QUESTION 42 Two Blocks Of The Same Substance [Cp = 24.4 J/(mol*K)] And Of Equal Mass (500 G), One At

Understanding the Thermodynamics of Two Blocks of the Same Substance

Introduction to the Problem

QUESTION 42 Two Blocks Of The Same Substance [Cp = 24.4 J/(molK)] And Of Equal Mass (500 G), One At introduces a classic thermodynamics scenario involving two blocks of identical material. This problem typically involves exploring heat transfer, temperature changes, and specific heat capacities to understand how energy flows between objects. Such questions are fundamental in physics and chemistry, especially when analyzing thermal systems, heat exchange processes, and energy conservation principles.

In this article, we delve into the detailed analysis of this problem, providing a comprehensive understanding of the concepts involved, the mathematical calculations, and the real-world applications. Whether you're a student preparing for exams or a professional seeking a refresher, this guide will clarify the key ideas behind the thermal interactions of identical substances.

Key Concepts in Heat Transfer and Specific Heat Capacity

Specific Heat Capacity (Cp)

Specific heat capacity, denoted as Cp, is a measure of how much heat energy is required to raise the temperature of a substance per mole and per degree Kelvin (or Celsius). It is expressed in units of Joules per mole per Kelvin (J/(mol·K)). The value of Cp indicates the substance's ability to store thermal energy.

For the substance in question, Cp = 24.4 J/(mol·K). This relatively moderate value suggests that it requires 24.4 Joules of energy to increase the temperature of one mole of this substance by one Kelvin.

Mass and Moles Relationship

Given the mass of each block is 500 grams, understanding the relationship between mass and moles is essential:

- Molar mass (M): The molar mass of the substance determines how many moles are present in a given mass.
- Number of moles (n): Calculated as $n = \frac{\text{mass}}{M}$.

Knowing the molar mass allows precise calculation of heat energy needed for temperature changes.

Analyzing the Scenario: Two Identical Blocks

Initial Conditions and Assumptions

Suppose the problem states that:

- Both blocks are made of the same substance with $C_p = 24.4$ J/(mol·K).
- Each block has a mass of 500 grams.
- One block is at a higher initial temperature (say, T_1), and the other at a lower initial temperature (T_2).
- The goal is to determine the final equilibrium temperature after heat exchange or to find the amount of heat transferred.

This scenario exemplifies a typical heat exchange process where energy flows from the hotter to the cooler object until thermal equilibrium is reached.

Calculating Moles in Each Block

To proceed, we need the molar mass of the substance. Let's assume, for illustration, that the molar mass M is 100 g/mol (common for many organic compounds).

Number of moles in each 500 g block:

$$
n = \frac{500\, \text{g}}{100\, \text{g/mol}} = 5\, \text{mol}
$$

This simplifies calculations, as both blocks contain the same number of moles.

Energy Transfer and Final Temperature

Calculation

Heat Transfer Principles

The fundamental principle governing heat exchange is the conservation of energy. When two objects are in thermal contact:

- The heat lost by the hot object equals the heat gained by the cold object (assuming no heat loss to surroundings).
- The heat transfer (Q) is related to temperature change (ΔT) and the specific heat capacity:

$$
Q = n \times C_p \times \Delta T
$$

Where:
- Q is the heat transferred.
- n is the number of moles.
- C_p is the molar heat capacity.
- ΔT is the change in temperature.

Determining the Final Equilibrium Temperature

Suppose the hot block starts at temperature T_{hot} and the cold block at T_{cold}. When they reach equilibrium at temperature T_f:

$$
\text{Heat lost by hot block} = \text{Heat gained by cold block}
$$

Expressed mathematically:

$$
n \times C_p \times (T_{hot} - T_f) = n \times C_p \times (T_f - T_{cold})
$$

Since the blocks are identical:

$$
T_{hot} - T_f = T_f - T_{cold}
$$

$$
T_f = \frac{T_{hot} + T_{cold}}{2}
$$

The final temperature is simply the arithmetic mean of the initial temperatures, assuming equal masses and heat capacities.

Example Calculation

If:
- $T_{hot} = 80^\circ C$
- $T_{cold} = 20^\circ C$

Then:
$$
T_f = \frac{80 + 20}{2} = 50^\circ C
$$

This demonstrates that the final temperature equilibrates to the average of the initial temperatures, provided the masses and heat capacities are the same.

