By How Much Does The Entropy Of 100 G Of Water At 100 OC Change If The Water Is Very Slowly Converted

By How Much Does The Entropy Of 100 G Of Water At 100°C Change If The Water Is Very Slowly Converted

Understanding the change in entropy during a gradual transformation of water at its boiling point is fundamental in thermodynamics. When 100 grams of water at 100°C undergoes a very slow, or quasi-static, conversion—such as vaporization—the entropy change provides insight into the irreversibility and energy dispersal associated with the phase change. This article explores the detailed calculations and concepts behind this entropy change, elucidating the thermodynamic principles involved.

Fundamental Concepts in Thermodynamics and Entropy

What Is Entropy?

Entropy is a thermodynamic property that quantifies the degree of disorder or randomness within a system. It is a measure of the number of microscopic configurations that correspond to a system's macroscopic state. When a process occurs at constant temperature and pressure, the change in entropy (\(\Delta S\)) reflects the dispersal of energy as heat.

Relevance of Quasi-Static Processes

A quasi-static or reversible process occurs infinitely slowly, ensuring the system remains in equilibrium at every stage. Under such conditions, the change in entropy can be precisely calculated using thermodynamic relationships, making the analysis ideal for theoretical evaluations like the present scenario.

Thermodynamics of Water at Its Boiling Point

Properties of Water at 100°C and 1 atm

At standard atmospheric pressure (1 atm), water boils at 100°C. Key properties relevant to entropy calculations include:

- Enthalpy of vaporization (ΔH_{vap}) at 100°C: approximately 40.7 kJ/mol
- Specific volume of liquid water at 100°C: about 0.001043 m³/kg
- Specific volume of water vapor at 100°C and 1 atm: approximately 1.673 m³/kg

Phase Change: Vaporization of Water

The process involves converting liquid water into vapor without changing temperature—an isothermal process. Because the process is very slow, it is considered reversible, and entropy change can be accurately computed.

Calculating the Entropy Change During Vaporization

Step 1: Determine Moles of Water

Given the mass of water:

- Mass, $m = 100\,g = 0.1\,kg$
- Molar mass of water, $M_{H_2O} = 18.015\,g/mol$

Number of moles:

$$
n = \frac{m}{M_{H_2O}} = \frac{100\,g}{18.015\,g/mol} \approx 5.55\, \text{mol}
$$

Step 2: Use Enthalpy of Vaporization to Find ΔH_{vap}

The molar enthalpy of vaporization at 100°C:

$$
\Delta H_{vap} \approx 40.7\, \text{kJ/mol}
$$

Total heat absorbed during vaporization:

$$
Q_{vap} = n \times \Delta H_{vap} = 5.55\, \text{mol} \times 40.7\, \text{kJ/mol} \approx 226.2\,
$$

$$
\text{kJ}
$$

Step 3: Calculate the Entropy Change ΔS

Since the process is isothermal and reversible, the entropy change associated with vaporization is:

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

Where:
- $Q_{rev} =$ heat absorbed during vaporization
- $T = 100^\circ C = 373.15\,K$

Thus,

$$
\Delta S = \frac{226.2\, \text{kJ}}{373.15\,K} \approx 0.606\, \text{kJ/K}
$$

Expressed in joules:

$$
\Delta S \approx 606\, \text{J/K}
$$

Interpreting the Results: Total Entropy Change

Effect of a Quasi-Static Vaporization on Entropy

Since the process involves converting 100 g of water at 100°C into vapor very slowly, the total entropy change of the universe increases by approximately 606 J/K. This change signifies the dispersal of energy and the increase in disorder as liquid water transitions into vapor.

Implications for Reversibility and Irreversibility

A quasi-static process is idealized as reversible; theoretical calculations assume no entropy is produced within the system during the phase change. The only entropy change considered is due to the heat transfer at a finite temperature. In real-world scenarios, irreversibilities would generate additional entropy, making the actual entropy increase slightly higher.

Additional Considerations in the Entropy Change Calculation

Role of Vapor Pressure and Non-Idealities

The calculation assumes ideal behavior at the boiling point under 1 atm pressure. In practice, vapor pressure variations, impurities, and non-ideal gas behavior can slightly alter ΔH_{vap} and, consequently, the entropy change.

Temperature Dependence of ΔH_{vap}

Enthalpy of vaporization varies with temperature. The value used here is approximate at 100°C; more precise calculations can incorporate temperature dependence using Kirchhoff's equation or thermodynamic tables.

Scaling to Different Masses

The entropy change scales linearly with the amount of water vaporized. Therefore, vaporizing a different mass would require proportionally adjusting ΔH_{vap} and the resulting ΔS.

