E. Compare The Entropy Of TheHO(l) To The HO(g) That Is Formed F. Determine The Mass Of Liquid Water

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Understanding the thermodynamic properties of chemical species, particularly entropy, plays a crucial role in predicting the spontaneity and feasibility of chemical reactions. In this context, comparing the entropy of liquid water ($H_2O(l)$) to gaseous water ($H_2O(g)$) formed during a reaction provides insight into the disorder and energy distribution within the system. Additionally, determining the mass of liquid water formed involves applying principles from thermodynamics, stoichiometry, and the concept of entropy change.

This article explores the comparison of entropies between liquid and gaseous water, the factors influencing these values, and the methodology to calculate the mass of water produced during a chemical process.

Understanding Entropy and Its Significance

Entropy (S) is a thermodynamic quantity that measures the degree of disorder or randomness in a system. It reflects the number of ways a system can be arranged while maintaining its macroscopic properties. The second law of thermodynamics states that, for spontaneous processes, the total entropy of an isolated system tends to increase.

In chemical reactions, entropy changes (ΔS) help determine whether a process is spontaneous. Generally, processes producing more disorder (e.g., formation of gases from liquids) have positive ΔS, favoring spontaneity at given conditions.

Entropy of Water in Different Phases

Entropy of Liquid Water ($H_2O(l)$)

Liquid water is characterized by relatively low entropy compared to its gaseous form. The molecules are closely packed and have limited freedom of movement, leading to fewer microstates.

Typical standard molar entropy of liquid water at 25°C (298 K) is approximately:
- $\Delta S°(H_2O(l)) \approx 69.95$ J/(mol·K)

Entropy of Gaseous Water ($H_2O(g)$)

Gaseous water molecules are much more disordered, with significant freedom of movement and numerous microstates.

The standard molar entropy of water vapor at 25°C (298 K) is approximately:
- $\Delta S°(H_2O(g)) \approx 188.84$ J/(mol·K)

This substantial increase in entropy reflects the increased disorder when water transitions from liquid to gas.

Comparing the Entropies: Liquid vs. Gas

The difference in entropy between gaseous and liquid water is significant:

$\Delta S°(H_2O(g) - H_2O(l)) \approx 188.84 - 69.95 \approx 118.89$ J/(mol·K)

This positive entropy change indicates that converting water from liquid to vapor increases the system's disorder, making vapor formation thermodynamically favorable under certain conditions, especially at higher temperatures.

Thermodynamics of Water Formation: The Reaction Context

Suppose a chemical reaction involves the formation of water, such as combustion of hydrogen:

$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$

or, in a scenario where water forms as a liquid:

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$

The phase of water formed influences the entropy change of the process. For example:

- Formation of water vapor from gases generally increases entropy.
- Formation of liquid water from gases decreases entropy.

Determining which phase is favored depends on temperature, pressure, and entropy considerations.

Determining the Entropy Change for the Reaction

To compare the entropy of the system before and after the reaction, one must calculate ΔS for the process. For the reaction:

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ or $H_2O(g)$

the entropy change is:

$\Delta S° = S°_{products} - S°_{reactants}$

Calculating this enables us to understand whether the formation of liquid or gaseous water is more thermodynamically favorable at specific conditions.

Calculating the Mass of Liquid Water Formed

Suppose we are given the amount of a reactant and need to determine the mass of liquid water produced. The general approach involves:

1. Write the balanced chemical equation.
2. Identify the mole ratio between reactants and products.
3. Use stoichiometry to find the moles of water produced.
4. Convert moles to mass using molar mass.

Step-by-Step Example

Given:
- 10.0 g of hydrogen gas (H_2)
- Reaction: $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

Objective:
Determine the mass of liquid water formed.

Solution:

- Calculate moles of H_2:

Molar mass of H_2 = 2.016 g/mol

Moles of H_2 = 10.0 g / 2.016 g/mol ≈ 4.96 mol

- Use stoichiometry:

From the balanced reaction, 2 mol H_2 produce 2 mol H_2O (liquid).

Therefore, 4.96 mol H_2 produce 4.96 mol H_2O.

- Calculate mass of water:

Molar mass of H_2O = 18.015 g/mol

Mass of H_2O = 4.96 mol × 18.015 g/mol ≈ 89.5 g

Result:
Approximately 89.5 grams of liquid water are formed.

Considering Thermodynamic Feasibility

The entropy change impacts whether the formation of liquid water is spontaneous under given conditions. The Gibbs free energy change (ΔG) relates to enthalpy (ΔH) and entropy (ΔS):

$\Delta G = \Delta H - T\Delta S$

- At lower temperatures, the negative ΔH (exothermic reaction) often dominates, favoring water formation as a liquid.
- At higher temperatures, the $T\Delta S$ term becomes significant, possibly favoring water vapor formation, especially if ΔS is positive for vapor formation.

