

A 59.9g Sample Of Brass, Which Has A Specific Heat Capacity Of $0.375 \text{ J/g}^\circ\text{C}$, Is Put Into A Calorimeter

Introduction

The Significance of Studying Heat Transfer in Materials

A 59.9g sample of brass, which has a specific heat capacity of $0.375 \text{ J/g}^\circ\text{C}$, is placed into a calorimeter. This scenario is a classic example used in thermodynamics to understand heat transfer, specific heat capacity, and the principles governing thermal equilibrium. Investigating this process provides insight into how materials absorb, store, and transfer heat, which has practical applications across engineering, metallurgy, and experimental physics.

Understanding the Basic Concepts

What Is Specific Heat Capacity?

Specific heat capacity (c) is defined as the amount of heat energy required to raise the temperature of one gram of a substance by one degree Celsius (or Kelvin). It is an intrinsic property of materials that indicates how resistant they are to temperature change. For brass, this value is $0.375 \text{ J/g}^\circ\text{C}$, meaning that it takes 0.375 joules of energy to increase its temperature by one degree Celsius per gram.

Heat Transfer Principles

When a hot brass sample is placed into a calorimeter containing water or another medium, heat will transfer from the brass to the surrounding medium until thermal equilibrium is reached. The fundamental principle governing this process is the conservation of energy: the heat lost by the brass equals the heat gained by the surrounding medium (assuming no heat loss to the environment).

The Experimental Setup and Process

Components Involved

- Brass sample (mass = 59.9 g, specific heat capacity = $0.375 \text{ J/g}^\circ\text{C}$)
- Calorimeter (typically containing water or another fluid)

- Thermometer or temperature sensor
- Heat source (for initial heating of brass or water)

Typical Procedure

1. Heat the brass sample to a known initial temperature, often higher than the water's temperature.
2. Record the initial temperature of the brass (T_1).
3. Prepare the calorimeter with water at a known initial temperature (T_2).
4. Quickly transfer the hot brass into the calorimeter, minimizing heat loss to the environment.
5. Allow the system to reach thermal equilibrium; record the final temperature (T_f).

Theoretical Calculations

Heat Transfer Equation

The heat transferred (Q) to or from a substance is calculated as:

$$Q = mc\Delta T$$

- m = mass of the substance
- c = specific heat capacity
- ΔT = change in temperature ($T_{\text{final}} - T_{\text{initial}}$)

Applying Conservation of Energy

In the ideal case (no heat loss), the heat lost by the brass equals the heat gained by the water:

$$Q_{\text{brass}} = -Q_{\text{water}}$$

Expressed mathematically:

$$m_{\text{brass}} \times c_{\text{brass}} \times (T_{\text{final}} - T_1) + m_{\text{water}} \times c_{\text{water}} \times (T_{\text{final}} - T_2) = 0$$

Example Calculation

Suppose the water in the calorimeter has a mass of 100 g, a specific heat capacity of 4.18 J/g°C, initial temperature $T_2 = 20^\circ\text{C}$, and the brass was initially at $T_1 = 80^\circ\text{C}$. After equilibrium, the final temperature T_f is recorded as 30°C .

- Calculate heat lost by brass:
- $Q_{\text{brass}} = 59.9 \text{ g} \times 0.375 \text{ J/g}^\circ\text{C} \times (30^\circ\text{C} - 80^\circ\text{C}) = 59.9 \times 0.375 \times (-50) = -1121.25 \text{ J}$
- Calculate heat gained by water:
- $Q_{\text{water}} = 100 \text{ g} \times 4.18 \text{ J/g}^\circ\text{C} \times (30^\circ\text{C} - 20^\circ\text{C}) = 100 \times 4.18 \times 10 = 418 \text{ J}$

Since the heat lost by brass is -1121.25 J and gained by water is +418 J, the discrepancy indicates heat loss to surroundings or measurement errors, emphasizing the importance of experimental accuracy and insulation.

