

The Vapor Pressure Over An Aqueous Solution Of Urea ($\text{CH}_4\text{N}_2\text{O}$) Is 294.7 Mm Hg. The Vapor Pressure Of Pure

The Vapor Pressure Over An Aqueous Solution Of Urea ($\text{CH}_4\text{N}_2\text{O}$) Is 294.7 Mm Hg. The Vapor Pressure Of Pure water and its solutions is a fundamental concept in chemistry, particularly in understanding solution properties, colligative phenomena, and practical applications in industries such as agriculture, pharmaceuticals, and chemical manufacturing. This article provides an in-depth exploration of vapor pressure, focusing on aqueous urea solutions, the factors influencing vapor pressure, and the significance of the given data point of 294.7 mm Hg.

Understanding Vapor Pressure and Its Significance

What Is Vapor Pressure?

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

Importance of Vapor Pressure in Chemistry and Industry

Vapor pressure plays a critical role in:

- Determining boiling points of liquids
- Designing distillation processes
- Understanding evaporation rates
- Assessing the stability of solutions
- Formulating pharmaceuticals and agrochemicals

Vapor Pressure of Pure Water vs. Aqueous Urea Solution

Vapor Pressure of Pure Water at Room Temperature

At standard room temperature (approximately 25°C), pure water has a vapor pressure of about 23.8 mm Hg. This value varies with temperature — as temperature increases, vapor pressure increases exponentially, indicating higher volatility.

Vapor Pressure of Aqueous Urea Solution

The article states that the vapor pressure over an aqueous solution of urea ($\text{CH}_4\text{N}_2\text{O}$) is 294.7 mm Hg. This value is notably higher than that of pure water, which might seem counterintuitive initially. However, context is essential: vapor pressure readings depend on the specific conditions and definitions used, including temperature and solution composition.

It's important to clarify that the value of 294.7 mm Hg is likely measured at a specific temperature, perhaps near or above room temperature, and under particular experimental conditions. The key takeaway is that the presence of urea influences the vapor pressure of the solution, which can be explained through colligative properties and solution chemistry principles.

Factors Affecting Vapor Pressure of Solutions

1. Composition of the Solution

The amount and type of solute dissolved in the solvent significantly impact vapor pressure. According to Raoult's Law, the vapor pressure of a solvent in a solution is proportional to its mole fraction:

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

where:

- P_{solution} is the vapor pressure of the solvent in the solution,
- X_{solvent} is the mole fraction of the solvent,
- $P^{\circ}_{\text{solvent}}$ is the vapor pressure of pure solvent.

In the case of urea (a non-volatile solute), it reduces the vapor pressure of water in the solution because it displaces some water molecules, decreasing the mole fraction of water.

2. Temperature

Temperature profoundly influences vapor pressure; as temperature increases, molecules gain kinetic energy, leading to higher vapor pressures. This relationship is often described by the Clausius-Clapeyron equation.

3. Nature of the Solute and Solvent

Non-volatile solutes like urea lower vapor pressure due to their inability to vaporize, unlike volatile solutes that can contribute to vapor pressure directly.

Applying Raoult's Law to Urea Solutions

Raoult's Law is fundamental for understanding vapor pressure changes in solutions:

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

where:

- P_{solution} is the vapor pressure of water in the solution,
- X_{water} is the mole fraction of water,
- P°_{water} is the vapor pressure of pure water at the same temperature.

Since urea is non-volatile, it decreases X_{water} , thus lowering the vapor pressure compared to pure water. The measured vapor pressure of 294.7 mm Hg indicates the extent of this effect at the specific temperature.

Significance of the Vapor Pressure Data for Urea Solutions

Industrial and Agricultural Applications

Urea is widely used as a nitrogen fertilizer in agriculture due to its high nitrogen content. Understanding its vapor pressure helps in:

- Designing efficient fertilizer storage and handling systems
- Predicting evaporation rates to minimize losses

- Formulating controlled-release fertilizers

Chemical and Pharmaceutical Industries

Accurate vapor pressure data is essential for:

- Developing formulations involving urea
- Optimizing evaporation processes in manufacturing
- Ensuring stability and shelf-life of products

Calculating the Effect of Urea on Water's Vapor Pressure

Determining Mole Fractions

To understand how urea affects vapor pressure, consider the mole fractions:

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

where:

- n_{water} is the number of moles of water,
- n_{urea} is the number of moles of urea.

The greater the amount of urea dissolved, the lower X_{water} , and consequently, the lower the vapor pressure of the solution.

Vapor Pressure Depression

The depression in vapor pressure (ΔP) can be estimated as:

$$\Delta P = P^{\circ}_{\text{water}} - P_{\text{solution}}$$

which helps quantify the colligative effect of dissolved urea.

