85) What Is The Change In Entropy When 15.0 G Of Water At 100C Are Turned Into Steam At 100C? The Latent

85) What Is The Change In Entropy When 15.0 G Of Water At 100°C Are Turned Into Steam At 100°C? The Latent

Understanding the concept of entropy and how it changes during phase transitions is fundamental in thermodynamics. Specifically, calculating the change in entropy when water transforms from liquid to vapor at its boiling point provides insight into the molecular disorder and energy dispersal involved in such processes. In this article, we will explore the detailed calculation of entropy change for the conversion of 15.0 grams of water at 100°C into steam at the same temperature, focusing on the latent heat involved during vaporization.

Introduction to Entropy and Phase Changes

What Is Entropy?

Entropy is a thermodynamic property that measures the degree of disorder or randomness in a system. In simple terms, higher entropy indicates greater disorder, while lower entropy corresponds to a more ordered state. When a substance undergoes a phase change—such as melting, boiling, or sublimation—its entropy typically changes because the molecular arrangement and energy distribution are altered.

Phase Changes and Entropy

During phase transitions at constant temperature and pressure, the system absorbs or releases latent heat. The entropy change associated with such processes is directly related to the amount of heat transferred divided by the temperature at which the transition occurs. Specifically, for a phase change at constant temperature:

$$
\Delta S = \frac{Q_{\text{rev}}}{T}
$$

where:
- ΔS is the change in entropy,
- Q_{rev} is the reversible heat absorbed or released,

- T is the absolute temperature in Kelvin.

Understanding the Vaporization of Water

Latent Heat of Vaporization

The latent heat of vaporization (L_v) is the amount of heat required to convert one gram or mole of a substance from liquid to vapor without changing its temperature. For water at 100°C (373.15 K), the latent heat of vaporization is approximately:

$$
L_v = 2260 \, \text{J/g}
$$

This means that to vaporize 1 gram of water at 100°C, 2260 Joules of energy must be absorbed.

Relevance of Latent Heat in Entropy Calculation

Since the phase change occurs at constant temperature, the entropy change associated with vaporization can be calculated using the latent heat and the temperature of transition.

Calculating the Entropy Change for 15.0 g of Water

Step 1: Convert Mass to Moles or Use Mass Directly

Given:
- Mass of water, $m = 15.0\, \text{g}$
- Latent heat of vaporization, $L_v = 2260\, \text{J/g}$
- Temperature, $T = 100^\circ C = 373.15\, \text{K}$

Since the latent heat is given per gram, we can proceed directly with mass units.

Step 2: Calculate the Total Heat Absorbed During Vaporization

$$
Q = m \times L_v = 15.0\, \text{g} \times 2260\, \text{J/g} = 33,900\, \text{J}
$$

This is the amount of heat absorbed by the water to convert from liquid to vapor at 100°C.

Step 3: Apply the Entropy Change Formula

$$
\Delta S = \frac{Q}{T} = \frac{33,900\, \text{J}}{373.15\, \text{K}} \approx 90.8\, \text{J/K}
$$

Thus, the entropy of the system increases by approximately 90.8 Joules per Kelvin during the vaporization of 15.0 grams of water at 100°C.

Significance of the Calculated Entropy Change

Understanding Molecular Disorder

The positive change in entropy indicates an increase in molecular disorder as water molecules transition from a structured liquid phase to a more random gaseous phase. This increase aligns with the second law of thermodynamics, which states that entropy tends to increase in spontaneous processes.

Application in Thermodynamic Cycles

Calculating entropy changes during phase transitions is vital in designing engines, refrigerators, and other thermodynamic systems. It helps in assessing efficiency, feasibility, and the reversibility of processes involving phase changes.

Additional Considerations and Variations

Entropy Change at Different Conditions

While this calculation assumes ideal conditions at standard boiling point, real-world factors such as pressure variations can influence the latent heat and, consequently, the entropy change.

Entropy Change for Other Substances

The methodology demonstrated here can be applied to other substances undergoing phase changes, provided the latent heat and temperature are known.

Entropy Change in Reverse Process

Reversing the process—condensation of steam back into water—results in an entropy decrease of the same magnitude (–90.8 J/K in this case), illustrating the reversible nature of ideal phase transitions.

