21) How Much Heat Must Be Removed From 456 G Of Water At 25.0C To Change It Into Ice At -10.0C? The Specific

21) How Much Heat Must Be Removed From 456 G Of Water At 25.0°C To Change It Into Ice At -10.0°C? The Specific heat removal process involves understanding the phase change from water to ice and the temperature decrease of the ice below its freezing point. This thermodynamics problem requires calculating the total heat energy that must be extracted from the water to convert it into ice at a lower temperature. To find the solution, we need to consider the heat removed during three distinct steps:

1. Cooling water from 25.0°C to 0°C
2. Freezing water at 0°C into ice
3. Cooling ice from 0°C to -10.0°C

In this article, we will explore these steps in detail, including the relevant formulas, constants, and calculations involved in determining the total heat that must be removed from the water.

Understanding the Thermodynamic Process

Before diving into calculations, it’s essential to understand the physical processes involved when removing heat from water to turn it into ice at a lower temperature:

- Cooling water from 25.0°C to 0°C: The water cools down to its freezing point.
- Freezing water at 0°C: The phase change from liquid to solid releases latent heat.
- Cooling ice from 0°C to -10.0°C: The solid ice is further cooled below its melting point.

Each of these steps involves specific heat capacities and latent heats, which are crucial in calculating the total heat removed.

Key Concepts and Constants

Understanding the calculations requires familiarity with certain thermodynamic properties:

Specific Heat Capacity of Water

- $c_{water} = 4.18 \, \text{J/g°C}$

Latent Heat of Fusion of Water

- $L_f = 334 \, \text{kJ/kg} = 334,000 \, \text{J/kg}$

Specific Heat Capacity of Ice

- $c_{ice} = 2.09 \, \text{J/g°C}$

Note: All calculations will use these constants, converting units where necessary.

Step-by-Step Calculation

To determine the total heat removed, we will calculate the heat for each step and sum them up.

Step 1: Cooling Water from 25.0°C to 0°C

The heat removed during temperature decrease is given by:

$$ Q_1 = m \times c_{water} \times \Delta T $$

Where:
- $m = 456\, \text{g}$
- $c_{water} = 4.18\, \text{J/g°C}$
- $\Delta T = 25.0°C - 0°C = 25.0°C$

Calculating:

$$ Q_1 = 456 \times 4.18 \times 25.0 $$
$$ Q_1 = 456 \times 104.5 $$
$$ Q_1 \approx 47,772\, \text{J} $$

This is the heat removed to bring water down to freezing point.

Step 2: Freezing Water at 0°C into Ice

The latent heat of fusion must be removed to change the phase from liquid to solid:

$$ Q_2 = m \times L_f $$

Convert mass to kilograms:

$$ m = 456\, \text{g} = 0.456\, \text{kg} $$

Calculating:

$$ Q_2 = 0.456 \times 334,000 $$
$$ Q_2 \approx 152,304\, \text{J} $$

This is the energy removed during the phase change.

Step 3: Cooling Ice from 0°C to -10.0°C

Finally, cool the ice from 0°C down to -10.0°C:

$$ Q_3 = m \times c_{ice} \times \Delta T $$

Where:
- $ c_{ice} = 2.09\, \text{J/g°C} $
- $ \Delta T = 0°C - (-10.0°C) = 10.0°C $

Calculating:

$$ Q_3 = 456 \times 2.09 \times 10.0 $$
$$ Q_3 = 456 \times 20.9 $$
$$ Q_3 \approx 9,542.4\, \text{J} $$

This is the heat removed to cool the ice further below freezing.

Total Heat Removed

Adding all three amounts:

$$ Q_{total} = Q_1 + Q_2 + Q_3 $$
$$ Q_{total} = 47,772 + 152,304 + 9,542.4 $$
$$ Q_{total} \approx 209,618.4\, \text{J} $$

Therefore, approximately 209,618 Joules of heat must be removed from 456 grams of water at 25.0°C to convert it into ice at -10.0°C.

Practical Applications and Significance

Understanding how much heat must be removed during such a phase change is crucial in various scientific and engineering fields, including:

- **Climate Science:** Modeling ice formation and glacier dynamics.
- **Food Preservation:** Designing efficient freezing processes.
- **Engineering:** Developing cooling systems for electronic devices or industrial processes.
- **Physics Education:** Demonstrating principles of heat transfer and phase changes.

Accurate calculations help in optimizing refrigeration systems, understanding environmental processes, and designing more energy-efficient cooling methods.

Summary

In summary, to convert 456 grams of water at 25.0°C into ice at -10.0°C, about 209,618 Joules of heat must be removed. This process involves three key steps: cooling the water to its freezing point, removing latent heat during freezing, and further cooling the ice below freezing temperature. Mastery of these calculations enhances understanding of thermodynamics and heat transfer, which are fundamental concepts in physics and engineering.

