A 0.100 M Solution Of Which One Of The Following Solutes Will Have The Lowest Vapor Pressure?a. Sucroseb.

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Understanding vapor pressure and how it is affected by solutes is fundamental in chemistry, especially in the study of solutions and colligative properties. When considering solutions such as those containing sucrose or other solutes, the vapor pressure of the solvent decreases relative to pure solvent. This phenomenon is explained by Raoult's Law, which states that the vapor pressure of a solvent above a solution is proportional to the mole fraction of the solvent in the solution. The key factor influencing vapor pressure depression is the number of solute particles present in the solution. Therefore, the type of solute, whether it is a molecular compound like sucrose or an ionic compound like sodium chloride, significantly impacts the vapor pressure of the solution.

In this article, we will explore the concept of vapor pressure depression, compare how different solutes such as sucrose and electrolytes influence vapor pressure, and analyze why a 0.100 M sucrose solution would have a particular vapor pressure relative to other solutions. We will delve into the principles governing colligative properties, examine the role of solute particles, and provide insights into practical applications of these concepts in chemistry.

Understanding Vapor Pressure and Colligative Properties

What Is Vapor Pressure?

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

Colligative Properties: Key Concepts

Colligative properties depend solely on the number of solute particles in a solution, not their identity. The main colligative properties include:

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

- Osmotic pressure

Among these, vapor pressure lowering is directly influenced by the presence of solute particles.

Raoult's Law and Vapor Pressure Depression

Raoult's Law states that the vapor pressure of a solvent in a solution (P_solution) is proportional to the mole fraction of the solvent (X_solvent):

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

When a non-volatile solute is added, the mole fraction of the solvent decreases, leading to a reduction in vapor pressure. The extent of this depression depends on the number of solute particles.

Impact of Solute Types on Vapor Pressure

Molecular Solutes: Sucrose

Sucrose ($C_{12}H_{22}O_{11}$) is a covalent, molecular compound that dissolves in water without dissociation. In solution, each sucrose molecule remains intact, contributing as a single particle, regardless of concentration.

- Number of particles: Equal to the molar amount of sucrose.
- Effect on vapor pressure: Causes vapor pressure depression proportional to the molar concentration.

Electrolytes: Ionic Compounds

In contrast, electrolytes like sodium chloride (NaCl) dissociate into ions in solution:

$$ \mathrm{NaCl} \rightarrow \mathrm{Na}^+ + \mathrm{Cl}^- $$

- Number of particles: Increases due to dissociation; one mole of NaCl yields two moles of particles.
- Effect on vapor pressure: Greater vapor pressure depression at the same molar concentration because more particles are present.

Comparison of Sucrose and Electrolytes

Solute Type	Dissociation in Water	Particles per Mole	Effect on Vapor Pressure

Sucrose (molecular)	No	1	Moderate
Sodium chloride ($NaCl$)	Yes	2	Greater
Calcium chloride ($CaCl_2$)	Yes	3	Even greater

From this comparison, it is clear that the extent of vapor pressure depression depends heavily on the number of particles in solution.

Analyzing the 0.100 M Solution

Sucrose Solution

In a 0.100 M sucrose solution:

- Moles of sucrose: 0.100 mol per liter
- Particles in solution: 0.100 mol (since sucrose does not dissociate)

Since sucrose does not dissociate, the total number of particles contributing to vapor pressure depression is 0.100 mol.

Electrolyte Solution at the Same Molarity

In a 0.100 M $NaCl$ solution:

- Dissociation: 1 mol $NaCl$ yields 2 mol particles
- Particles in solution: 0.100 mol × 2 = 0.200 mol

Similarly, for a 0.100 M $CaCl_2$ solution:

- Dissociation: 1 mol $CaCl_2$ yields 3 mol particles
- Particles in solution: 0.100 mol × 3 = 0.300 mol

Thus, at the same molarity, electrolytes produce a higher number of particles than sucrose, leading to a greater vapor pressure depression.

Which Solute Results in the Lowest Vapor Pressure?

Based on colligative property principles, the vapor pressure lowering is directly proportional to the number of particles present in the solution. Therefore:

- Sucrose: 0.100 mol particles
- NaCl: 0.200 mol particles
- $CaCl_2$: 0.300 mol particles

Since vapor pressure is inversely related to particle number, the solution with the highest number of particles will have the lowest vapor pressure.

Conclusion: Among solutions with the same molarity, the electrolyte that dissociates into the most particles will cause the greatest vapor pressure depression. Therefore, a 0.100 M solution of sucrose will have a higher vapor pressure than a 0.100 M NaCl or $CaCl_2$ solution.

However, when comparing solutions with different solutes and similar molarities, sucrose solutions will generally have a higher vapor pressure than electrolyte solutions at the same molarity because the latter produce more particles.