Additional Considerations in the Problem

Impact of Different Initial Temperatures

When initial temperatures differ significantly, the heat transfer process remains similar, but the actual energy exchanged can be calculated:

- Heat lost by the hot block:
$$
Q_{hot} = n \times C_p \times (T_{hot} - T_f)
$$
- Heat gained by the cold block:
$$
Q_{cold} = n \times C_p \times (T_f - T_{cold})
$$

Since energy is conserved:

$$
Q_{hot} = Q_{cold}
$$

Leading to the same average temperature as before.

Considering Heat Losses to Surroundings

In real-world scenarios, heat losses to the environment, conduction, convection, and radiation can affect the final temperature. These factors require more complex models, including heat transfer coefficients and environmental conditions.

Applications of This Thermodynamic Analysis

Industrial Processes

Understanding heat transfer between identical substances is vital in designing efficient heat exchangers, manufacturing processes, and thermal management systems.

Laboratory Experiments

This scenario serves as a foundational experiment in physics and chemistry labs to demonstrate conservation of energy and specific heat capacity principles.

Engineering and Material Science

Engineers utilize these principles to select materials with appropriate thermal properties for building insulation, electronic device cooling, and energy storage.

Common Mistakes and Clarifications

Mistake: Assuming No Heat Loss

In theoretical calculations, assuming perfect insulation simplifies analysis. However, real systems experience heat losses that can alter outcomes.

Clarification: Equal Masses and Moles

When the masses differ, or the substances are different, calculations must account for varying molar masses and heat capacities.

Misinterpretation: Final Temperature Equals Initial Temperatures

The final temperature is not necessarily equal to either initial temperature unless the substances start at the same temperature.

Summary and Conclusion

Understanding the thermodynamics of two blocks of the same substance involves analyzing heat transfer, specific heat capacities, and initial temperatures. When both blocks have equal masses and are made of the same material, the final equilibrium temperature after heat exchange is simply the average of their initial temperatures. This principle is fundamental in thermal physics and has broad applications in engineering, science, and everyday life.

By mastering these concepts, students and professionals can better predict and control thermal processes, optimize energy efficiency, and design systems that effectively manage heat. Whether analyzing simple experiments or complex industrial systems, the core ideas outlined here provide a solid foundation for understanding heat transfer between identical substances.

Keywords: heat transfer, specific heat capacity, thermal equilibrium, molar heat capacity, energy conservation, thermodynamics, heat exchange, heat capacity calculation, thermal systems

Frequently Asked Questions

What is the significance of specific heat capacity (Cp) in comparing two blocks of the same substance?

The specific heat capacity (Cp) indicates the amount of heat needed to raise the temperature of one mole of the substance by one Kelvin, allowing comparison of how different masses or states of the same substance respond to heat energy.

How does the equal mass of two blocks affect their heat transfer when subjected to the same thermal process?

Since both blocks have the same mass, the heat transfer calculations rely primarily on their specific heat capacities and temperature changes, simplifying the comparison of heat absorption or release.

Given two blocks of the same substance and mass but different initial temperatures, how can we determine the heat exchanged?

Using the formula $Q = m\ Cp\ \Delta T$, where m is mass, Cp is specific heat capacity, and ΔT is the temperature change, we can calculate the heat exchanged for each block.

What role does the specific heat capacity Cp = 24.4 J/(mol·K) play in thermal calculations involving these blocks?

It determines the amount of energy required to change the temperature of one mole of the substance by one Kelvin, essential for calculating heat transfer in molar terms.

If one block is initially at a higher temperature than the other, how can we find the final equilibrium temperature after heat exchange?

Assuming no heat loss, set the heat lost by the hotter block equal to the heat gained by the cooler block using $Q = m\ C_p\ \Delta T$, and solve for the final temperature.

Why is it important to consider molar specific heat capacity (Cp) instead of mass-specific heat capacity in these calculations?

Because Cp = 24.4 J/(mol·K) is given per mole, calculations must convert mass to moles to accurately determine heat transfer for the blocks.

How do you convert the given mass of 500 g into moles for use with the molar specific heat capacity?

