If One (1) Gram Of Each Is Dissolved In 1.00 L Of Water, Which Will Lower The Vapor Pressure The Most?

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This intriguing question touches on fundamental principles of chemistry, specifically colligative properties, which describe how the addition of solutes influences the physical properties of a solvent. When different solutes are dissolved in the same amount of solvent, their impact on properties like vapor pressure depends primarily on the number of particles they produce in solution, not their chemical nature. Understanding which substance causes the greatest decrease in vapor pressure requires a detailed analysis of molar masses, dissociation behavior, and the resulting particle concentrations in solution. This article explores these concepts thoroughly, providing clarity on how to determine the solute that most significantly depresses vapor pressure when equal masses are dissolved in water.

Understanding Vapor Pressure and Colligative Properties

Vapor pressure is the pressure exerted by a vapor in equilibrium with its liquid phase in a closed system. When solutes are added to a solvent like water, the vapor pressure typically decreases—a phenomenon explained by Raoult’s law. The extent of this decrease depends on the number of solute particles present in the solution, which is why colligative properties are dependent on the quantity, not the identity, of solute particles.

Key colligative properties include:
- Vapor pressure lowering
- Boiling point elevation
- Freezing point depression
- Osmotic pressure

In the context of vapor pressure lowering, the critical factor is the number of solute particles per unit volume of solvent, which is influenced by the molar mass of the solute and whether it dissociates into multiple particles in solution.

Calculating the Effect of Different Solutes on Vapor Pressure

To determine which solute lowers vapor pressure the most, we need to analyze the number of particles each solute produces when dissolved in water. This involves calculating the molar amount of each solute based on their mass, and then considering their dissociation behavior.

Step 1: Calculate Moles of Each Solute

Given that each solute weighs 1 gram and is dissolved in 1.00 liter of water, the initial step is to find out how many moles of each solute are present.

- Moles = mass (g) / molar mass (g/mol)

For example:
- If the solute is sodium chloride (NaCl), with a molar mass of approximately 58.44 g/mol:
Moles of NaCl = 1 g / 58.44 g/mol ≈ 0.01712 mol

Similarly, for other solutes, the molar mass determines the molar amount.

Step 2: Determine Particle Number in Solution

The number of particles in solution depends on whether the solute dissociates:

- Non-electrolytes (e.g., glucose): do not dissociate; particles = moles dissolved.
- Electrolytes (e.g., salts like NaCl): dissociate into ions, increasing the total particle count.

The dissociation behavior can be represented by the van 't Hoff factor, i, which indicates how many particles are produced per formula unit.

Examples:
- NaCl dissociates into Na^+ and Cl^-: i = 2
- $MgCl_2$ dissociates into Mg^{2+} and 2 Cl^-: i = 3
- Glucose ($C_6H_{12}O_6$) does not dissociate: i = 1

Calculating total particles:
Total particles = moles × i

Step 3: Comparing the Effect on Vapor Pressure

The vapor pressure lowering (ΔP) is proportional to the molality (molality = moles of solute per kilogram of solvent) and the van 't Hoff factor:

$\Delta P = i \times K_p \times \text{molality}$

Since the solvent volume is fixed at 1.00 L and assuming density of water is close to 1 kg/L, molality roughly equals moles per kilogram of water:

Molality ≈ moles of solute / 1 kg water

Because all solutions are prepared similarly, the key comparison reduces to the total number of particles in each solution. The greater the number of particles, the greater the vapor pressure lowering.

Application: Which Solute Lowers Vapor Pressure Most?

Using the above principles, we can analyze specific examples to determine the one that causes the greatest vapor pressure decrease.

Example Solutes and Their Molar Masses:

- Sodium chloride (NaCl): 58.44 g/mol, i = 2
- Calcium chloride ($CaCl_2$): 110.99 g/mol, i = 3
- Glucose ($C_6H_{12}O_6$): 180.16 g/mol, i = 1
- Potassium sulfate (K_2SO_4): 174.26 g/mol, i = 2

Calculations:

1. NaCl:
Moles = 1 / 58.44 ≈ 0.01712 mol
Particles = 0.01712 × 2 ≈ 0.03424 particles

2. $CaCl_2$:
Moles = 1 / 110.99 ≈ 0.00901 mol
Particles = 0.00901 × 3 ≈ 0.02703 particles

3. Glucose:
Moles = 1 / 180.16 ≈ 0.00555 mol
Particles = 0.00555 × 1 ≈ 0.00555 particles

4. K_2SO_4:
Moles = 1 / 174.26 ≈ 0.00574 mol
Particles = 0.00574 × 2 ≈ 0.01148 particles

Result:
NaCl produces the most particles (0.03424), thus, it will lower the vapor pressure the most among these options.

Conclusion: Which Substance Lowers Vapor Pressure the Most?

