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Understanding thermodynamic properties such as entropy and enthalpy is essential in the study of phase changes and material science. In this article, we will explore how to calculate the entropy change associated with melting a specific mass of metal, given its enthalpy of fusion and melting point temperature. Through detailed explanations, step-by-step calculations, and relevant thermodynamic principles, we aim to provide a comprehensive understanding of this process.

Introduction to Thermodynamic Concepts

Before delving into calculations, it is important to understand key thermodynamic concepts:

1. Enthalpy of Fusion (ΔH_{fus})

- Represents the heat energy required to convert a substance from solid to liquid phase at its melting point.
- Measured in kilojoules per mole (kJ/mol).
- For the given metal, ΔH_{fus} = 22 kJ/mol.

2. Entropy (S)

- A measure of the disorder or randomness in a system.
- Changes during phase transitions are critical in understanding material behavior.
- The entropy change during melting, ΔS_{fus}, can be calculated using thermodynamic relations.

3. Phase Transition: Melting

- The process involves a solid becoming a liquid at a specific temperature.
- The associated entropy change can be derived from the enthalpy of fusion and the temperature at which melting occurs.

Calculating the Entropy Change During Melting

The fundamental relation connecting enthalpy and entropy during a phase change at constant temperature is:

$$\Delta S_{fus} = \Delta H_{fus} / T^{melting}$$

Where:

- ΔS_{fus} is the entropy change during fusion (J/K).
- ΔH_{fus} is the enthalpy of fusion (J/mol).
- $T_{melting}$ is the melting temperature in Kelvin.

Step-by-Step Calculation

Let's proceed with the detailed calculation, considering the provided data:

- Mass of metal, m = 18 g
- Melting point, Tmelting = 1225°C
- Enthalpy of fusion, □Hfus = 22 kJ/mol

Step 1: Convert melting temperature to Kelvin

T(K) = T(°C) + 273.15

T = 1225 + 273.15 = 1498.15 K

Step 2: Convert □Hfus to Joules per mole

□Hfus = 22 kJ/mol = 22,000 J/mol

Step 3: Calculate the molar mass of the metal

Since the problem does not specify the metal, but provides mass and molar enthalpy, we'll proceed with the calculation assuming the molar enthalpy is per mole of the metal, and that the mass corresponds to a certain number of moles.

However, to find the molar amount, we need the molar mass (M). The problem doesn't specify M, so we will assume the enthalpy of fusion is per mole of the metal being melted.

Step 4: Calculate the number of moles in the 18 g sample

Number of moles, n = m / M

But M is unknown. To proceed, since □Hfus is given per mol, and we want the entropy change for the entire 18 g sample, the total entropy change (ΔS_{total}) can be expressed as:

$$\Delta S_{total} = n\, \Delta S_{fus} = (m / M)\, (\Delta H_{fus} / T)$$

This allows us to compute the total entropy change once M is known. If M is unknown, the calculation can be expressed per mole of the metal.

Calculating Entropy of Fusion per Mole

Using the relation:

$$\Delta S_{fus} = \Delta H_{fus} / T^{melting}$$

Plugging in the values:

$$\Delta S_{fus} = 22{,}000\ \text{J/mol} / 1498.15\ \text{K} \approx 14.69\ \text{J/(mol·K)}$$

Therefore, the entropy change of fusion per mole of metal is approximately 14.69 J/(mol·K).

Calculating Total Entropy Change for 18 g of Metal

Assuming the molar mass (M) of the metal is known, the total entropy change during melting of 18 g is:

$$\Delta S_{total} = (m / M)\, \Delta S_{fus}$$

Suppose the molar mass M of the metal is known or can be estimated (e.g., for aluminum M ≈ 26.98 g/mol). Let's use aluminum as an example:

Example: Aluminum

- M = 26.98 g/mol
- Number of moles: n = 18 g / 26.98 g/mol ≈ 0.6667 mol

Total entropy change:

ΔS_{total} = 0.6667 mol 14.69 J/(mol·K) ≈ 9.80 J/K

This means that melting 18 g of aluminum at 1225°C results in an entropy increase of approximately 9.80 J/K.

Additional Considerations and Applications

Understanding entropy changes during melting is crucial for various applications:

1. Material Processing

- Controlling phase changes during alloy formation.
- Designing melting and casting processes.

2. Thermodynamic Stability

- Calculating free energy changes to predict phase stability.

- Assessing the feasibility of melting under different conditions.

3. Energy Efficiency

- Estimating the energy required for melting in industrial processes.

- Reducing energy consumption by optimizing melting temperatures.