Real-World Applications and Significance

Material Selection and Engineering

Understanding the specific heat capacity of materials like brass is essential in designing thermal systems, heat exchangers, and cooling mechanisms. For instance, brass's moderate heat capacity makes it suitable for applications requiring good thermal conductivity but controlled heat absorption.

Calorimetry in Scientific Research

Calorimetry experiments, like the one described, are fundamental in determining various thermodynamic properties of materials, including specific heat capacities, enthalpy changes, and phase transition energies. These measurements inform material processing and quality control in manufacturing industries.

Environmental and Energy Efficiency Considerations

Knowledge of how different materials absorb and transfer heat helps optimize energy efficiency in buildings, appliances, and industrial processes. Materials with specific heat capacities tailored to particular applications can lead to energy savings and improved performance.

Factors Affecting Heat Transfer in the Experiment

Heat Loss to Surroundings

In practical settings, some heat escapes to the environment due to imperfect insulation, leading to discrepancies between theoretical calculations and experimental results. Proper insulation and rapid transfer are necessary to minimize such losses.

Material Purity and Homogeneity

Impurities or inconsistencies in the brass sample can affect its thermal properties, including specific heat capacity. Ensuring material uniformity is crucial for accurate measurements.

Measurement Accuracy

Precise temperature readings are vital. Using sensitive thermometers and ensuring proper calibration minimizes errors that can significantly impact the calculated heat transfer quantities.

Advanced Considerations and Extensions

Heat Capacity of Composite Materials

In more complex scenarios, materials may be composites or alloys with varying thermal properties. Determining the combined specific heat capacity involves weighted averages based on component proportions.

Transient vs. Steady-State Measurements

While steady-state calorimetry assumes thermal equilibrium, transient methods analyze heat transfer during the process, providing dynamic insights into thermal behavior.

Numerical Modeling and Simulation

Modern computational tools allow for detailed modeling of heat transfer processes, accounting for conduction, convection, and radiation, leading to more accurate predictions and optimized experimental designs.

Conclusion

The experiment involving a 59.9g brass sample with a specific heat capacity of $0.375 \text{ J/g}^\circ\text{C}$ placed into a calorimeter exemplifies fundamental principles of thermodynamics. It underscores the importance of understanding material properties, precise measurement techniques, and the conservation of energy in thermal processes. Such studies are not only academically interesting but also practically essential in engineering, manufacturing, environmental science, and many other

fields. Mastery of calorimetry and heat transfer concepts enables scientists and engineers to develop better materials and thermal systems, advancing technology and improving efficiency across various industries.

Frequently Asked Questions

What is the purpose of measuring the temperature change of the brass sample in the calorimeter?

To determine the amount of heat transferred between the brass and the surrounding environment or other substances in the calorimeter.

How do you calculate the heat energy transferred when the brass sample's temperature changes?

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

If the initial temperature of the brass is 100°C and it cools to 25°C in the calorimeter, how much heat has it lost?

$Q = 59.9 \text{ g} \times 0.375 \text{ J/g}^\circ\text{C} \times (100^\circ\text{C} - 25^\circ\text{C}) = 59.9 \times 0.375 \times 75 = \text{approximately } 1683.75 \text{ Joules.}$

Why is brass used in calorimetry experiments?

Because brass has a relatively high thermal conductivity and a known specific heat capacity, making it suitable for controlled heat transfer studies.

What assumptions are commonly made when performing calorimetry calculations with brass samples?

Assumptions include no heat loss to the surroundings, the system is thermally isolated, and the specific heat capacity remains constant over the temperature range.

How does the mass of the brass sample influence the heat transfer in the experiment?

The heat transfer is directly proportional to the mass; a larger mass will absorb or release more heat for the same temperature change.

What role does the specific heat capacity of brass play in calorimetry calculations?