Additional Tips for Accurate Calculations

- Always ensure unit consistency, especially when converting grams to kilograms for latent heat calculations.
- Use precise values for specific heats and latent heats when high accuracy is required.
- Remember that phase change calculations involve latent heat, which is independent of temperature but critical during the phase transition.

By mastering these concepts, students and professionals can confidently tackle similar heat transfer problems involving phase changes and temperature variations, leading to better design, analysis, and understanding of thermal systems.

Frequently Asked Questions

What is the main goal when calculating the heat removed from water to convert it into ice at a lower temperature?

The main goal is to determine the total amount of heat energy that must be extracted from the water as it cools from 25.0°C to -10.0°C and then freezes into ice at -10.0°C.

Which specific heat capacities are relevant in calculating the heat removal in this process?

The specific heat capacities of water and ice are relevant, specifically the specific heat of water (about 4.18 J/g°C) and ice (about 2.09 J/g°C), along with the latent heat of fusion for water (approximately 334 J/g).

How do you break down the total heat removal into steps for this problem?

You calculate the heat removed in three steps: cooling water from 25.0°C to 0°C, freezing water at 0°C to ice, and then cooling ice from 0°C to -10.0°C, summing all these amounts for the total heat removed.

What is the formula used to calculate the heat removed during cooling or heating of water or ice?

The formula is $Q = mc\Delta T$, where Q is the heat removed or added, m is mass, c is specific heat capacity, and ΔT is the temperature change.

How is the latent heat of fusion incorporated into the calculation?

The latent heat of fusion is used to calculate the heat removed during the phase change from water to ice at 0°C: $Q = m \times Lf$, where Lf is the latent heat of fusion.

What is the total heat that must be removed from 456 g of water at 25.0°C to turn it into ice at -10.0°C?

The total heat removed is approximately 65,540 Joules, calculated by summing the heat for cooling water, freezing, and cooling ice to -10.0°C.

Why is it important to consider both phase change and temperature change when calculating heat

removal?

Because phase change involves latent heat which is significantly different from sensible heat during temperature change, both must be considered to accurately determine the total heat removed.

Additional Resources

How Much Heat Must Be Removed From 456 G of Water at 25.0°C to Convert It Into Ice at -10.0°C? An In-Depth Analysis of Heat Transfer and Phase Change Processes

Understanding the precise amount of heat involved in phase transitions is fundamental in thermodynamics, environmental science, and engineering applications. When considering the cooling of water from a typical ambient temperature to a sub-zero temperature, the process encompasses multiple stages, each governed by specific heat capacities, phase change enthalpies, and temperature differentials. This article provides a comprehensive and detailed examination of the total heat removal required to convert 456 grams of water at 25.0°C into ice at -10.0°C, elucidating the underlying principles, calculations, and significance of each step.

Introduction: The Significance of Quantifying Heat Removal in Phase Changes

The transfer of heat during phase changes is a cornerstone concept in thermodynamics, with applications ranging from climate modeling to industrial refrigeration. Precisely quantifying the heat removed during such processes not only aids in designing efficient cooling systems but also enhances our understanding of natural phenomena. In this context, the specific problem involves cooling a known mass of water from room temperature to a sub-zero temperature where it becomes solid ice, specifically from 25.0°C down to -10.0°C.

This scenario encapsulates multiple thermal processes:

1. Cooling liquid water from 25.0°C to 0°C.
2. The phase change from water to ice at 0°C.
3. Cooling the newly formed ice from 0°C to -10.0°C.

Each process involves different thermal parameters, such as specific heat capacities and enthalpy of fusion, which must be carefully considered. The comprehensive calculation involves summing the heat removed in each stage to determine the total energy extractable or required.

Fundamental Concepts and Thermodynamic Principles

Before delving into calculations, it is essential to understand the key thermodynamic concepts relevant to this problem:

- Specific Heat Capacity (c): The amount of heat required to raise the temperature of a unit mass of a substance by 1°C (or 1 K). For water, it is approximately 4.18 J/g°C.
- Latent Heat of Fusion (Lf): The heat energy required to convert a unit mass of a substance from liquid to solid at its melting point without changing temperature. For water, Lf ≈ 334 J/g.
- Heat Transfer: The process of heat flow from one body or region to another, driven by temperature differences, governed by the principles of thermodynamics.

The calculation involves sequential steps, each involving different parameters and energy exchanges, which are additive in nature.

Step-by-Step Breakdown of the Cooling Process

The total heat removal (Q_total) can be expressed as the sum of heats associated with each stage:

Q_total = Q1 + Q2 + Q3

Where:

- Q1: Heat removed to cool water from 25.0°C to 0°C.
- Q2: Heat removed during the phase change from water at 0°C to ice at 0°C.
- Q3: Heat removed to cool ice from 0°C to -10.0°C.

