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Introduction

When exploring the fascinating world of thermodynamics and heat transfer, one common problem involves calculating how much heat is exchanged between different materials at varying temperatures. A classic example is dropping a hot metal object into a cold liquid, such as copper into liquid nitrogen. This scenario not only demonstrates fundamental principles of energy conservation but also illustrates the practical applications of heat capacity, thermal conductivity, and phase change.

In this article, we will delve into a detailed analysis of the problem: A 1.00-kg block of copper at 20.0°C is dropped into a large vessel of liquid nitrogen at 77.3K. We aim to determine how much heat is transferred, how much the copper cools, and whether the copper can reach thermal equilibrium with the nitrogen. Our comprehensive approach will include calculations of heat transfer, considerations of specific heat capacities, and thermodynamic principles, all optimized for clarity and SEO relevance.

Understanding the Scenario and Key Concepts

Before diving into calculations, it’s essential to understand the core concepts involved:

- Specific Heat Capacity (c): The amount of heat energy required to raise the temperature of 1 kg of a substance by 1°C (or 1K). For copper, this value is approximately 385 J/(kg·K).
- Thermal Equilibrium: The state where two objects in contact reach the same temperature, resulting in no net heat transfer.
- Heat Transfer: The process of heat moving from the hotter object to the cooler one, governed by the conservation of energy.
- Liquid Nitrogen (LN_2): A cryogenic liquid with a boiling point of approximately 77.3K, used for cooling applications.

Given Data and Parameters

Let’s organize the known data:

Parameter	Value	Description
Mass of copper (m_1)	1.00 kg	Mass of copper block
Initial temperature of copper (T_1)	20.0°C	Starting temperature of copper
Final temperature of copper (T_f)	?	To be determined
Specific heat capacity of copper (c_1)	385 J/(kg·K)	Heat capacity of copper
Mass of liquid nitrogen (m_2)	Large vessel	Assumed sufficient for heat exchange
Temperature of liquid nitrogen (T_2)	77.3 K	Initial temperature of nitrogen
Final temperature of nitrogen (T_{2_final})		Expected to approach T_f

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Step 1: Convert Temperatures to Kelvin

Since thermodynamic calculations are clearer in Kelvin, convert initial temperatures:

- Copper initial temperature: 20.0°C + 273.15 = 293.15 K
- Liquid nitrogen temperature: 77.3 K (already in Kelvin)

Step 2: Determine the Final Equilibrium Temperature

The goal is to find the final temperature (T_f) when the copper and nitrogen reach thermal equilibrium, assuming the nitrogen is large enough to act as a thermal reservoir.

Assumption: The temperature of the nitrogen remains approximately constant at 77.3K because of its large volume and high heat capacity.

Note: If the nitrogen's temperature remains effectively unchanged, then the heat lost by the copper equals the heat gained (or lost) by the nitrogen, which is negligible for large volumes.

Step 3: Calculate Heat Lost by Copper

The heat lost by the copper as it cools from 293.15K to 77.3K is:

$$
Q_{copper} = m_{copper} \times c_{copper} \times (T_{initial} - T_{final})
$$

$$
Q_{copper} = 1.00\, \text{kg} \times 385\, \text{J/(kg·K)} \times (293.15\, \text{K} - 77.3\, \text{K})
$$

$$
Q_{copper} = 385 \times (215.85)
$$

$$
Q_{copper} \approx 83,177.25\, \text{J}
$$

This is the amount of heat the copper loses if it cools all the way down to 77.3K.

Step 4: Assessing the Feasibility of Copper Reaching Liquid Nitrogen Temperature

Since the nitrogen is at 77.3K, the copper cannot cool below this temperature if the nitrogen remains at the same temperature. The copper's temperature will decrease from 293.15K to approximately 77.3K, transferring roughly 83,177 J of heat to the nitrogen.

Important considerations:

- The large volume of nitrogen acts as a heat sink.
- The actual temperature of nitrogen may increase slightly, but for simplicity, assume it remains at 77.3K.
- If the nitrogen volume is sufficiently large, it will absorb this heat without significant temperature change.

Step 5: Calculating the Temperature Drop of Copper

The temperature change:

$$
\Delta T_{copper} = T_{initial} - T_{final} = 293.15\, \text{K} - 77.3\, \text{K} \approx 215.85\, \text{K}
$$

This confirms the copper cools down to the nitrogen temperature, reaching thermal equilibrium, assuming ideal conditions.

Additional Considerations: Phase Change and Practical Factors

In real-world scenarios, dropping a hot copper block into liquid nitrogen involves additional factors:

- Phase Change of Nitrogen: At 77.3K, nitrogen transitions from liquid to gas at boiling point, absorbing latent heat (approximately 199 kJ/kg).
- Heat Transfer Rate: The rate at which heat is transferred depends on contact, surface area, and thermal conductivity.
- Supercooling and Freezing: Copper remains solid; no phase change occurs in the copper itself.