Practical Considerations and Experimental Measurement

Measuring Vapor Pressure

Vapor pressure is typically measured using:

- Manometers
- Vapor pressure osmometry
- Dynamic methods involving temperature control

In laboratory settings, maintaining precise temperature control ensures accurate measurements, especially when dealing with solutions containing non-volatile solutes like urea.

Interpreting the Given Data

The vapor pressure of 294.7 mm Hg suggests that the solution was measured under controlled conditions, likely at a temperature where water's vapor pressure is higher than at room temperature, or that the data corresponds to a specific solution concentration.

Summary and Key Takeaways

- The vapor pressure of an aqueous urea solution at a given temperature is 294.7 mm Hg, indicating the solution's volatility relative to pure water.
- Urea, as a non-volatile solute, reduces the vapor pressure of water due to colligative effects, following Raoult's Law.
- Understanding vapor pressure is essential for optimizing processes in agriculture, pharmaceuticals, and chemical industries.
- Temperature and solution composition are critical factors influencing vapor pressure.

- Accurate measurement and interpretation of vapor pressure data enable better control and design of industrial applications involving urea solutions.

Conclusion

The vapor pressure over an aqueous solution of urea being 294.7 mm Hg provides valuable insight into the solution's physical properties and behavior under various conditions. Recognizing how solutes like urea influence vapor pressure helps chemists and engineers manipulate solution conditions to achieve desired outcomes, whether in manufacturing, agriculture, or research. As an essential colligative property, vapor pressure serves as a key indicator of solution composition and thermodynamic stability, making it a cornerstone concept in physical chemistry.

Frequently Asked Questions

What is vapor pressure, and how does it relate to an aqueous urea solution?

Vapor pressure is the pressure exerted by the vapor of a liquid in equilibrium with its liquid phase. For an aqueous urea solution, it indicates how readily urea molecules escape into the vapor phase compared to pure water.

Given the vapor pressure of the urea solution is 294.7 mm Hg, how can we determine the vapor pressure of pure water at the same temperature?

Using Raoult's law, the vapor pressure of pure water can be calculated if the mole fraction of water in the solution is known. Alternatively, if the solution's vapor pressure and composition are known, the vapor pressure of pure water can be inferred by rearranging the law.

How does the presence of urea affect the vapor pressure of water in the solution?

The addition of urea, a non-volatile solute, reduces the vapor pressure of water compared to pure water due to the solute molecules occupying space and lowering the water molecules' escape tendency, demonstrating a colligative property.

What is the significance of measuring vapor pressure in solutions like aqueous urea, especially in industrial or medical contexts?

Measuring vapor pressure helps determine solution composition, purity, and osmotic properties. In medical applications, it can relate to osmolality, while in industry, it informs processes like distillation and evaporation control.

How can the vapor pressure data of an aqueous urea solution be used to calculate its molar mass or degree of solvation?

By applying colligative property equations such as Raoult's law and knowing the solution's vapor pressure depression, one can estimate the molar mass or the number of moles of solute present, aiding in characterization of the solution.

Additional Resources

The Vapor Pressure Over An Aqueous Solution Of Urea ($\text{CH}_4\text{N}_2\text{O}$) Is 294.7 mm Hg. The Vapor Pressure Of Pure water at standard conditions is significantly higher, approximately 760 mm Hg at 100°C. This statement highlights an essential aspect of colligative properties—how the addition of a solute like urea impacts the vapor pressure of water. Understanding vapor pressure, especially in solutions containing solutes like urea, is fundamental in fields such as chemistry, chemical engineering, and environmental science. This article provides a detailed exploration of vapor pressure concepts, the specific case of urea solutions, and their broader significance.

Understanding Vapor Pressure and Its Significance

What is Vapor Pressure?

Vapor pressure is the pressure exerted by a vapor in thermodynamic 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 into the vapor phase. The higher the vapor pressure, the more volatile the substance.

For pure water at 100°C, the vapor pressure is 760 mm Hg, which equals atmospheric pressure at sea level. When substances are dissolved in water, the vapor pressure typically decreases, a phenomenon explained by Raoult's law. This reduction occurs because solute particles interfere with the escape of solvent molecules into the vapor phase.

Importance in Practical Applications

Understanding vapor pressure is essential for:

- Designing distillation and purification processes
- Predicting evaporation rates
- Formulating pharmaceuticals and food products
- Analyzing environmental processes such as evaporation and transpiration
- Determining boiling points under various conditions

Vapor Pressure of Urea Solutions: A Closer Look

Urea: Chemical Profile and Properties

Urea ($\text{CH}_4\text{N}_2\text{O}$) is an organic compound widely used in fertilizers, pharmaceuticals, and chemical synthesis. It is highly soluble in water, forming homogeneous solutions. Urea's solubility and non-volatility influence the vapor pressure of solutions it forms.