Practical Applications and Significance

Understanding how different solutes affect vapor pressure has practical implications in various fields:

1. Food Preservation: Sucrose is used in jams and jellies to lower water activity, which inhibits microbial growth.
2. Pharmaceuticals: Colligative properties influence drug formulation, especially in controlling osmotic pressure.
3. Industrial Processes: Boiling point elevation and freezing point depression are harnessed in processes like antifreeze formulation.
4. Chemical Engineering: Accurate knowledge of vapor pressure helps in designing distillation and evaporation processes.

Summary and Key Takeaways

- Vapor pressure depression depends on the number of solute particles in solution.
- Molecular compounds like sucrose do not dissociate, contributing fewer particles at a given molarity.
- Electrolytes dissociate into multiple ions, increasing particle count and causing greater vapor pressure depression.
- At 0.100 M concentration, sucrose solutions will have a higher vapor pressure than electrolyte solutions like NaCl or $CaCl_2$.
- The lowest vapor pressure among solutions with the same molarity will be observed in solutions containing electrolytes that dissociate into more particles.

Final Thoughts

When evaluating solutions and their properties, it is essential to consider the nature of the solute—whether it remains intact or dissociates into ions. This understanding helps predict how solutions will behave under various conditions, including vapor pressure, boiling point, and freezing point. In practical scenarios, choosing the appropriate solute can optimize processes, enhance preservation, or control physical properties effectively.

In summary, a 0.100 M solution of sucrose will have a higher vapor pressure compared to solutions of electrolytes like sodium chloride or calcium chloride at the same molarity, due to its non-dissociating nature and fewer particles in solution. This fundamental principle highlights the importance of solute type in determining colligative properties in chemistry.

Frequently Asked Questions

Which solute among sucrose, NaCl, and $CaCl_2$ will cause the lowest vapor pressure in a 0.100 M solution?

NaCl or $CaCl_2$, because they are electrolytes that dissociate into multiple ions, leading to a greater number of particles and thus a lower vapor pressure compared to sucrose.

Why does the dissociation of electrolytes like NaCl and $CaCl_2$ result in a lower vapor pressure than non-electrolytes like sucrose?

Because electrolytes dissociate into multiple ions, increasing the total particle concentration in solution, which enhances the effect of vapor pressure lowering according to Raoult's law.

In a 0.100 M solution, which solute has the greatest effect on lowering vapor pressure?

Electrolytes such as NaCl or $CaCl_2$, since they produce more particles per formula unit upon dissociation, leading to a greater reduction in vapor pressure.

How does molality influence vapor pressure depression in solutions?

Vapor pressure depression is directly proportional to the molality of the solute; higher molality results in greater vapor pressure lowering, but the number of particles from dissociation also plays a crucial role.

Between sucrose and electrolytes like NaCl, which will have a lower vapor pressure at the same molarity, and why?

Electrolytes like NaCl will have a lower vapor pressure because they dissociate into multiple ions, increasing the effective particle count in solution.

What is the primary factor determining the lowest vapor pressure among different solutes in dilute solutions?

The number of particles the solute produces in solution; more particles lead to a greater decrease in vapor pressure.

If you have a 0.100 M sucrose solution and a 0.100 M NaCl solution, which has a lower vapor pressure and why?

The 0.100 M NaCl solution has a lower vapor pressure because NaCl dissociates into two ions, increasing the particle number and thus reducing vapor pressure more than sucrose, which remains as a single molecule.

Additional Resources

Vapor Pressure Depression in A 0.100 M Solution: An In-Depth Analysis of Solute Effects

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Introduction

Vapor pressure is a fundamental property in chemistry, reflecting the tendency of molecules in a liquid to escape into the gaseous phase. When a non-volatile solute is dissolved in a solvent, the vapor pressure of the solution typically decreases relative to that of the pure solvent. This phenomenon is described quantitatively by Raoult's Law, which states that the vapor pressure of the solvent in a solution is proportional to the mole fraction of the solvent present.

In this discussion, we explore how different solutes at the same molarity influence vapor pressure, with particular emphasis on understanding why a 0.100 M solution of sucrose would exhibit a specific vapor pressure relative to other potential solutes. We aim to determine which solute, among a set of options, would result in the lowest vapor pressure in a 0.100 M solution.

Fundamental Concepts: Vapor Pressure and Colligative Properties

What Is Vapor Pressure?

- Vapor pressure (P_1) is the pressure exerted by vapor molecules of a liquid in equilibrium with its liquid phase.
- It depends on temperature, intermolecular forces, and the nature of the liquid.

Why Does Dissolving Solute Lower Vapor Pressure?

- When a solute dissolves, it reduces the number of solvent molecules at the surface available to escape, effectively decreasing the vapor pressure.
- The extent of vapor pressure depression depends on the mole fraction of the solvent in the solution, not on the identity of the solute, assuming the solute is non-volatile and non-reactive.

Raoult's Law

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

- $X_{solvent}$: Mole fraction of the solvent.
- $P_{pure\, solvent}$: Vapor pressure of pure solvent.

