

The Increase In Boiling Point Temperature Due To The Presence Of A Nonvolatile Solvent Is Called Boiling

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Understanding the phenomenon of boiling is fundamental in chemistry and various industrial processes. When a liquid is heated, it eventually reaches a temperature at which its vapor pressure equals the external atmospheric pressure, leading to the formation of vapor bubbles within the liquid. This process is known as boiling. However, the presence of solutes, especially nonvolatile solvents, significantly influences the boiling point of a liquid. This article explores the concept of boiling, focusing on how the addition of a nonvolatile solvent increases the boiling point temperature of a solution, a phenomenon known as boiling point elevation.

What Is Boiling?

Boiling is a phase transition from the liquid state to the vapor state that occurs when a liquid's vapor pressure reaches atmospheric pressure or the pressure exerted on its surface. Unlike evaporation, which occurs at the surface and at temperatures below the boiling point, boiling involves the formation of vapor bubbles within the bulk of the liquid.

Conditions for Boiling

- The temperature of the liquid reaches the boiling point.
- The vapor pressure of the liquid equals the external pressure.
- Bubbles of vapor form within the liquid and rise to the surface.

Boiling Point

The boiling point is the temperature at which the vapor pressure of a liquid equals the external pressure. At sea level, where atmospheric pressure is approximately 1 atm (101.3 kPa), pure water boils at 100°C. However, this temperature varies with changing pressure and the presence of dissolved substances.

Effect of Nonvolatile Solvent on Boiling Point

When a nonvolatile solute is dissolved in a solvent, the boiling point of the resulting solution is higher than that of the pure solvent. This phenomenon is termed boiling point elevation. It is a colligative property, meaning it depends on the number of solute particles in the solution, not their identity.

What Is a Nonvolatile Solvent?

A nonvolatile solvent is a substance that does not vaporize easily at the boiling point of the solvent. When dissolved in a solvent, it does not contribute to vapor pressure directly, but it influences the thermodynamic properties of the solution.

Why Does Boiling Point Increase?

The increase occurs because the presence of solute particles disrupts the ability of solvent molecules to escape into the vapor phase. This lowering of vapor pressure necessitates a higher temperature to reach the vapor pressure equal to atmospheric pressure, thereby elevating the boiling point.

Understanding Boiling Point Elevation

The phenomenon of boiling point elevation can be explained using colligative property principles and vapor pressure concepts.

Vapor Pressure and Boiling

- Pure solvents have a characteristic vapor pressure at each temperature.
- Dissolving a nonvolatile solute reduces the solvent's vapor pressure.
- The solution must be heated to a higher temperature to reach the external pressure, leading to a higher boiling point.

Raoult's Law

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

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

where:

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

Since the mole fraction of the solvent decreases with added solute, the vapor pressure decreases, resulting in boiling point elevation.

Quantitative Explanation of Boiling Point Elevation

The boiling point elevation can be quantified using the following relation:

$$\Delta T_b = i \times K_b \times m$$

where:

- ΔT_b = boiling point elevation
- i = van't Hoff factor (number of particles the solute dissociates into)
- K_b = ebullioscopic constant (a property of the solvent)
- m = molality of the solution (moles of solute per kilogram of solvent)

Key Components of the Formula:

- Van't Hoff Factor (i): For non-electrolyte solutes (like sugar), $i = 1$. For electrolytes (like sodium chloride), which dissociate into ions, i is greater than 1 (e.g., NaCl dissociates into Na^+ and Cl^- , so $i \approx 2$).
- Ebullioscopic Constant (K_b): A property specific to each solvent, indicating how much the boiling point increases per molal concentration of a nonvolatile solute.

Practical Example:

Suppose 1 mol of NaCl is dissolved in 1 kg of water, and K_b for water is $0.512^\circ\text{C}\cdot\text{kg/mol}$. Since NaCl dissociates into 2 ions, $i \approx 2$.

The boiling point elevation:

$$\Delta T_b = 2 \times 0.512 \times 1 = 1.024^\circ\text{C}$$

Thus, the boiling point of the solution increases by approximately 1.024°C , so water now boils at about 101.024°C instead of 100°C .

Applications of Boiling Point Elevation

Understanding boiling point elevation has several practical applications across different fields:

- **Cooking:** Salt is added to water to increase its boiling point, which can help in cooking food more efficiently, especially in high-altitude regions where atmospheric pressure is lower.
- **Antifreeze in Automobiles:** Ethylene glycol increases the boiling point of water in cooling systems, preventing overheating.
- **Pharmaceuticals and Chemical Synthesis:** Precise control of boiling points ensures purity and proper reaction conditions.
- **Distillation Processes:** Adjusting boiling points to separate components effectively.