Factors Affecting Entropy and Melting Processes

While the fundamental calculations are straightforward, several factors influence the entropy change and melting process:

- **Impurities:** Can alter melting point and enthalpy of fusion.
- **Pressure:** Affects melting temperature and phase stability.
- **Alloy Composition:** Complexities arise in mixed metals with different melting points and enthalpies.
- **Crystallinity:** The degree of order in the solid phase impacts entropy calculations.

Conclusion

Calculating the entropy change associated with melting a metal involves understanding the relationship between enthalpy of fusion, temperature, and entropy. The key formula:

$$\Delta S_{fus} = \Delta H_{fus} / T^{melting}$$

allows for straightforward computation once the melting temperature and enthalpy of fusion are known. For the given data—an 18 g piece of metal melting at 1225°C with an enthalpy of fusion of 22 kJ/mol—the molar entropy of fusion is approximately 14.69 J/(mol·K). The total entropy change can then be determined based on the molar mass of the metal.

Understanding these concepts is vital in thermodynamics, materials science, and industrial applications where phase changes play a critical role. Proper calculation of entropy changes enables better control over manufacturing processes, energy management, and material design.

Keywords: entropy, enthalpy of fusion, melting point, thermodynamics, phase transition, material science, melting process, molar entropy, energy calculation, phase change entropy

Frequently Asked Questions

What is the entropy change when 18g of metal melts at 1225°C with an enthalpy of fusion of 22 kJ/mol?

First, convert mass to moles: molar mass = 18g. Since the molar mass is not given, assume the metal's molar mass is M g/mol. Number of moles = 18 / M. Entropy change (ΔS) = ΔH / T. Convert temperature to Kelvin: 1225°C = 1225 + 273 = 1498 K. Then, ΔS = (22,000 J/mol) / 1498 K $\approx$ 14.7

J/(mol·K). Multiply by the number of moles to get total □S: (18 / M) 14.7 J/K. Without molar mass, the specific □S per mole is approximately 14.7 J/(mol·K).

How do you calculate the entropy of fusion for a metal given its enthalpy of fusion and melting point?

Calculate the entropy of fusion using the formula □S = □H / T_melting, where □H is the enthalpy of fusion and T_melting is the melting temperature in Kelvin.

If the enthalpy of fusion is 22 kJ/mol and the melting point is 1225°C, what is the entropy of fusion per mole?

Convert melting point to Kelvin: 1225°C + 273 = 1498 K. Then, □S = 22,000 J/mol / 1498 K □ 14.7 J/(mol·K).

Why is it important to convert temperature to Kelvin when calculating entropy change?

Because entropy change calculations require absolute temperature in Kelvin to ensure the thermodynamic equations are dimensionally consistent and accurate.

What assumptions are made when calculating entropy of fusion in this problem?

Assumptions include that the enthalpy of fusion remains constant over the temperature range, and the process occurs at the melting point with no supercooling or superheating effects.

Can the entropy of fusion be negative? Why or why not?

Typically, the entropy of fusion is positive because melting is an endothermic process that increases disorder. Negative values would imply a decrease in entropy upon melting, which is thermodynamically unlikely.

How does the molar mass of the metal influence the total entropy change during melting?

The total entropy change depends on the number of moles (mass divided by molar mass). A larger molar mass results in fewer moles for a given mass, thus reducing the total entropy change.

What is the significance of knowing the enthalpy of fusion and melting temperature in thermodynamics?

These values allow calculation of entropy changes during phase transitions, which are essential for understanding material stability, phase diagrams, and thermodynamic properties.

If the metal's molar mass is 50 g/mol, what is the entropy of fusion for 18g of the metal?

Number of moles = 18 g / 50 g/mol = 0.36 mol. Using □S per mol = 14.7 J/(mol·K), total □S = 0.36 mol 14.7 J/(mol·K) □ 5.29 J/K.

Additional Resources

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Understanding the thermodynamic properties of materials is crucial in fields ranging from materials science to chemical engineering. Today, we explore a specific scenario involving a metallic substance with a known melting point and enthalpy of fusion. Such calculations not only deepen our grasp of phase transitions but also demonstrate fundamental principles of thermodynamics in action. Our focus centers on determining the entropy change associated with melting—an essential parameter that sheds light on the disorder introduced during phase transition.

Introduction to the Thermodynamic Context

Thermodynamics offers a powerful framework for analyzing transformations in matter, especially phase changes such as melting, vaporization, or sublimation. When a solid metal melts, it transitions from an ordered crystalline structure to a more disordered liquid state. This change in disorder is quantified by the entropy change (ΔS), which is central to understanding the spontaneity and energy dynamics of the process.

In our case, the key parameters provided are:

- Mass of the metal sample: 18 grams
- Melting temperature (Tm): 1225°C
- Enthalpy of fusion ($\Delta Hfus$): 22 kJ/mol

The goal is to calculate the entropy of melting ($\Delta Sfus$), which reflects the increase in randomness per mole of metal during melting.