Divide the mass by the molar mass of the substance: moles = 500 g / molar mass (g/mol). For example, if the substance is water (molar mass 18 g/mol), moles = 500 / 18 ≈ 27.78 mol.

Can the specific heat capacity Cp change with temperature, and how does that affect calculations?

Yes, Cp can vary with temperature, but for small temperature ranges, it is often approximated as constant. Significant temperature changes may require more complex models.

What practical applications involve calculating heat exchange between two blocks of the same substance and equal mass?

Applications include thermal insulation design, calorimetry experiments, and understanding heat transfer in manufacturing processes involving homogeneous materials.

Additional Resources

Thermodynamics
Exploring the Heat Capacity and Thermal Behavior of Equal Mass Blocks of the Same Substance

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Introduction

Imagine two identical blocks of a common substance, each weighing 500 grams, yet subjected to different thermal conditions. Despite their similarities in mass and composition, their thermal responses can differ dramatically depending on their initial temperatures, heat exchange processes, and specific heat capacities. This scenario offers a fascinating window into the principles of thermodynamics, specifically focusing on the concept of specific heat capacity (C_p)—a critical property that governs how substances absorb and transfer heat.

In this detailed analysis, we will dissect the thermodynamic behavior of two equal-mass blocks of the same substance, each with a molar heat capacity (C_p) of 24.4 J/(mol·K). We aim to clarify how their heat capacities influence their temperature changes, energy exchanges, and overall thermal behavior under various conditions. By examining these factors, we can better understand the practical implications for thermal management, material science, and engineering applications.

Understanding the Basics: What is Specific Heat Capacity?

Before delving into the specifics of the problem, it's essential to clarify some foundational concepts:

- Specific Heat Capacity (c): The amount of heat required to raise the temperature of a unit mass of a substance by one Kelvin (or degree Celsius). It is usually expressed in J/(kg·K).

- Molar Heat Capacity (C_p): The heat capacity per mole of substance, expressed in J/(mol·K). It relates to the specific heat capacity via the molar mass (M):

$$
C_p = c \times M
$$

- Heat Energy (Q): The amount of thermal energy transferred into or out of a substance, calculated as:

$$
Q = m \times c \times \Delta T
$$

- Temperature Change (ΔT): The difference in temperature before and after heat exchange.

The Scenario: Two Blocks of the Same Substance

Suppose we have:

- Mass of each block: 500 grams (0.5 kg)
- Molar heat capacity (C_p): 24.4 J/(mol·K)
- Initial conditions: One block is at a higher temperature T_{hot}, and the other at a lower temperature T_{cold}. Over time, heat flows from the hotter to the colder block until thermal equilibrium is reached.

The key questions we want to answer include:

- How much heat is needed to change the temperature of each block?
- How does the heat capacity affect the rate and magnitude of temperature change?
- What happens during heat exchange if the blocks are brought into contact?

Calculating Molar Mass and Specific Heat Capacity

To analyze these blocks accurately, we need to determine the molar mass (M) of the substance based on the given molar heat capacity:

$$
C_p = c \times M
$$

Given:

$$
C_p = 24.4\, \text{J/(mol·K)}
$$

and assuming a typical specific heat capacity for common substances (for example, water's molar heat capacity is about 75.3 J/(mol·K)), this indicates the substance might be a material with a relatively low molar heat capacity, such as metals like aluminum or copper, which have molar masses and heat capacities in similar ranges.

Suppose we want to find the specific heat capacity per unit mass:

$$
c = \frac{C_p}{M}
$$

But since C_p is given, and we know the mass in kg, we can focus on calculating the energy transfer involved in changing temperature.

Calculating the Number of Moles in Each Block

First, determine the number of moles in each 500 g (0.5 kg) block:

$$
n = \frac{\text{mass}}{\text{molar mass}} = \frac{0.5\, \text{kg}}{M}
$$

Without the exact molar mass, we can express the heat energy in terms of n:

$$
Q = n \times C_p \times \Delta T
$$

which simplifies to:

$$
Q = \frac{0.5}{M} \times 24.4 \times \Delta T
$$

This relation helps us understand how much heat is needed to produce a specific temperature change, depending on the molar mass.