Each component is calculated separately using relevant formulas.

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1. Cooling Water From 25.0°C to 0°C

This initial stage involves lowering the temperature of the water from its initial temperature (25.0°C) down to the melting point (0°C).

Formula:

$Q1 = m \times c\_water \times \Delta T$

Where:
- $m = 456$ g
- $c\_water \approx 4.18$ J/g°C
- $\Delta T = (0°C - 25.0°C) = -25.0°C$ (the negative sign indicates heat removal)

Calculation:

$Q1 = 456 \text{ g} \times 4.18 \text{ J/g°C} \times (-25.0°C)$

Since we're interested in the magnitude of heat removed, we take the absolute value:

$Q1 = 456 \times 4.18 \times 25.0 = 456 \times 104.5 \approx 47{,}722$ J

Approximate value: 47,722 Joules

This is the energy extracted to cool the water to its freezing point.

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2. Phase Change from Water at 0°C to Ice at 0°C

This phase change involves the removal of latent heat necessary to convert liquid water into solid ice at the same temperature, 0°C.

Formula:

$Q2 = m \times Lf$

Where:
- $m = 456$ g
- $Lf \approx 334$ J/g

Calculation:

$Q2 = 456 \text{ g} \times 334 \text{ J/g} \approx 152{,}304$ J

Approximate value: 152,304 Joules

This substantial energy removal facilitates the transition from liquid to solid without altering the temperature.

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3. Cooling Ice From 0°C to -10.0°C

After solidification at 0°C, the ice must be further cooled down to -10.0°C.

Formula:

$Q3 = m \times c_{ice} \times \Delta T$

Where:
- $c_{ice} \approx 2.09$ J/g°C (specific heat capacity of ice)
- $\Delta T = (-10.0°C - 0°C) = -10.0°C$

Calculating:

$Q3 = 456 \text{ g} \times 2.09 \text{ J/g°C} \times 10.0°C \approx 456 \times 20.9 \approx 9{,}542 \text{ J}$

Approximate value: 9,542 Joules

This step accounts for the final lowering of temperature of the solid ice.

Summing Up the Total Heat Removed

Adding all three components gives the total heat that must be extracted from the initial water to reach the final state:

$Q_{total} = Q1 + Q2 + Q3$

$Q_{total} \approx 47{,}722 \text{ J} + 152{,}304 \text{ J} + 9{,}542 \text{ J} \approx 209{,}568 \text{ J}$

Final Result:

Approximately 209,568 Joules (or about 209.6 kJ) of heat must be removed to transform 456 grams of water at 25.0°C into ice at -10.0°C.

Implications and Applications of the Calculation

This detailed calculation underscores several critical points relevant in practical and scientific contexts:

- Energy Efficiency in Cooling Systems: Understanding the precise energy

requirements helps optimize refrigeration and air conditioning systems, reducing energy consumption.
- Environmental Impact: Quantifying heat removal is fundamental in climate science, especially in modeling processes like ice formation in natural bodies of water, glaciers, and polar regions.
- Industrial Processes: In manufacturing sectors involving cryogenics or food preservation, accurate heat calculations ensure safety, efficiency, and product quality.
- Thermodynamic Education: Such problems serve as cornerstone examples in physics and engineering education, illustrating the interplay of specific heat, latent heat, and temperature change.

Additional Considerations and Assumptions

While the calculations above provide a solid framework, it’s important to acknowledge the assumptions and potential variations:

- Constant Specific Heats: The specific heats for water and ice are assumed constant over the temperature ranges, which is a good approximation but may vary slightly in reality.
- Pure Substances: The calculation assumes pure water and pure ice, neglecting impurities, dissolved substances, or phase impurities that could alter heat values.
- Reversibility: The process is considered reversible and ideal, ignoring any heat losses to surroundings or inefficiencies.
- No Supercooling: The calculation presumes no supercooling occurs during freezing or cooling, which can happen in practice.

Conclusion: The Significance of Quantifying Heat Transfer in Phase Changes

The process of removing approximately 209.6 kJ of heat from 456 grams of water at 25.0°C to produce ice at -10.0°C exemplifies the intricate interplay of thermodynamic principles governing phase changes. Each stage—cooling, phase transition, and further cooling—contributes significantly to the total energy expenditure, emphasizing the importance of detailed analysis in scientific and engineering applications.

Understanding these calculations not only aids in designing effective cooling systems but also enhances our grasp of natural phenomena, environmental processes, and the fundamental laws of thermodynamics. As technology advances and energy conservation becomes increasingly vital, such detailed thermodynamic analyses will continue to play a critical role in shaping sustainable solutions and scientific understanding.

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