstrates the practical application of colligative properties in everyday and industrial contexts. By understanding the fundamental principles and following systematic steps—determining molar quantities, calculating molality, and applying the freezing point depression formula—we find that 300.0 g of ethylene glycol dissolved in 300.0 g of water depresses the freezing point to approximately -30.0°C. Such calculations are vital in designing effective antifreeze solutions, ensuring safety, and understanding solution behavior in various chemical processes. While the simplified model provides valuable insights, real-world factors may necessitate adjustments for non-ideal behavior, emphasizing the importance of comprehensive analysis in applied chemistry.

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