Summary of Key Points

- Entropy change during vaporization at constant temperature is calculated by dividing the heat absorbed by the transition temperature.
- For 15.0 g of water at 100°C, the entropy increases by approximately 90.8 J/K when it turns into steam.
- This change reflects increased molecular disorder and energy dispersal in the gaseous phase.
- The calculation hinges on the latent heat of vaporization, which is temperature-dependent and specific to each substance.

Conclusion

The change in entropy during the vaporization of water at its boiling point is a fundamental concept illustrating how energy transfer affects molecular arrangements. By understanding and calculating this entropy change, scientists and engineers can optimize processes involving phase transitions, improve energy efficiency, and deepen their grasp of thermodynamic principles. The specific case of 15.0 grams of water highlights the practical application of these concepts and demonstrates the importance of latent heat and temperature in thermodynamic calculations.

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Note: The calculations assume ideal, reversible phase change conditions. Real-world entropy changes may vary due to irreversibilities and environmental factors.

Frequently Asked Questions

What is the change in entropy when 15.0 g of water at 100°C is converted to steam at 100°C?

The change in entropy can be calculated using the formula $\Delta S = Q_{rev} / T$, where Q_{rev} is the heat absorbed during vaporization. For 15.0 g of water, Q_{rev} = m × latent heat of vaporization = 15.0 g × 40.7 kJ/mol ÷ 18.015 g/mol ≈ 33.9 kJ. Since T = 100°C = 373.15 K, ΔS ≈ 33,900 J / 373.15 K ≈ 90.8 J/K.

What is the significance of the latent heat in calculating entropy change during vaporization?

Latent heat represents the amount of energy required to change the phase of a substance at constant temperature and pressure. It directly determines the heat absorbed during vaporization, which is used to compute the entropy change in phase transition calculations.

How do you convert grams of water to moles for entropy calculations?

To convert grams to moles, divide the mass in grams by the molar mass of water: moles = mass (g) / 18.015 g/mol. For 15.0 g of water, moles ≈ 0.832 mol.

What is the formula for calculating the entropy change during phase change at constant temperature?

The formula is $\Delta S = \Delta H / T$, where ΔH is the enthalpy (latent heat) of phase change and T is the absolute temperature in Kelvin.

Why is temperature considered constant during the phase change from water to steam at 100°C?

Because during a phase change at boiling point, the temperature remains constant while the substance absorbs heat to convert from liquid to vapor, making the process isothermal.

What is the approximate entropy change for converting 15.0 g of water at 100°C to steam at the same temperature?

Approximately 90.8 J/K, based on the calculation using the latent heat of vaporization and the mass of water involved.

How does the mass of water affect the entropy change during vaporization?

The entropy change is directly proportional to the mass of water; doubling the mass doubles the entropy change because more heat is absorbed during vaporization.

Can you explain the role of the latent heat of vaporization in entropy calculations?

Yes, the latent heat of vaporization quantifies the energy needed for phase change at constant temperature and is essential for calculating the entropy change during vaporization.

What units are used for the change in entropy in these calculations?

Entropy change is typically expressed in Joules per Kelvin (J/K).

Is the entropy change positive or negative when water turns into steam at 100°C?

The entropy change is positive because the disorder increases as water transitions from a liquid to a gaseous state.

Additional Resources

What Is The Change In Entropy When 15.0 G Of Water At 100°C Are Turned Into Steam At 100°C? The Latent Heat

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Introduction

Entropy, a fundamental concept in thermodynamics, measures the degree of disorder or randomness in a system. Understanding how entropy changes during phase transitions, such as boiling water into steam, provides insights into the underlying molecular behavior and energy exchanges. This article aims to investigate what is the change in entropy when 15.0 grams of water at 100°C are turned into steam at 100°C, with particular emphasis on the role of latent heat during vaporization.

Fundamental Concepts in Thermodynamics and Entropy

Defining Entropy

Entropy (denoted as S) quantifies the number of microscopic arrangements consistent with a system’s macroscopic state. It is a state function, meaning its change depends solely on initial and final states, not on the process pathway.

Mathematically, for reversible processes:

$$
\Delta S = \frac{Q_{rev}}{T}
$$

where:
- ΔS = change in entropy
- Q_{rev} = heat absorbed or released in a reversible process
- T = absolute temperature in Kelvin

In phase changes like boiling, heat transfer occurs at constant temperature, making the calculation straightforward.