It determines how much heat is required to change the temperature of the brass by a certain amount,

impacting the calculation of heat transfer.

If the brass sample is placed in water at a known temperature, how can you determine the specific heat capacity of the water?

By measuring the temperature change of both the brass and the water, and applying conservation of energy: $Q_{\text{brass}} = Q_{\text{water}}$, then solving for the water's specific heat capacity.

What are potential sources of error in calorimetry experiments involving brass, and how can they be minimized?

Errors can arise from heat loss to surroundings, incomplete thermal equilibrium, or measurement inaccuracies. These can be minimized by insulating the calorimeter, ensuring thorough mixing, and using precise thermometers.

Additional Resources

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Introduction

In the realm of experimental thermodynamics, calorimetry remains a fundamental technique for understanding heat transfer processes between substances. The precise measurement of heat capacities, temperature changes, and thermal properties hinges on the careful use of materials and instrumentation. This investigation focuses on a specific scenario: a 59.9-gram sample of brass, characterized by a specific heat capacity of $0.375 \text{ J/g}^\circ\text{C}$, is introduced into a calorimeter. The goal is to analyze the underlying principles, experimental setup, potential sources of error, and implications of such a procedure within scientific research and practical applications.

This detailed review aims to dissect the process, providing insight into the thermophysical properties of brass, the calibration and function of calorimeters, and the significance of accurate heat capacity measurements in various fields, including materials science, engineering, and applied physics.

Understanding the Material: Brass and Its Thermophysical Properties

What is Brass?

Brass is an alloy primarily composed of copper and zinc, with the exact composition varying depending on the desired properties. It is valued in engineering and manufacturing for its

machinability, corrosion resistance, and attractive appearance.

Common Characteristics of Brass:

- Density: Typically around 8.4 to 8.7 g/cm³
- Melting Point: Approximately 900–940°C, depending on alloy composition
- Thermal Conductivity: Ranges from 100 to 120 W/m·K
- Specific Heat Capacity: Usually around 0.380 to 0.385 J/g°C, with variations based on alloying elements

The specific heat capacity (0.375 J/g°C in this case) is a measure of how much energy is needed to raise the temperature of a unit mass of brass by one degree Celsius. It influences how brass responds to thermal processes and is critical in heat transfer calculations.

Relevance of Specific Heat Capacity in Experiments

In calorimetry, knowing the specific heat capacity of the material is essential for:

- Calculating heat transfer during temperature changes
- Determining thermal equilibrium conditions
- Evaluating the energy involved in heating or cooling processes

Given that the sample's mass is 59.9 g, the total heat capacity (C) of the sample can be calculated as:

$$C = \text{mass} \times \text{specific heat capacity} = 59.9 \text{ g} \times 0.375 \text{ J/g}^\circ\text{C} \approx 22.46 \text{ J/}^\circ\text{C}$$

This value indicates the amount of heat required to change the brass sample's temperature by one degree Celsius.

The Calorimeter: Instrumentation and Function

What Is a Calorimeter?

A calorimeter is a device designed to measure the heat exchanged during physical or chemical processes. Its core principle revolves around isolating the system to prevent heat loss to the environment, allowing for precise calculation of heat transfer based on temperature changes.

Types of Calorimeters:

- Coffee cup calorimeters (simple, used in solution chemistry)
- Bomb calorimeters (used for combustion or high-temperature reactions)
- Differential scanning calorimeters (for detailed thermal analysis)

For the scenario involving brass, a typical solid metal calorimeter or water-based calorimeter might be used, depending on the experimental aim.