Summary of Key Findings

1. For 100 g of water at 100°C undergoing a very slow vaporization, the approximate entropy increase is about 606 J/K.

2. The calculation relies on molar properties and assumes an ideal, reversible process.

3. The entropy change reflects the dispersal of energy as heat and the increase in disorder associated with phase transition.

4. Real-world deviations may cause slight differences, but the idealized calculation provides a robust estimate.

Concluding Remarks

The thermodynamic analysis of water vaporization at 100°C reveals the fundamental principles governing entropy changes during phase transitions. The process's quasi-static nature ensures the calculation's accuracy within the idealized framework. Such analyses are essential in understanding not only fundamental thermodynamics but also practical applications such as designing efficient heat engines, refrigeration systems, and understanding natural phenomena involving phase changes.

Ultimately, the entropy increase of approximately 606 J/K for 100 g of water at 100°C during very slow vaporization encapsulates the core concept that energy dispersal and disorder increase as water transitions from liquid to vapor, aligning with the second law of thermodynamics.

Frequently Asked Questions

What is the significance of calculating entropy change when water is slowly converted at 100°C?

Calculating the entropy change helps understand the thermodynamic efficiency and the amount of disorder introduced during the phase change, which is essential for processes like boiling and condensation analysis.

How do you determine the entropy change of water when it slowly converts at its boiling point?

The entropy change can be determined using the formula $\Delta S = Q_{rev} / T$, where Q_{rev} is the heat absorbed during the phase change and T is the absolute temperature, assuming a reversible process.

What is the approximate entropy change of 100 g of water when it undergoes vaporization at 100°C?

The approximate entropy change is about 0.4 J/K, calculated based on the heat of vaporization (~2260 kJ/kg) and the temperature (373 K).

Does the entropy of water increase or decrease during its vaporization at 100°C?

The entropy of water increases during vaporization because the molecules become more disordered in the gaseous phase compared to the liquid phase.

How much heat is involved when 100 g of water is converted to vapor at 100°C?

Approximately 226 kJ of heat is involved in vaporizing 100 g of water at 100°C, based on the latent heat of vaporization.

What assumptions are made when calculating the entropy change for this process?

Assumptions include that the process is reversible, occurs at constant temperature, and the water is pure, with no heat losses to the surroundings.

How does the slow conversion process affect the entropy change calculation for water at 100°C?

A slow, quasi-static process ensures the system remains close to equilibrium, making the entropy change calculation accurate and based on reversible process assumptions.

Additional Resources

By How Much Does The Entropy Of 100 G Of Water At 100°C Change If The Water Is Very Slowly Converted

Understanding the thermodynamic behavior of water during phase transitions is not only fundamental to physics and chemistry but also crucial for various industrial applications, environmental processes, and scientific research. A specific question that often arises pertains to the change in entropy of a given mass of water — specifically, 100 grams at 100°C — as it undergoes a very slow transformation, such as boiling or vaporization. This article provides a comprehensive analysis of this process, detailing the principles involved, the calculations required, and the implications of the entropy change in such a scenario.

Introduction: The Significance of Entropy in Phase Transitions

Entropy is a thermodynamic quantity that measures a system's disorder or the number of microscopic arrangements consistent with its macroscopic state. When water transitions from liquid to vapor, its entropy increases because the molecules become more dispersed and occupy a greater number of microstates. Understanding the magnitude of this change is essential for thermodynamic modeling, energy calculations, and efficiency assessments.

The process of converting water at its boiling point (100°C at standard atmospheric pressure) into vapor is a classic example of a phase change characterized by a substantial increase in entropy. When this change occurs very slowly, it approximates a quasi-static process, meaning the system remains very close to equilibrium at each stage, allowing us to use thermodynamic state functions to accurately compute the entropy change.

Fundamental Concepts and Thermodynamic Principles

1. The First and Second Laws of Thermodynamics

- First Law (Conservation of Energy): The energy required to vaporize water is equal to the heat added at constant pressure, known as the latent heat of vaporization.
- Second Law (Entropy): The entropy change associated with a process reflects the irreversibility and dispersal of energy. For a reversible process, the change in entropy can be precisely calculated using state functions.

2. Phase Change at Equilibrium

When water is at 100°C and 1 atm pressure, it exists in equilibrium between liquid and vapor phases. During very slow vaporization, the process can be considered reversible, and the entropy change can be derived from thermodynamic relations involving heat transfer and temperature.

3. Entropy Change During Vaporization

For a reversible phase change at constant temperature T, the entropy change ΔS is given by:

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

where Q_{rev} is the heat absorbed during vaporization.