The Phase Transition: Vaporization at 100°C

Physical Overview

Boiling water at 100°C (373.15 K) involves transitioning from the liquid phase to vapor. This process requires overcoming intermolecular forces, quantified by the latent heat of vaporization (L_v). For water:

$$
L_v \approx 40.7\, \text{kJ/mol}
$$

at 100°C under standard atmospheric pressure.

Molecular Perspective

During vaporization:
- Water molecules absorb energy to break hydrogen bonds.
- The entropy increases as molecules gain freedom in the gas phase.
- The process occurs at constant temperature, with heat supplied being the latent heat.

Quantitative Analysis

Step 1: Convert Mass to Moles

Given:
- Mass of water = 15.0 g
- Molar mass of water (M_{H_2O}) = 18.015 g/mol

Number of moles (n):

$$
n = \frac{15.0\, \text{g}}{18.015\, \text{g/mol}} \approx 0.832\, \text{mol}
$$

Step 2: Determine the Heat Required for Vaporization

The total latent heat (Q) for 15.0 g:

$$
Q = n \times L_v
$$

Converting L_v to J/mol:

$$
L_v = 40.7\, \text{kJ/mol} = 40,700\, \text{J/mol}
$$

Calculate Q:

$$
Q = 0.832\, \text{mol} \times 40,700\, \text{J/mol} \approx 33,888\, \text{J}
$$

Calculating the Entropy Change

Since the phase change occurs at constant temperature, the entropy change is:

$$
\Delta S = \frac{Q_{rev}}{T}
$$

where $T = 373.15\, \text{K}$.

$$
\Delta S = \frac{33,888\, \text{J}}{373.15\, \text{K}} \approx 90.8\, \text{J/K}
$$

Therefore, the entropy of the system increases by approximately 90.8 J/K when 15.0 g of water at 100°C are vaporized into steam at the same temperature.

Deeper Insights: Implications and Context

The Significance of the Entropy Change

This entropy increase reflects the transition from a relatively ordered liquid phase to a much more disordered gaseous phase. It quantifies the gain in molecular randomness as water molecules escape into the vapor phase.

Comparing to Other Phase Changes

Phase Transition	Approximate Entropy Change per Mole (J/K)	Total for 15 g	
Melting (ice to water)	~22 J/K (per mol)	~18.2 J/K	
Vaporization	~88.0 J/K (per mol)	~90.8 J/K	(our calculation)

Note: The entropy change during vaporization is significantly larger than during melting due to the greater energy required to overcome intermolecular forces.

Broader Thermodynamic Context

Reversibility and Practical Considerations

While the calculation assumes a reversible process, actual vaporization involves irreversibilities, but the entropy change of the system remains the same as calculated. The surroundings absorb the same amount of entropy, maintaining the overall entropy balance.

Entropy and the Second Law of Thermodynamics

The increase in entropy during vaporization aligns with the second law, which states that entropy of the universe tends to increase in spontaneous processes. Vaporization at boiling point is spontaneous, consistent with this principle.

Real-World Applications and Significance

Understanding the entropy change during phase transitions has practical implications across various fields:

- Power Generation: Designing efficient steam turbines relies on thermodynamic principles, including entropy considerations.
- Climate Science: Water vapor is a potent greenhouse gas; its formation and dissipation involve entropy changes influencing atmospheric processes.
- Chemical Engineering: Phase change calculations guide the design of distillation, evaporation, and other separation processes.

Critical Examination and Limitations

While the calculation provides a clear estimate, several factors can influence the actual entropy change:

- Pressure Variations: The latent heat of vaporization depends on pressure; deviations from standard conditions alter the entropy change.
- Impurities and Non-idealities: Real water contains impurities affecting phase transition energetics.
- Heat Transfer Rates: In practical systems, finite rates and irreversibilities can impact the process efficiency.

Summary and Conclusions

In summary, the change in entropy when 15.0 g of water at 100°C is turned into steam at the same temperature is approximately 90.8 J/K. This calculation hinges on the latent heat of vaporization and illustrates how phase transitions significantly increase the entropy of a system, reflecting a transition to a more disordered state.

Understanding such entropy changes is vital in thermodynamics, influencing the design and analysis of numerous industrial and natural processes. This case exemplifies the elegant interplay between energy, molecular behavior, and disorder—a core theme in physical science.

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Final Remarks

This analysis underscores the importance of fundamental thermodynamic principles in understanding everyday phenomena like boiling water. The precise quantification of entropy changes during phase transitions not only deepens scientific comprehension but also enhances technological innovations across diverse sectors.

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