Operational Principles of a Calorimeter

The basic steps involved in calorimetric measurements include:

- Calibration of the calorimeter to determine its heat capacity
- Placing the sample within the calorimeter
- Initiating a thermal process (e.g., heating or cooling)
- Recording temperature changes over time
- Calculating heat transfer using the measured temperature change and the calorimeter's known heat capacity

The core equation often used is:

$$Q = (C_{\text{cal}} + C_{\text{sample}}) \times \Delta T$$

where:

- Q is the heat transferred
- C_{cal} is the heat capacity of the calorimeter
- C_{sample} is the heat capacity of the sample
- ΔT is the change in temperature

Experimental Setup and Procedure

Preparation of the Brass Sample

Prior to the experiment, the brass sample must be:

- Cleaned to remove any surface contaminants that could affect thermal contact
- Precisely weighed using an analytical balance to confirm the 59.9 g mass
- Conditioned to a known initial temperature, often by immersing in a controlled environment or using a pre-heated or cooled bath

Calibration of the Calorimeter

Calibration involves:

- Using a substance with a known heat capacity (such as water)
- Running a test to measure temperature response
- Determining the calorimeter's heat capacity (C_{cal}) based on the known heat input and observed temperature change

Calibration ensures that subsequent measurements of temperature change are accurately converted into heat transfer values.

Conducting the Measurement

Typical procedure:

1. Record the initial temperature of the calorimeter and the brass sample.
2. Insert the brass sample into the calorimeter, which may contain a known quantity of water or other medium.
3. Allow the system to reach thermal equilibrium, recording temperature changes at regular intervals.
4. Note the final equilibrium temperature once the system stabilizes.
5. Calculate the heat transfer based on the temperature change, considering the calorimeter's known heat capacity.

Analysis and Calculations

Determining the Heat Exchange

Suppose the initial temperature of the brass sample is T_{initial} and the final equilibrium temperature in the calorimeter is T_{final} . The temperature change is:

$$\Delta T = T_{\text{final}} - T_{\text{initial}}$$

Total heat gained or lost by the brass:

$$Q_{\text{brass}} = C_{\text{brass}} \times \Delta T$$

Similarly, the calorimeter's contribution:

$$Q_{\text{cal}} = C_{\text{cal}} \times \Delta T$$

The principle of conservation of energy dictates:

$$Q_{\text{brass}} + Q_{\text{cal}} = 0$$

which implies that the heat lost by brass is equal to the heat gained by the calorimeter, or vice versa, depending on the direction of temperature change.

Sources of Error and Uncertainty

Measurement Errors in Mass and Temperature

- Calibration inaccuracies in the balance or temperature sensors
- Surface contamination affecting heat transfer rates
- Incomplete thermal contact between the brass and the calorimeter

Environmental Factors

- Heat loss to surroundings due to imperfect insulation
- Evaporative cooling if water is involved
- Variations in ambient temperature affecting readings

Material Variability

- Slight differences in the alloy composition of brass, influencing specific heat capacity
- Surface oxidation or corrosion altering thermal characteristics

Implications and Applications

Understanding the heat capacity of brass and accurately measuring thermal exchanges has broad applications:

- Designing heat exchangers and thermal management systems
- Developing materials with tailored thermal properties
- Enhancing the precision of calorimetric techniques in research laboratories
- Contributing to the calibration of temperature sensors and thermometers

Furthermore, such experiments underpin the fundamental understanding of thermophysical properties crucial for material selection in engineering applications.

Conclusion

The investigation of a 59.9g sample of brass, with a known specific heat capacity of $0.375 \text{ J/g}^\circ\text{C}$, within a calorimetric setup exemplifies core principles of thermodynamics and experimental physics. Through meticulous preparation, calibration, and measurement, scientists can derive meaningful insights into the heat transfer characteristics of metallic alloys. Recognizing sources of error and ensuring rigorous methodology are vital for obtaining reliable data, which can influence theoretical models and practical implementations.

As materials science advances, such fundamental experiments continue to underpin innovations in thermal management, alloy development, and precision measurement. The precise understanding of

how materials like brass respond to thermal stimuli not only enriches scientific knowledge but also informs engineering design and industrial processes, emphasizing the enduring importance of calorimetric investigations in the physical sciences.

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