Is the Copper Fully Cooled?

Given the calculations, the copper can theoretically reach the temperature of nitrogen (~77.3K), transferring about 83 kJ of heat. If the nitrogen volume is large enough, it will not significantly increase in temperature, validating our assumption.

Conclusion: How Many Joules of Heat Are Transferred?

Answer:

The total heat transferred from the copper to the nitrogen as the copper cools from 20.0°C (293.15K) to 77.3K is approximately 83,177 Joules.

Implications and Practical Applications

- Cryogenics: Understanding heat transfer between metals and cryogenic liquids is essential in cryogenics and low-temperature physics.
- Material Processing: Cooling metals rapidly using liquid nitrogen is common in materials science to alter microstructure.
- Thermal Management: Designing systems that involve cryogenic cooling requires precise calculations of heat exchange.

Summary of Key Points

- The heat transferred from the copper is approximately 83,177 Joules.
- Copper cools from 20.0°C to roughly 77.3K, reaching the temperature of the liquid nitrogen.
- The large volume of nitrogen acts as a thermal reservoir, absorbing heat without a significant temperature increase.
- Practical factors such as phase change, heat transfer rates, and contact surface area influence real-world scenarios.

Final Thoughts

Understanding the heat transfer in scenarios involving metals and cryogenic liquids is fundamental in thermodynamics. This analysis demonstrates how to quantify energy exchange, predict temperature changes, and appreciate the principles governing thermal equilibrium. Whether in laboratory settings or industrial applications, these calculations are vital for designing efficient cooling systems and managing thermal processes.

Keywords for SEO optimization: heat transfer, copper cooling, liquid nitrogen, thermodynamics, specific heat capacity, cryogenics, thermal equilibrium, heat calculation, phase change, low-temperature physics.

Frequently Asked Questions

How much heat is released when a 1.00-kg copper

block cools from 20.0°C to 77.3K upon immersion in liquid nitrogen?

The heat released is approximately 2,120 joules, calculated using $Q = mc\Delta T$, where ΔT is the temperature change from 20.0°C to 77.3K (−142.7°C).

What is the significance of the temperature difference between the copper block and liquid nitrogen in this process?

The temperature difference drives heat transfer from the copper to the nitrogen, causing the copper to cool and the nitrogen to absorb heat, leading to rapid cooling of the copper.

Why does copper cool down when dropped into liquid nitrogen, and what physical property governs this process?

Copper cools down due to heat transfer driven by temperature difference; its high thermal conductivity and specific heat capacity govern the rate and amount of heat exchanged.

How does the specific heat capacity of copper influence the amount of heat transferred during cooling in this scenario?

The specific heat capacity determines how much heat is needed to change the copper's temperature; a higher capacity means more heat is absorbed or released during temperature changes.

What would happen if the copper block had a different mass? How would that affect the heat transfer?

A different mass would proportionally change the amount of heat transferred; a larger mass would release or absorb more heat, resulting in a greater temperature change.

Is the process of dropping the copper into liquid nitrogen an example of an exothermic or endothermic process?

It is an exothermic process for the copper, as it releases heat to the liquid nitrogen, causing the copper to cool rapidly.

Additional Resources

A 1.00-kg Block of Copper at 20.0°C Dropped into Liquid Nitrogen at 77.3K: An In-Depth Analysis

When examining the interaction between a solid metal and a cryogenic liquid, such as copper immersed in liquid nitrogen, several fundamental principles of thermodynamics, heat transfer, and material properties come into play. This detailed discussion aims to explore the process meticulously, answering the question: How much heat is transferred, and what are the implications of dropping a 1.00-kg copper block at 20.0°C into a large vessel of liquid nitrogen at 77.3K?

Understanding the Scenario

The problem involves a copper block with a mass of 1.00 kg initially at room temperature (which is 20.0°C) being immersed into liquid nitrogen (LN_2) maintained at 77.3K. The key points to consider include:

- The initial temperature of the copper: 20.0°C (which is 293.15K in absolute temperature)
- The temperature of liquid nitrogen: 77.3K
- The mass of copper: 1.00 kg
- The physical properties of copper, especially its specific heat capacity
- The phase change of nitrogen, which remains in liquid form during heat exchange, assuming the vessel is large enough to serve as a heat sink

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Fundamental Concepts and Principles

1. Heat Transfer and Thermodynamics

The process involves heat transfer from the copper block to the liquid nitrogen, primarily through conduction and convection. Since the copper initially is warmer than the nitrogen, heat will flow from the copper to the nitrogen until thermal equilibrium is reached, or until the copper has cooled substantially.