Limitations and Considerations

While boiling point elevation is predictable and calculable under ideal conditions, several factors can influence the actual temperature:

- Impurities: Other impurities can alter vapor pressures and boiling points.
- Dissociation: Complete dissociation of electrolytes affects the van't Hoff factor.

- Temperature Dependence: The boiling point elevation formula assumes dilute solutions where interactions are minimal.
- Pressure Variations: Changes in external pressure (e.g., high altitude) affect boiling points significantly.

Summary

The increase in boiling point temperature due to the presence of a nonvolatile solvent is a fundamental colligative property known as boiling point elevation. It occurs because dissolved nonvolatile solutes lower the vapor pressure of the solvent, requiring a higher temperature to reach the boiling point. This phenomenon is quantitatively described by the relation:

$$\Delta T_b = i \times K_b \times m$$

and has wide-ranging applications in cooking, industrial processes, and scientific research. Understanding this concept is essential for controlling and predicting the behavior of solutions under various conditions.

Conclusion

In summary, the phenomenon where the boiling point of a solvent increases due to the addition of a nonvolatile solute is called boiling point elevation. It exemplifies how colligative properties depend on the number of solute particles rather than their identity. Recognizing and applying the principles of boiling point elevation enables advancements in various technological and everyday applications, highlighting the importance of solution chemistry in practical scenarios.

Frequently Asked Questions

What is the phenomenon called when the boiling point of a solvent increases due to the addition of a nonvolatile solute?

This phenomenon is called boiling point elevation, which is a colligative property where the boiling point of a solvent increases when a nonvolatile solute is dissolved in it.

How does the presence of a nonvolatile solvent cause an increase in boiling point temperature?

The addition of a nonvolatile solute reduces the vapor pressure of the solvent, requiring a higher temperature to reach the vapor pressure equal to atmospheric pressure, thus increasing the boiling point.

Is boiling point elevation affected by the type of nonvolatile solute added?

No, boiling point elevation depends only on the number of solute particles (molar concentration), not on their chemical identity, making it a colligative property.

What is the formula used to calculate the boiling point elevation due to a nonvolatile solute?

The boiling point elevation is given by $\Delta T_b = i K_b m$, where ΔT_b is the increase in boiling point, i is the van't Hoff factor, K_b is the molal boiling point elevation constant, and m is the molality of the solution.

Why is the boiling point elevation important in practical applications like cooking or industrial processes?

Understanding boiling point elevation helps in controlling boiling temperatures in cooking and industrial processes, such as antifreeze solutions, where adjusting the boiling point can prevent overheating or boiling over.

Does the presence of a nonvolatile solute affect the freezing point of a solvent as well?

Yes, similar to boiling point elevation, the addition of a nonvolatile solute lowers the freezing point of the solvent, a phenomenon known as freezing point depression, another colligative property.

Additional Resources

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Introduction

In the realm of chemistry and physical sciences, understanding how substances behave under various conditions is fundamental. One such phenomenon that has significant implications in both theoretical and practical applications is the elevation of the boiling point when a nonvolatile solvent is added to a liquid. This phenomenon, commonly referred to as boiling point elevation, is a colligative property—a property that depends on the number of solute particles present in a solution rather than their identity. This article aims to provide a comprehensive exploration of this phenomenon, elucidating its underlying principles, mathematical descriptions, real-world applications, and implications in various scientific and industrial contexts.

What Is Boiling Point Elevation?

Definition and Concept

Boiling point elevation is the increase in the boiling point of a solvent caused by the addition of a nonvolatile solute. When a nonvolatile substance—meaning one that does not readily vaporize—is dissolved in a solvent, the resulting solution requires a higher temperature to reach the vapor pressure necessary for boiling. This rise in boiling point is quantitatively related to the number of solute particles in the solution and is a classic example of a colligative property.

Historical Background

The phenomenon was first systematically studied in the 19th century through the work of scientists like Jacobus Henricus van 't Hoff and others, who established the quantitative relationships governing colligative properties. Their work laid the foundation for understanding how solute particles influence solvent properties, which has since become integral in fields ranging from chemistry and physics to engineering and medicine.

Fundamental Principles Underlying Boiling Point Elevation

Colligative Properties: An Overview

Colligative properties are properties of solutions that depend solely on the number of dissolved particles, regardless of their chemical nature. The key colligative properties include:

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

Among these, boiling point elevation is directly related to the decrease in vapor pressure caused by the presence of solutes.

Vapor Pressure and Boiling Point

The boiling point of a pure solvent is defined as the temperature at which its vapor pressure equals the external atmospheric pressure. When a nonvolatile solute is added:

- The vapor pressure of the solvent decreases due to the solute particles disrupting the solvent's surface.
- To reach the vapor pressure equal to atmospheric pressure, the temperature must be increased.
- Hence, the boiling point of the solution is higher than that of the pure solvent.