Colligative Properties and Their Dependence on Solute Characteristics

Key Colligative Properties:

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

Factors Affecting Colligative Properties:

- Number of solute particles in solution (not their identity)
- Particle nature: whether they are molecules or ions
- Degree of dissociation or association in solution

The Role of Solute Type and Molecular Weight

While colligative properties depend primarily on the number of particles, the type of solute can influence the actual magnitude of the effect through:

- Dissociation: Ionic compounds dissociate into multiple particles, increasing the total particle count.
- Association: Some molecules tend to associate, decreasing the number of independent particles.

For a fixed molarity (0.100 M), the particle count per unit volume is crucial.

Analyzing the Given Solute: Sucrose

Characteristics of Sucrose:

- Chemical formula: $C_{12}H_{22}O_{11}$
- Molecular weight: approximately 342 g/mol
- Non-electrolyte: does not dissociate or ionize in solution
- Molecular nature: molecules stay intact

Implications for Vapor Pressure:

- Since sucrose is non-volatile and does not dissociate, each mole of sucrose contributes exactly one particle.
- At 0.100 M, the solution contains 0.100 moles of sucrose per liter, translating to 0.100 moles of solute particles per liter.

Effect on Vapor Pressure:

- The mole fraction of the solvent (water, assuming aqueous solution) will be high, given the low molarity of sucrose.
- The vapor pressure depression is proportional to the molality and number of particles; with only one particle per molecule, the effect is straightforward.

Comparing Other Common Solutes at 0.100 M

To understand which solute results in the lowest vapor pressure, consider other possible solutes:

1. Sodium chloride (NaCl)
2. Calcium chloride ($CaCl_2$)
3. Potassium sulfate (K_2SO_4)
4. Sucrose (already discussed)
5. Urea

Dissociation and Particle Count:

Solute	Molecular Weight (g/mol)	Dissociation	Particles per formula unit	Moles in 1 L at 0.100 M	Total particles per liter
NaCl	58.44	1	2 ($Na^+ + Cl^-$)	0.100 mol	0.200 mol particles
$CaCl_2$	110.98	1	3 ($Ca^{2+} + 2Cl^-$)	0.100 mol	0.300 mol particles
K_2SO_4	174.26	1	3 ($2K^+ + SO_4^{2-}$)	0.100 mol	0.300 mol particles
Urea	60.06	1	1	0.100 mol	0.100 mol particles

Note: Ionic compounds dissociate into their ions, increasing the number of particles in solution, thus increasing colligative effects.

Quantitative Analysis: Effect on Vapor Pressure

Given that vapor pressure lowering is proportional to the total number of solute particles, solutions containing electrolytes that dissociate into multiple ions will have a greater reduction in vapor pressure.

- For the same molarity, ionic compounds produce more particles than non-electrolytes like sucrose or urea.
- Therefore, ionic salts generally cause a greater vapor pressure depression compared to non-electrolyte molecules at the same molarity.

Implication for Sucrose

Since sucrose:

- Does not dissociate.
- Is a molecular, non-electrolyte.
- Produces one particle per mole.

It will cause the least vapor pressure depression among the solutes listed at the same molarity because the number of particles per unit volume is minimal.

Final Assessment: Which Solute Has the Lowest Vapor Pressure?

- Vapor pressure depression increases with the number of particles in solution.
- At 0.100 M, ionic compounds like NaCl, $CaCl_2$, K_2SO_4 produce more particles than sucrose.
- Sucrose, being a non-electrolyte, produces the fewest particles and thus results in the least vapor pressure depression.

Conclusion:

> A 0.100 M solution of sucrose will have the highest vapor pressure among the options, or equivalently, the lowest vapor pressure depression.

This means sucrose causes the least decrease in vapor pressure among the potential solutes at the same molarity.

Broader Context and Practical Significance

Understanding the relationship between solute type and vapor pressure is crucial in various scientific and industrial applications:

- Food preservation: Sucrose's non-electrolyte nature makes it ideal in maintaining moisture without significantly lowering vapor pressure.
- Pharmaceutical formulations: Controlling vapor pressure influences stability and evaporation rates.
- Chemical engineering: Design of solutions with desired vapor pressures for distillation or separation processes.

Summary

- Vapor pressure in solutions is lowered by the presence of solutes.
- The degree of lowering depends on the number of particles in solution.
- Non-electrolytes like sucrose produce fewer particles per molar concentration and thus cause less vapor pressure depression.
- Electrolyte salts dissociate into multiple ions, increasing particle count and decreasing vapor pressure more significantly.
- Therefore, a 0.100 M solution of sucrose will have the lowest vapor pressure depression, making it the solution with the highest vapor pressure among the options.

Final Thought

In the realm of colligative properties, the nature of the solute—whether molecular or ionic—plays an essential role in determining how much the vapor pressure is affected. When evaluating solutions at the same molarity, the non-electrolyte sucrose stands out as the solute causing the least reduction in vapor pressure, highlighting its unique behavior in solution chemistry.

Remember: Always consider the dissociation behavior and molecular weight when analyzing colligative properties to predict the effects accurately.

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