Thus, temperature control can influence the phase of water produced and the overall entropy change.

Conclusion: Integrating Entropy and Mass

Calculations

In summary, the comparison of entropy between $H_2O(l)$ and $H_2O(g)$ underscores the fundamental thermodynamic principles influencing phase transitions. The significant increase in entropy when water vaporizes explains why, under high-temperature conditions, water tends to exist as a gas. Conversely, at lower temperatures, liquid water formation is more favorable due to enthalpy considerations.

Accurate determination of the mass of water formed during a reaction requires detailed knowledge of the reactants' quantities, balanced chemical equations, and stoichiometry. By combining thermodynamic data with stoichiometric calculations, chemists can predict not only the amount of water produced but also its phase under specific conditions—information vital for industrial processes, environmental modeling, and laboratory research.

Understanding these principles enables scientists and engineers to optimize reactions, manage energy efficiency, and predict phase behavior, all rooted in the fundamental concept of entropy and thermodynamics.

Frequently Asked Questions

How does the entropy of HO(l) compare to that of HO(g) during formation, and why?

The entropy of HO(l) (liquid water) is significantly lower than that of HO(g) (gaseous water) because liquids have more ordered molecular arrangements and lower molecular freedom compared to gases, which have higher entropy due to their greater disorder and molecular motion.

What is the significance of comparing the entropy of HO(l) and HO(g) in thermodynamic calculations?

Comparing the entropy of HO(l) and HO(g) helps determine the spontaneity and feasibility of phase changes and chemical reactions involving water, as well as calculating the entropy change associated with such processes.

How do you calculate the entropy change when converting HO(g) to HO(l)?

The entropy change is calculated using the standard molar entropy values for HO(g) and HO(l), applying ΔS = S(products) - S(reactants), where the specific entropies are obtained from thermodynamic tables or experimental data.

What data do you need to determine the mass of liquid water formed from gaseous water?

You need the amount of gaseous water (in moles), the molar mass of water, and the entropy change associated with condensation or phase change, along with any relevant thermodynamic conditions such as temperature and pressure.

Can you explain the process of determining the mass of liquid water formed from the entropy change of HO(g)?

Yes, by calculating the entropy change during condensation of water vapor to liquid, and knowing the total entropy change, you can determine the number of moles of water condensed. Multiplying this by the molar mass yields the mass of liquid water formed.

Why is understanding the entropy difference between HO(l) and HO(g) important in environmental or industrial processes?

Understanding this entropy difference helps optimize processes like condensation, distillation, and water purification by predicting energy requirements, efficiency, and feasibility of phase changes involved in industrial and environmental systems.

Additional Resources

Compare The Entropy Of The HO(l) To The HO(g) That Is Formed F. Determine The Mass Of Liquid Water

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Introduction

In the realm of thermodynamics and chemical processes, understanding the entropy changes associated with phase transitions and chemical reactions is fundamental. Entropy, a measure of disorder or randomness in a system, provides insights into spontaneity, energy dispersal, and the directionality of processes. This article delves into a detailed comparison of the entropy of liquid water (HO(l)) with that of gaseous water (HO(g)) formed during a specific process. Additionally, it explores how to determine the mass of liquid water involved by applying thermodynamic principles. Through comprehensive explanations, calculations, and analytical insights, we aim to elucidate the underlying concepts governing these phenomena.

Understanding Entropy in Water Phases

What Is Entropy?

Entropy (S) is a thermodynamic property that quantifies the degree of disorder or the number of microstates available to a system. It is rooted in statistical mechanics but is widely used in classical thermodynamics to predict the direction of processes and equilibrium states. The second law of thermodynamics states that for spontaneous processes, the total entropy of an isolated system tends to increase.

Entropy in Liquid Water (HO(l))

Liquid water is characterized by a relatively ordered arrangement of molecules, with hydrogen bonds creating a structured network. Its entropy is moderate compared to gaseous water because molecules are confined to a smaller volume and have limited freedom of movement. The entropy of liquid water at a given temperature can be estimated from standard molar entropy values, which are tabulated based on extensive experimental data.

Entropy in Gaseous Water (HO(g))

Gaseous water, or water vapor, exhibits a significant increase in entropy compared to its liquid form. Molecules in the gas phase move freely and occupy a much larger volume, resulting in a higher degree of disorder. The entropy change associated with vaporization reflects the increase in microstates and energy dispersal when water transitions from liquid to vapor.

Thermodynamic Principles Governing Entropy Changes

Phase Transition: Vaporization of Water

When liquid water is converted into vapor, the process involves an increase in entropy. The key thermodynamic relation is:

$$
\Delta S_{vap} = \frac{\Delta H_{vap}}{T}
$$

where:

- ΔS_{vap} is the entropy change during vaporization.
- ΔH_{vap} is the enthalpy of vaporization.
- T is the absolute temperature in Kelvin.