Quantitative Analysis: Calculating the Entropy Change of 100 g Water at 100°C

1. Establishing the Known Data

To perform the calculation, we need:

- Mass of water, $m = 100\, \text{g} = 0.1\, \text{kg}$
- Temperature, $T = 100^\circ C = 373.15\, \text{K}$
- Latent heat of vaporization of water at 100°C, L_v

Latent heat of vaporization, L_v:
At 100°C, the latent heat of vaporization of water is approximately 2257 kJ/kg.

2. Calculating the Heat Absorbed (Q) During Vaporization

The total heat required to vaporize 100 g of water:

$$
Q = m \times L_v = 0.1\, \text{kg} \times 2257\, \text{kJ/kg} = 225.7\, \text{kJ}
$$

Expressed in joules:

$$
Q = 225.700\, \text{kJ} \times 1000 = 225,700\, \text{J}
$$

3. Computing the Entropy Change (ΔS)

Since the vaporization occurs at constant temperature and pressure, the entropy change is:

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

Plugging in the numbers:

$$
\Delta S = \frac{225,700\, \text{J}}{373.15\, \text{K}} \approx 604.8\, \text{J/K}
$$

This value represents the entropy increase of the water as it is transformed from liquid to vapor under ideal, reversible conditions.

Interpreting the Results: Magnitude and Significance

The calculated entropy change of approximately 605 J/K for 100 grams of water vaporized at 100°C illustrates the substantial increase in disorder. This is a typical magnitude for phase change processes and demonstrates how a relatively small mass can lead to a significant increase in entropy.

Contextual implications:

- Energy efficiency: The entropy change relates directly to the energy dispersal during vaporization, which is critical in designing boilers, turbines, and other thermodynamic systems.
- Environmental processes: Understanding entropy changes during evaporation informs models related to climate, water cycles, and natural evaporation.
- Scientific modeling: Precise calculations, like the one above, enable scientists to simulate real-world processes with high accuracy.

Factors Influencing the Entropy Change

While the above calculation assumes ideal conditions, real-world processes may involve variations due to:

- Temperature deviations: Slight changes in temperature alter the latent heat, affecting the entropy change.
- Pressure variations: Non-standard pressures shift the boiling point and latent heat, influencing the magnitude of \(\Delta S \).
- Impurities and non-idealities: The presence of solutes or impurities can modify phase change energetics.

In practical applications, these factors are often accounted for through correction factors and empirical data.

Why "Very Slowly" Matters: Reversibility and Thermodynamic Accuracy

The phrase "very slowly" is crucial because it indicates a process close to thermodynamic reversibility. In real systems, processes are often irreversible, leading to additional entropy production within the system. However, when vaporization occurs quasi-statically:

- The system remains in near-equilibrium states throughout.
- The calculated entropy change closely approximates the true reversible entropy change.
- No additional entropy is generated internally due to irreversibilities.

This idealization simplifies calculations and provides a benchmark for understanding real process efficiencies.

Broader Implications and Applications

Industrial Applications:

- Power plants: Understanding entropy changes during evaporation and condensation cycles helps optimize thermal efficiency.
- Distillation: Accurate entropy calculations enable better design of separation processes.
- Refrigeration systems: Phase change entropy data guide the selection of refrigerants and cycle efficiencies.

Environmental and Scientific Studies:

- Water cycle modeling: Entropy considerations influence predictions of evaporation rates and atmospheric moisture transport.
- Climate modeling: The energetic and entropic aspects of phase change are integral to understanding weather patterns and global heat balance.

Educational Significance:

- Demonstrating the calculation of entropy change during a phase transition reinforces core thermodynamic principles for students and researchers alike.

Conclusion: Quantitative and Qualitative Insights

The entropy of 100 grams of water at 100°C increases by approximately 605 Joules per Kelvin during very slow vaporization under ideal conditions. This significant entropy change underscores the fundamental thermodynamic principle that phase transitions involve substantial increases in disorder. It also highlights the importance of process conditions—such as reversibility, temperature, and pressure—in accurately determining entropy variations.

Understanding these changes not only deepens our comprehension of water's thermodynamic behavior but also informs a wide array of practical applications, from energy production to environmental science. As science advances, precise entropy calculations remain vital for optimizing processes, designing efficient systems, and furthering our grasp of natural phenomena.

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Note: The calculations and assumptions are based on standard thermodynamic data at atmospheric pressure and approximate ideal conditions. Real-world values may vary slightly depending on specific circumstances.

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Change If The Water Is Very Slowly Converted

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