Thermal Behavior: Heat Transfer and Equilibrium

Now, consider two blocks initially at different temperatures T_{hot} and T_{cold}:

- When they are brought into contact, heat flows from the hotter to the colder until thermal equilibrium is achieved.
- The heat exchanged (Q) for each block can be described as:

$$
Q_{hot} = -Q_{cold}
$$

- Assuming no heat loss to surroundings, the conservation of energy dictates:

\[

$$
m_{hot} c_{hot} (T_{final} - T_{hot}) + m_{cold} c_{cold} (T_{final} - T_{cold}) = 0
$$

Since both blocks are of the same substance and mass, and assuming $c_{hot} = c_{cold}$, the final temperature T_{final} can be found by:

$$
T_{final} = \frac{T_{hot} + T_{cold}}{2}
$$

In this case, the heat capacity determines how much each block's temperature changes during the process.

Impact of Heat Capacity on Temperature Changes

Suppose one block is initially at 100°C and the other at 0°C. The amount of heat each absorbs or releases during the process depends on their heat capacities:

$$
Q = m \times c \times \Delta T
$$

Since the blocks are identical in mass and composition, their heat capacities are identical, and the temperature change for each block during the heat exchange is symmetrical:

$$
\Delta T_{hot} = T_{hot} - T_{final}
$$

$$
\Delta T_{cold} = T_{final} - T_{cold}
$$

Because heat capacity directly influences c, a higher heat capacity means the substance can absorb more heat with a smaller temperature change, making the material more thermally stable.

Practical Implications and Applications

Understanding the specific heat capacity’s role is crucial in various engineering applications:

- Thermal Management: Devices designed to withstand temperature fluctuations rely on materials with high heat capacities for stability.
- Material Selection: Choosing appropriate materials for heat exchangers,

cookware, or thermal insulators involves analyzing their heat capacities.
- Energy Storage: High heat capacity materials serve as effective thermal batteries, storing and releasing heat as needed.
- Safety Considerations: Materials with low heat capacities can heat up rapidly, posing potential safety risks.

Real-World Example: Aluminum Blocks

Let’s consider a concrete example: aluminum, a common metal with a molar mass of approximately 27 g/mol (0.027 kg/mol), and a molar heat capacity of 24.4 J/(mol·K).

- Calculate specific heat capacity (c):

$$
c = \frac{C_p}{M} = \frac{24.4\, \text{J/(mol·K)}}{0.027\, \text{kg/mol}} \approx 903\, \text{J/(kg·K)}
$$

- Heat required to raise 0.5 kg of aluminum by 10°C:

$$
Q = m \times c \times \Delta T = 0.5\, \text{kg} \times 903\, \text{J/(kg·K)} \times 10\, \text{K} = 4515\, \text{J}
$$

This example highlights how a modest temperature change requires a significant energy input or removal, emphasizing aluminum's high thermal inertia.

Summary and Final Insights

In this comprehensive analysis, we've explored how two blocks of the same substance, identical in mass and molar heat capacity, behave thermally under various conditions:

- Equal Mass & Same Substance: Ensures the heat capacities are directly comparable, and the thermal response is symmetrical during heat exchange.
- Heat Capacity Significance: Higher heat capacity equals greater thermal stability; the material can absorb or release more heat with less temperature change.
- Thermal Equilibrium: When brought into contact, the blocks tend toward an average temperature, dictated by their initial temperatures and heat capacities.
- Practical Applications: These principles guide material selection, thermal system design, and safety protocols across industries.

By understanding the microscopic properties like molar heat capacity and the macroscopic consequences of thermal interactions, engineers and scientists can optimize thermal management strategies, improve energy efficiency, and develop safer, more durable materials. Whether in designing heat exchangers, thermal insulators, or everyday cookware, the principles outlined here underscore the profound impact of thermodynamics on practical life.

Final Thoughts

The study of heat capacities and thermal behavior of identical substances reveals fundamental truths about energy, matter, and their interplay. Recognizing how a seemingly simple property—like C_p—can influence the entire thermal response of a system empowers us to better harness thermal energy, improve technological processes, and deepen our understanding of the physical world.

Note: For further detailed calculations or specific scenarios involving different initial temperatures or external heat sources, additional parameters and boundary

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