The Role of Nonvolatile Solutes

Nonvolatile solutes do not vaporize or contribute to vapor pressure; their primary effect is to dilute the solvent molecules, reducing the solvent's vapor pressure. The magnitude of this vapor pressure reduction is proportional to the number of solute particles, which explains the colligative nature of boiling point elevation.

Mathematical Description of Boiling Point Elevation

The Key Equation

The quantitative relationship governing boiling point elevation is expressed as:

$$\Delta T_b = i K_b m$$

Where:

- ΔT_b = boiling point elevation (in °C or K)
- i = van 't Hoff factor (number of particles into which a solute dissociates)
- K_b = ebullioscopic constant of the solvent (a property specific to each solvent)
- m = molality of the solution (moles of solute per kilogram of solvent)

Explanation of the Variables

- van 't Hoff factor (i): accounts for the degree of dissociation. For example, NaCl dissociates into Na^+ and Cl^- , so $i \approx 2$. Non-electrolyte solutes like sugar do not dissociate, so $i=1$.
- Ebullioscopic constant (K_b): a property that depends on solvent characteristics such as molecular weight, intermolecular forces, and heat capacity. For water, $K_b \approx 0.512^\circ\text{C}\cdot\text{kg/mol}$.
- Molality (m): the moles of solute per kilogram of solvent, ensuring concentration independence from temperature and volume variations.

Derivation of the Equation

The derivation involves understanding vapor pressure depression and the Clausius-Clapeyron equation. By equating vapor pressures and applying Raoult's law, the change in boiling point can be related directly to molality and the number of particles, leading to the above simple expression.

Factors Affecting Boiling Point Elevation

Nature of the Solute

- Nonvolatile: As the phenomenon specifically involves nonvolatile solutes, their vapor pressure contribution is negligible.
- Dissociation: Electrolytes that dissociate into multiple ions cause a larger elevation, proportional to i .

Concentration of the Solution

- Higher molality results in greater boiling point elevation.
- The relationship is linear within dilute solutions, as per the equation.

Solvent Properties

- Solvents with higher (K_b) values will exhibit more significant boiling point elevations for a given concentration of solute.
- Examples: water ($(K_b \approx 0.512)$), benzene, ethylene glycol.

Temperature Range

- The linear approximation holds best at low to moderate concentrations; at higher concentrations, deviations may occur due to interactions between solute particles.

Practical Applications and Significance

Industrial and Laboratory Uses

1. Antifreeze Formulations:

- Ethylene glycol or propylene glycol are added to water in car radiators.
- Both are nonvolatile and elevate the boiling point, preventing overheating.

2. Cooking and Food Industry:

- Salt or sugar solutions alter boiling points, impacting cooking times and preservation.

3. Pharmaceuticals:

- Formulating solutions with precise boiling points for sterilization processes.

4. Distillation and Purification:

- Controlling boiling points to separate mixtures efficiently.

Scientific and Analytical Implications

- Determination of Molecular Weights:
 - Colligative properties like boiling point elevation help determine molar masses of unknown solutes.
- Monitoring Dissociation:
 - Van 't Hoff factors can be deduced from observed boiling point increases, providing insights into electrolyte behavior.

Environmental and Biological Contexts

- Osmotic Regulation:
 - Understanding how solutes like salts and sugars influence boiling and freezing points in biological systems.
- Climate and Water Chemistry:
 - Salinity impacts the boiling point of seawater, influencing climate models and oceanography.

Limitations and Considerations

Deviations at Higher Concentrations

- The linear relationship breaks down at high solute concentrations due to interactions such as ion pairing or clustering.

Non-ideal Solutions

- Real solutions may exhibit deviations from ideal behavior, requiring correction factors.

Temperature and Pressure Conditions

- The equations assume constant pressure; variations in external pressure alter boiling points and must be considered.

Conclusion

The phenomenon whereby the increase in boiling point temperature due to the presence of a nonvolatile solvent is observed and quantified through the concept of boiling point elevation. Rooted in colligative property principles, this process underscores the influence of solute particles on solvent vapor pressure and phase transition temperatures. Its theoretical foundations, embodied in the key equations, are crucial for numerous practical applications across industries, scientific research, and environmental science. Understanding the factors that influence boiling point elevation enables scientists and engineers to manipulate solution properties effectively, optimize processes, and develop innovative solutions to complex problems. As a testament to the intricate interplay between molecular interactions and macroscopic properties, boiling point elevation remains a fundamental concept that bridges theoretical chemistry with real-world utility.

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