Based on calculations, the solute that produces the highest number of particles per liter of solution—namely, sodium chloride (NaCl)—will cause the greatest decrease in vapor pressure when 1 gram is dissolved in 1.00 liter of water. This outcome emphasizes the importance of molar mass and dissociation behavior in colligative properties.

Key Takeaways:
- The lowering of vapor pressure depends on the number of particles in solution, not their chemical nature.
- Electrolytes that dissociate into multiple ions have a more significant effect than non-electrolytes of similar molar amounts.
- When equal masses are dissolved, the solute with the lower molar mass and higher dissociation factor will produce more particles, leading to a greater vapor pressure depression.

Additional Considerations

While the above analysis provides a clear theoretical framework, real-world factors such as solubility limits, ion pairing, and activity coefficients can influence the actual extent of vapor pressure lowering. Nonetheless, understanding the fundamental principles allows chemists to predict and manipulate colligative properties effectively.

Summary:
- Dissolving 1 gram of different substances in water results in different molar amounts due to varying molar masses.
- The degree of dissociation (van 't Hoff factor) amplifies the effect of electrolytes.
- The substance that produces the most particles per unit volume will lower the vapor pressure the most, with sodium chloride being the most impactful in the given scenarios.

By mastering these principles, students and professionals can better understand solutions' behavior and design experiments or processes that leverage colligative properties for practical applications such as freezing point depression, boiling point elevation, and vapor pressure control.

Frequently Asked Questions

How does the molar mass of a solute affect its impact on the vapor pressure of a solution?

A higher molar mass means fewer moles are present for the same mass, resulting in a smaller number of particles and thus a lesser effect on lowering vapor pressure compared to a substance with lower molar mass.

Between substances with equal masses dissolved in water, which will lower the vapor pressure more: the one with the higher molar mass or lower molar mass?

The substance with the lower molar mass will lower the vapor pressure more because it produces more moles per gram, increasing the total particle count in solution and resulting in greater vapor pressure depression.

Why does the number of moles of solute matter more than the mass when determining vapor pressure lowering?

Vapor pressure lowering depends on the number of solute particles in solution, not just their total mass. More moles mean more particles, which more effectively disrupt the solvent's vapor pressure.

If 1 gram of substance A and 1 gram of substance B are both dissolved in water, and A has a lower molar mass than B, which solution will have a lower vapor pressure?

The solution with substance A (the one with the lower molar mass) will have a lower vapor pressure because it produces more moles of solute, leading to greater vapor pressure depression.

How does the concept of Raoult's Law relate to the question of which solute lowers vapor pressure more?

Raoult's Law states that the vapor pressure of a solvent is proportional to its mole fraction; adding more solute particles (more moles) decreases the mole fraction of the solvent, thus lowering vapor pressure. Therefore, the substance producing more moles (lower molar mass at the same mass) will lower vapor pressure more.

Additional Resources

If One (1) Gram Of Each Is Dissolved In 1.00 L Of Water, Which Will Lower The Vapor Pressure The Most?

Understanding how different substances affect the vapor pressure of a solvent is a fundamental concept in chemistry, particularly in the study of solutions and colligative properties. When a small amount of solute is dissolved in water, it alters the vapor pressure of the solvent, a phenomenon explained by Raoult's Law. This question — which asks, if one gram of each of several substances is dissolved in one liter of water, which will lower the vapor pressure the most — is insightful for understanding the relative effects of different solutes on water's vapor pressure. The answer hinges on the principles of molality, molar mass, and the nature of the solutes involved.

Understanding Vapor Pressure and Colligative Properties

Before delving into the specifics, it’s essential to grasp what vapor pressure is and how it is affected by solutes.

What is Vapor Pressure?

Vapor pressure is the pressure exerted by a vapor in equilibrium with its liquid phase at a given temperature. Pure water has a specific vapor pressure at a certain temperature, but when a solute is added, this pressure decreases.

Colligative Properties

Colligative properties are properties that depend on the number of solute particles in a solvent, not on their identity. These include:
- Vapor pressure lowering
- Boiling point elevation
- Freezing point depression
- Osmotic pressure

Since vapor pressure lowering depends on the number of dissolved particles, the key factor is how many moles of solute are present in the solution.

The Role of Moles and Molality in Vapor Pressure Lowering

The extent of vapor pressure reduction is directly proportional to the number of solute particles present, which depends on the molar quantity, not just the mass.

Raoult's Law

Raoult's Law states:
$$P_{solution} = X_{water} \times P^\circ_{water}$$
where:
- $P_{solution}$ = vapor pressure of the solution
- X_{water} = molar fraction of water
- P°_{water} = vapor pressure of pure water

Adding solutes decreases X_{water}, thus lowering the vapor pressure. The more particles, the greater the reduction.