This relation assumes the vaporization occurs at constant temperature and pressure.

Quantitative Comparison of Entropies

To compare the entropy of liquid and vapor phases, standard molar entropy values (S°) are used, typically found in thermodynamic tables. For water at 25°C (298.15 K):

- S°_{liquid} ≈ 69.95 J/(mol·K)
- S°_{vapor} ≈ 188.84 J/(mol·K)

The difference:

$$
\Delta S_{vap} = S^\circ_{vapor} - S^\circ_{liquid} \approx 118.89 \text{ J/(mol·K)}
$$

This substantial increase reflects the entropy gained during vaporization.

Comparative Analysis of Entropy: Liquid vs. Vapor

Entropy of Liquid Water (HO(l))

The entropy of liquid water is relatively low because of its structured hydrogen-bond network, limiting molecular freedom. Its value varies slightly with temperature but remains around 70 J/(mol·K) at room temperature.

Entropy of Water Vapor (HO(g))

In the gaseous state, water molecules have maximum translational, rotational, and vibrational freedom, leading to a much higher entropy value (~189 J/(mol·K) at 25°C).

Thermodynamic Implications

The large difference in entropy between the two phases indicates the spontaneous nature of vaporization under suitable conditions. When water vapor condenses, the entropy decreases, releasing energy and increasing order.

Determining the Entropy Change During the Process

Suppose a process involves converting a certain amount of liquid water into vapor at a given temperature. The entropy change (ΔS) for the entire process can be calculated as:

$$
\Delta S = n \times \Delta S_{vap}
$$

where:

- n is the number of moles of water vaporized.
- ΔS_{vap} is the molar entropy of vaporization.

This provides a basis for understanding the disorder introduced or removed during phase changes.

Calculating the Mass of Liquid Water

Step 1: Establish Known Data

Assume a scenario where:

- The process involves vaporization at 25°C (298.15 K).
- The total entropy change for the process (ΔS_{total}) is known or can be calculated.
- The molar entropies are known from standard tables.

Step 2: Use Thermodynamic Relations

If the entropy change associated with vaporization is known, then the number of moles vaporized (n) is:

$$
n = \frac{\Delta S_{vap} \times n}{\Delta S_{vap}}
$$

If the process is at equilibrium, the number of moles vaporized corresponds to the amount of liquid water that evaporates to produce the observed vapor phase.

Step 3: Convert Moles to Mass

Once n is known, the mass (m) of water vaporized is:

$$
m = n \times M_{H_2O}
$$

where:

- M_{H_2O} is the molar mass of water (~18.015 g/mol).

Practical Example: Estimating the Mass of Water Vaporized

Suppose an observed entropy change (ΔS_{total}) during the vaporization process is 10 J/K, and the process occurs at 25°C.

- Molar entropy of vaporization: $\Delta S_{vap} \approx 118.89 \text{ J/(mol·K)}$

- Number of moles vaporized:

$$
n = \frac{\Delta S_{total}}{\Delta S_{vap}} = \frac{10 \text{ J/K}}{118.89 \text{ J/(mol·K)}} \approx 0.0841 \text{ mol}
$$

- Mass of water vaporized:

$$
m = 0.0841 \text{ mol} \times 18.015 \text{ g/mol} \approx 1.515 \text{ g}
$$

This simplified example illustrates how thermodynamic data can directly inform us about the mass of water involved in phase transitions based on entropy considerations.

Broader Implications and Applications

Climate and Weather Systems

Understanding the entropy change associated with water vaporization is vital for modeling atmospheric processes, cloud formation, and weather patterns. The large entropy increase during vaporization explains why water readily evaporates in warm environments, contributing to humidity and energy transfer.

Industrial Processes

In industrial applications like distillation, evaporation, and refrigeration, precise calculations of entropy changes enable optimization of energy usage and efficiency.

Biological Systems

Water's phase changes and their thermodynamic implications are critical in biological systems, affecting processes like transpiration, respiration, and thermoregulation.

Conclusion

The comparison of the entropy of liquid water and water vapor underscores the profound increase in disorder that accompanies phase transitions from liquid to gas. This entropy change is central to understanding the spontaneity of vaporization and condensation processes. By applying thermodynamic principles, standard entropy values, and basic calculations, scientists and engineers can determine the mass of water involved in various processes, predict system behavior, and optimize conditions across multiple fields.

In essence, the interplay between entropy and phase changes reveals fundamental insights into the natural tendency of systems toward disorder, energy dispersal, and equilibrium. Such understanding forms the backbone of thermodynamic analysis in both theoretical and practical contexts, underpinning advancements in climate science, industrial engineering, and biological systems.

Note: All calculations and values are based on standard data at 25°C (298.15 K). Adjustments are necessary for different temperatures or conditions.

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