Converting Units and Fundamental Concepts

Before delving into calculations, it’s essential to clarify units and foundational concepts:

- Temperature Conversion: Since thermodynamic formulas typically use Kelvin (K), convert Celsius to Kelvin:

Tm = 1225°C + 273.15 = 1498.15 K

- Moles of Metal: To link the given enthalpy (per mole) to the actual sample, we need to determine how many moles are present in 18 grams of the metal.

- Enthalpy of Fusion (ΔHfus): This is given per mole, so the total energy required to melt the sample depends on the number of moles.

Step 1: Calculating Moles of Metal in the Sample

The molar mass (M) of the metal is not explicitly provided, which is a common scenario in thermodynamics problems. However, for the purpose of illustration, let’s assume the metal in question is aluminum, which has a molar mass of approximately 26.98 g/mol. This assumption helps us proceed with a concrete example, but the method applies generally.

Number of moles (n):

n = mass / molar mass = 18 g / 26.98 g/mol ≈ 0.6667 mol

This calculation indicates that 18 grams of aluminum corresponds to roughly 0.6667 moles.

Step 2: Relating Enthalpy and Entropy

The fundamental thermodynamic relation for a phase change at equilibrium is:

$$
\Delta S_{fus} = \frac{\Delta H_{fus}}{T_m}
$$

Where:

- □Sfus is the entropy change per mole during melting,
- □Hfus is the enthalpy of fusion per mole,
- Tm is the melting temperature in Kelvin.

Given that □Hfus is 22 kJ/mol:

$$
\Delta H_{fus} = 22\, \text{kJ/mol} = 22,000\, \text{J/mol}
$$

Calculating □Sfus per mole:

$$
\Delta S_{fus} = \frac{22,000\, \text{J/mol}}{1498.15\, \text{K}} \approx 14.7\, \text{J/(mol·K)}
$$

This is the standard entropy change per mole during melting.

Step 3: Determining the Total Entropy Change for the Sample

Since entropy change is proportional to the amount of substance, the total entropy change for the 18-gram sample is:

$$
\Delta S_{total} = n \times \Delta S_{fus}
$$

$$
\Delta S_{total} = 0.6667\, \text{mol} \times 14.7\, \text{J/(mol·K)} \approx 9.8\, \text{J/K}
$$

\]

This value represents the total increase in entropy associated with melting the 18-gram sample of aluminum at its melting point.

Broader Implications and Real-World Relevance

While the calculation here is specific to a hypothetical aluminum sample, the methodology applies universally. Whether analyzing different metals or other crystalline solids, the core principles remain consistent:

- Convert all quantities to compatible units.
- Use the molar enthalpy of fusion to find the entropy change per mole.
- Scale this value according to the number of moles in the sample.

Such calculations are vital in:

- Materials Design: Understanding melting behaviors aids in selecting materials for high-temperature applications.
- Industrial Processes: Controlling phase transitions impacts casting, welding, and manufacturing.
- Thermodynamic Modeling: Accurate entropy values feed into larger models predicting system behavior under various conditions.

Limitations and Assumptions

It’s important to recognize certain assumptions made in this example:

- Pure Substance: The calculation assumes a pure metal with a well-defined melting point and enthalpy of fusion.

- Equilibrium Conditions: The melting occurs at equilibrium, and no supercooling or superheating effects are considered.
- Constant Molar Enthalpy: The enthalpy of fusion is treated as temperature-independent, which is a reasonable approximation over small temperature ranges near melting.

In practical scenarios, variations in purity, pressure, and other factors can influence these thermodynamic properties.

Extending the Analysis

Beyond melting, similar calculations can be extended to:

- Vaporization processes: Calculating entropy changes during boiling.
- Substitution effects: Analyzing how impurities alter phase transition energies.
- Thermodynamic cycles: Incorporating entropy changes into engines and refrigeration systems.

Understanding the entropy of phase transitions is a foundational aspect of thermal analysis, providing insights into the disorder and energy dispersal within materials.

Final Thoughts

The calculation of entropy change during melting, as demonstrated, combines fundamental thermodynamic principles with practical data interpretation. For the hypothetical 18-gram piece of metal melting at 1225°C with a known enthalpy of fusion, the total entropy increase is approximately 9.8 Joules per Kelvin. This figure encapsulates the essence of increased disorder and energy dispersal resulting from the phase change.

By mastering these calculations, scientists and engineers can better predict material behaviors, optimize processes, and innovate new materials tailored to specific thermal and mechanical requirements. Thermodynamics, after all, provides the language through which the energetic and structural transformations of matter are understood and harnessed.

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