Calculating Moles of Solute

Given:
- Mass of solute = 1 gram
- Volume of water = 1.00 L

We need:
- Molar mass of the solute
- Number of moles of solute = $\frac{\text{mass}}{\text{molar mass}}$

The number of moles determines the molality (moles of solute per kilogram of solvent), which correlates with vapor pressure lowering.

Analyzing Different Substances

Suppose the substances in question are common compounds such as:

1. NaCl (Sodium chloride)
2. Glucose ($C_6H_{12}O_6$)
3. $CaCl_2$ (Calcium chloride)
4. Ethanol (C_2H_5OH)
5. KNO_3 (Potassium nitrate)

Each has a different molar mass, and some dissociate into ions, affecting the total particle count.

Calculating Moles for Each Substance

Sodium chloride (NaCl):

- Molar mass ≈ 58.44 g/mol
- Moles = 1 g / 58.44 g/mol ≈ 0.0171 mol

Glucose ($C_6H_{12}O_6$):

- Molar mass ≈ 180.16 g/mol
- Moles ≈ 1 g / 180.16 g/mol ≈ 0.00555 mol

Calcium chloride ($CaCl_2$):

- Molar mass ≈ 110.98 g/mol
- Moles ≈ 1 g / 110.98 g/mol ≈ 0.00901 mol

Ethanol (C_2H_5OH):

- Molar mass ≈ 46.07 g/mol
- Moles ≈ 1 g / 46.07 g/mol ≈ 0.0217 mol

Potassium nitrate (KNO_3):

- Molar mass ≈ 101.10 g/mol
- Moles ≈ 1 g / 101.10 g/mol ≈ 0.00989 mol

Impact of Dissociation on Vapor Pressure Lowering

Some compounds dissociate into ions in solution, increasing the total number of particles, which amplifies vapor pressure lowering.

Ion Dissociation and Van't Hoff Factor (i)

- NaCl dissociates into Na^+ and Cl^-: $i \approx 2$
- $CaCl_2$ dissociates into Ca^{2+} and 2 Cl^-: $i \approx 3$
- KNO_3 dissociates into K^+ and NO_3^-: $i \approx 2$
- Glucose and ethanol do not dissociate: $i = 1$

The effective number of particles in solution is:
$$\text{Total particles} = \text{moles of solute} \times i$$

Calculating Effective Particle Number

Substance	Moles	Dissociation factor (i)	Total particles (moles)
NaCl	0.0171	2	0.0342
Glucose	0.00555	1	0.00555
$CaCl_2$	0.00901	3	0.0270
Ethanol	0.0217	1	0.0217
KNO_3	0.00989	2	0.01978

The higher the total particles, the greater the vapor pressure lowering.

Which Substance Lowers Vapor Pressure the Most?

Based on the calculations:

- NaCl produces approximately 0.0342 mol of particles.
- $CaCl_2$ produces approximately 0.027 mol.
- Ethanol produces 0.0217 mol.
- KNO_3 produces about 0.01978 mol.
- Glucose produces about 0.00555 mol.

Conclusion:
NaCl will cause the greatest vapor pressure reduction because, despite the same mass, it produces the highest number of particles due to its dissociation into two ions, and its molar mass is moderate, resulting in a relatively high molar count.

Additional Considerations

While the calculations above provide a solid theoretical understanding, real-world factors may slightly alter outcomes:

- Temperature: Higher temperatures increase vapor pressure but do not alter the relative effects of different solutes.
- Interactions between solute and solvent: Some solutes may have specific interactions with water that influence the extent of vapor pressure lowering.
- Complete dissociation assumption: For ionic compounds, complete dissociation is assumed, which is typical at dilute concentrations.

Features and Pros/Cons Summary

Features:
- Based on colligative property principles
- Considers dissociation effects (Van't Hoff factor)
- Uses molar mass to convert mass to moles
- Accounts for ion dissociation to evaluate particle count

Pros:
- Provides a clear quantitative method to compare effects
- Highlights the importance of ionization in colligative properties
- Useful in practical applications like solution preparation and boiling point elevation

Cons:
- Assumes complete dissociation for ionic compounds
- Does not account for specific interactions beyond dissociation
- Real solutions might deviate slightly due to activity coefficients

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Final Remarks

In summary, when one gram of various substances is dissolved in one liter of water, the substance with the highest effective number of particles in solution will lower the vapor pressure the most. Based on the calculations, sodium chloride (NaCl), owing to its dissociation into two ions and its molar mass, will produce the most significant vapor pressure reduction among the listed options. Understanding these principles is vital in fields like chemistry, chemical engineering, and environmental science, where controlling vapor pressures and solution behaviors are crucial.

This analysis underscores the importance of molar mass, dissociation, and particle count in predicting and manipulating colligative properties.

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