The Given Vapor Pressure: 294.7 mm Hg

The statement that the vapor pressure over an aqueous solution of urea is 294.7 mm Hg indicates that, at a specific temperature (likely near room temperature), the water-urea solution has this vapor pressure. Since pure water's vapor pressure at room temperature ($\sim 25^\circ\text{C}$) is approximately 23.8 mm Hg, the provided value suggests a higher temperature or different conditions, or perhaps an assumption for illustrative purposes.

Alternatively, if the vapor pressure of pure water at the same temperature is being considered, the comparison illustrates how the presence of urea reduces the vapor pressure compared to pure water, consistent with colligative property principles.

Implications of the Reduced Vapor Pressure

- Boiling Point Elevation: The presence of urea raises the boiling point of the solution relative to pure water.
- Osmotic Pressure: Urea's influence extends to osmotic properties, affecting biological and industrial processes.
- Solvent Behavior: The reduction in vapor pressure indicates the extent of urea's solute effect, which can vary with concentration and temperature.

Raoult's Law and Vapor Pressure Depression

Fundamentals of Raoult's Law

Raoult's law states that the vapor pressure of a solvent above a solution (P_{solution}) is proportional to the mole fraction of the solvent (X_{solvent}) and the vapor pressure of the pure solvent (P_{pure}):

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

This law assumes ideal solutions where interactions between solute and solvent molecules are similar to those among pure components.

Application to Urea Solutions

Urea solutions deviate slightly from ideality, but Raoult's law provides a good approximation for dilute solutions. The mole fraction of water decreases as urea concentration increases, leading to a proportionate decrease in vapor pressure.

- For dilute solutions: Vapor pressure depression is approximately linear.
- For concentrated solutions: Deviations may occur due to molecular interactions.

Calculating the Mole Fraction of Water

Given the vapor pressure of the solution (294.7 mm Hg) and assuming the vapor pressure of pure water at the same temperature is known, the mole fraction of water can be estimated:

$$X_{\text{water}} = \frac{P_{\text{solution}}}{P_{\text{pure}}}$$

This calculation aids in determining the concentration of urea in the solution and understanding colligative effects.

Factors Influencing Vapor Pressure of Urea Solutions

Temperature

Vapor pressure increases with temperature following the Clausius-Clapeyron relation. A rise in temperature causes more water molecules to escape into the vapor phase, raising vapor pressure.

Concentration of Urea

Higher urea concentrations lower the mole fraction of water, hence decreasing vapor pressure further. This effect is linear at low concentrations but can become complex at higher concentrations due to non-ideal interactions.

Molecular Interactions

Hydrogen bonding between water and urea molecules influences vapor pressure. Strong interactions can cause deviations from Raoult's law, affecting the accuracy of predictions.

Practical Applications and Significance

Industrial Processes

- Distillation: Knowledge of vapor pressure allows for the optimization of distillation processes to separate urea from water or concentrate solutions.
- Formulation of Pharmaceuticals: Controlling vapor pressure helps in stabilizing solutions and controlling evaporation rates.

Environmental and Biological Implications

Urea is a significant nitrogenous waste product in biological systems. Understanding its vapor pressure and solution behavior aids in:

- Waste treatment processes
- Fertilizer application strategies
- Modeling evaporation from soil and water bodies

Research and Development

Accurate data on vapor pressure helps in developing new formulations and understanding solute-solvent interactions at a molecular level.

Pros and Cons of Vapor Pressure Data in Urea Solutions

Pros:

- Provides insight into solution colligative properties

- Essential for designing industrial separation processes
- Helps predict boiling points and evaporation rates
- Useful in biological and environmental modeling

Cons:

- Assumes ideal behavior, which may not hold at high concentrations
- Requires precise temperature control for accurate measurements
- Deviations from Raoult's law can complicate calculations
- Data may vary based on purity and experimental conditions

Conclusion

The vapor pressure over an aqueous solution of urea, specified as 294.7 mm Hg, exemplifies the fundamental principles of colligative properties and solution chemistry. It underscores how solutes like urea influence solvent behavior, impacting boiling points, evaporation, and various industrial and biological processes. While idealized models like Raoult's law provide a foundational understanding, real-world applications often require consideration of molecular interactions and deviations from ideality. A thorough grasp of vapor pressure phenomena not only enriches scientific knowledge but also enhances practical capabilities in chemistry, environmental science, and engineering domains. Future research may focus on refining measurements at different concentrations and temperatures, further elucidating the complex behaviors of solute-solvent systems like urea solutions.

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