The fundamental equation governing the heat exchange is:

$$
Q = mc\Delta T

\]

Where:
- Q is the heat transferred
- m is the mass of the copper
- c is the specific heat capacity of copper
- ΔT is the temperature change of the copper

2. Specific Heat Capacity of Copper

- Copper has a relatively high specific heat capacity, about $c_{Cu} = 0.385\, \text{J/g·K}$.
- Since the mass is given in kilograms, convert it to grams: $1.00\, \text{kg} = 1000\, \text{g}$.

Thus:

$$
Q_{copper} = 1000\, \text{g} \times 0.385\, \text{J/g·K} \times (T_{initial} - T_{final})
$$

Calculating the Heat Transfer

1. Estimating the Final Temperature of the Copper

In an idealized scenario, assuming the vessel is large enough to act as a perfect heat sink, the copper will cool down to the temperature of the liquid nitrogen, i.e., approximately 77.3K.

- Assumption: The copper reaches thermal equilibrium with the nitrogen, which is a reasonable approximation given the large volume of LN_2.

Therefore:

$$
\Delta T = T_{initial} - T_{final} = 293.15\, \text{K} - 77.3\, \text{K} = 215.85\, \text{K}
$$

- The temperature difference drives heat flow from copper to nitrogen.

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2. Total Heat Transferred from Copper to Liquid Nitrogen

Using the heat capacity:

$$
Q = 1000\, \text{g} \times 0.385\, \text{J/g·K} \times 215.85\, \text{K}
$$

Calculating:

$$
Q \approx 1000 \times 0.385 \times 215.85 \approx 83,177\, \text{J}
$$

This means approximately 83.2 kJ of heat is extracted from the copper as it cools from 20.0°C to nearly 77.3K.

Implications of Heat Transfer in the System

1. Effect on Liquid Nitrogen

The large volume of LN_2 in the vessel acts as a heat sink, vaporizing as it absorbs heat:

- The energy required to vaporize nitrogen is governed by its latent heat of vaporization, approximately $L_{v} = 199\, \text{J/g}$.

- To understand how much nitrogen vaporizes, we can estimate:

$$
\text{Mass of nitrogen vaporized} = \frac{Q}{L_v} = \frac{83,177\, \text{J}}{199\, \text{J/g}} \approx 418\, \text{g}
$$

Thus, dropping the copper block causes approximately 418 grams of nitrogen to vaporize, assuming all heat goes into phase change.

2. Temperature of the Liquid Nitrogen Post-Interaction

In reality, the LN_2 remains at roughly 77.3K during the process, provided the vessel's volume and the supply of LN_2 are sufficient to absorb the heat without a significant temperature rise.

- The vaporization process absorbs heat, maintaining the temperature.

- The total vaporized nitrogen depends on the amount of LN_2 present and the rate at which heat is transferred.

3. Thermal Equilibrium and Final States

- The copper reaches approximately the temperature of the LN_2, i.e., 77.3K.
- The nitrogen absorbs the heat, vaporizes, and possibly causes localized boiling and splashing.

Additional Considerations and Real-World Factors

1. Non-Idealities in the Process

- Heat Losses: In practical situations, some heat may be lost to the surroundings, meaning less nitrogen vaporizes than the ideal calculation suggests.

- Temperature Gradients: The copper's surface cools before the interior cools uniformly, leading to temperature gradients.

- Vapor Bubble Formation: As nitrogen vaporizes at the copper's surface, bubbles form, which can influence heat transfer rates.

2. Material and Phase Changes

- Copper remains solid at these temperatures; no phase change occurs for the copper itself.
- Nitrogen remains in the liquid phase during the process, absorbing heat and vaporizing.

3. Safety and Handling

- Rapid cooling of the copper can cause thermal stresses, potentially leading to cracking if the material is brittle.
- Vaporized nitrogen expands rapidly, so proper venting is critical to prevent pressure buildup.

Conclusion

In summary, dropping a 1.00-kg copper block at 20.0°C into a large vessel of liquid nitrogen at 77.3K results in a significant heat transfer of approximately 83.2 kJ from the copper to the nitrogen. This heat transfer causes:

- The copper to cool down to near the nitrogen temperature.
- The vaporization of roughly 418 grams of nitrogen, assuming ideal conditions and complete heat absorption.

This process exemplifies fundamental thermodynamic principles, including heat capacity, phase change, and heat transfer mechanisms. It also highlights practical considerations in cryogenics, such as phase change management, safety, and the importance of large heat sinks to facilitate rapid cooling.

Understanding these processes is crucial in various applications, from cryopreservation and superconductivity to industrial cooling systems, where controlled heat exchange is vital. The interaction between metals and cryogenic liquids remains a fascinating and essential domain in thermodynamics and materials science.

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