A 126.1-gram Block Of Granite At 92.6c Is Dropped Into A Tub Of Water At 24.7c In An Isolated System.

A 126.1-gram Block Of Granite At 92.6c Is Dropped Into A Tub Of Water At 24.7c In An Isolated System. This scenario presents a fascinating opportunity to explore fundamental principles of thermodynamics, heat transfer, and conservation of energy. When a hot object, such as a granite block, is introduced into cooler water within an isolated system, various processes occur until a thermal equilibrium is established. Understanding these processes requires examining how heat flows from the hotter object to the cooler water, how the temperatures change over time, and how the system's total energy remains conserved.

In this article, we delve into the detailed analysis of this scenario, applying the principles of physics and thermodynamics to quantify the temperature changes, heat transfer, and final equilibrium state. This comprehensive exploration will also highlight important concepts such as specific heat capacity, heat transfer modes, and the assumptions involved in modeling such a process.

Understanding the System: Components and Initial Conditions

1. The Granite Block

The granite block has a mass of 126.1 grams (0.1261 kg) and an initial temperature of 92.6°C. Granite, a common igneous rock, has specific thermal properties that influence how it exchanges heat with its surroundings. Its specific heat capacity typically averages around 0.79 J/g°C, or 790 J/kg°C.

2. The Water

The water in the tub has an initial temperature of 24.7°C. Assuming the water is initially at this uniform temperature, its mass and specific heat capacity are essential for calculating heat absorption. The specific heat capacity of water is well-established at approximately 4,186 J/kg°C.

3. The Isolated System

The system is considered isolated, meaning no heat is lost to the environment, and the total energy remains constant. This assumption simplifies calculations by neglecting heat exchange with surroundings, radiation, or other external influences.

Fundamental Principles Governing the Process

1. Conservation of Energy

The total energy within an isolated system remains constant. As the hot granite cools down, it transfers heat to the water, which heats up accordingly. Mathematically:

$$ Q_{granite} + Q_{water} = 0 $$

since heat lost by granite is gained by water.

2. Heat Transfer and Specific Heat Capacity

The amount of heat exchanged by an object is given by:

$$ Q = mc\Delta T $$

where:
- m is mass,
- c is specific heat capacity,
- ΔT is the temperature change.

Calculating the Final Equilibrium Temperature

The primary goal is to find the final temperature T_f at which the system reaches thermal equilibrium, meaning the granite and water are at the same temperature T_f.

Applying the principle of conservation of energy:

$$ m_{granite} c_{granite} (T_{initial, granite} - T_f) = m_{water} c_{water} (T_f - T_{initial, water}) $$

Rearranged:

$$ m_{granite} c_{granite} (T_{initial, granite} - T_f) = m_{water} c_{water} (T_f - T_{initial, water}) $$

Assumptions and Simplifications

To proceed with calculations, several assumptions are made:

- No heat loss to surroundings or container.
- Thermal equilibrium is achieved uniformly within each substance.
- The water and granite are initially at uniform temperatures.
- The specific heat capacities are constant over the temperature range.

Step-by-Step Calculation

1. Known Values

- Mass of granite, $m_g = 0.1261 \, \text{kg}$
- Specific heat of granite, $c_g = 790 \, \text{J/kg°C}$
- Initial temperature of granite, $T_{g,i} = 92.6^\circ C$
- Mass of water, $m_w = \text{unknown}$ (assuming a typical volume, or specified in problem context)
- Specific heat of water, $c_w = 4186 \, \text{J/kg°C}$
- Initial temperature of water, $T_{w,i} = 24.7^\circ C$

Note: If the water's mass is not specified, the calculation cannot be completed precisely. For illustration, let's assume the water has a mass of 1 kg (which is a common volume in such problems).

2. Set up the heat balance equation

$$
m_g c_g (T_{g,i} - T_f) = m_w c_w (T_f - T_{w,i})
$$

Plugging in values:

$$
0.1261 \times 790 \times (92.6 - T_f) = 1 \times 4186 \times (T_f - 24.7)
$$

Calculating:

$$
(0.1261 \times 790) = 99.539
$$

So,

$$
99.539 \times (92.6 - T_f) = 4186 \times (T_f - 24.7)
$$

3. Expand and solve for T_f

$$
99.539 \times 92.6 - 99.539 T_f = 4186 T_f - 4186 \times 24.7
$$

Calculate:

$$
99.539 \times 92.6 \approx 9218.4
$$
$$
4186 \times 24.7 \approx 103,505.2
$$

Rearranged:

$$
9218.4 - 99.539 T_f = 4186 T_f - 103,505.2
$$

Bring all terms to one side:

$$
9218.4 + 103,505.2 = 4186 T_f + 99.539 T_f
$$

$$
112,723.6 = 4,285.539 T_f
$$

Finally, solve for T_f:

$$
T_f = \frac{112,723.6}{4,285.539} \approx 26.3^\circ C
$$

This is the approximate final temperature of the system.

Discussion of Results and Implications

1. Final Temperature Significance

Despite the initial high temperature of the granite, the final temperature is only slightly above the initial water temperature (24.7°C). This indicates that the water's large heat capacity significantly influences the equilibrium temperature.

2. Effect of Water Mass

If the water mass were different, the final temperature would change accordingly:
- Larger water mass results in a lower final temperature.
- Smaller water mass results in a higher final temperature.

This relationship underscores the importance of mass ratios in heat transfer problems.

3. Thermodynamic Considerations

The process exemplifies the principles of heat transfer as described by Fourier's law and the conservation of energy. It also demonstrates how energy transfer leads to thermal equilibrium, a state where no net heat flow occurs.

Practical Applications and Broader Context

1. Material Science and Engineering

Understanding how materials like granite respond to thermal inputs is vital in industries such as construction, where thermal stresses can impact structural integrity.

2. Thermodynamic Systems and Environmental Studies

Analyzing heat transfer scenarios such as this aids in designing efficient cooling or heating systems, thermal management in electronic devices, and studying natural processes like geothermal energy flow.

3. Educational Value

This problem serves as an excellent teaching example for students learning about specific heat capacities, heat transfer mechanisms, and conservation laws in physics.

Conclusion

The scenario of a hot granite block dropped into water within an isolated system highlights crucial thermodynamic principles. By applying the concepts of heat transfer, specific heat capacities, and energy conservation, we can accurately predict the final equilibrium temperature. Such analyses are foundational in many scientific and engineering disciplines, demonstrating the practical importance of understanding thermal processes. Whether in designing thermal systems, studying natural phenomena, or simply exploring fundamental physics, these principles form the backbone of thermal analysis.

Note: For precise calculations, the actual mass of water should be specified. The example above assumes 1 kg for illustrative purposes.

Frequently Asked Questions

What is the primary principle governing the temperature change of the granite block and water in this scenario?

The primary principle is the conservation of energy, specifically heat transfer, where heat lost by the hot granite block is gained by the cooler water until thermal equilibrium is reached.

How can we determine the final temperature of the system after the granite is dropped into the water?

By setting the heat lost by the granite equal to the heat gained by the water, using the specific heat capacities and masses, and solving for the final temperature.

What specific heat capacities are relevant in calculating the temperature change of the granite and water?

The specific heat capacity of granite (~0.79 J/g°C) and water (~4.18 J/g°C) are used to determine how much heat each substance gains or loses during the process.

Why is it important to consider the system as isolated in this problem?

An isolated system means no heat is exchanged with the surroundings, ensuring that the total heat lost by the granite equals the heat gained by the water, simplifying calculations.

What is the expected direction of heat transfer when the hot granite is dropped into the cooler water?

Heat will transfer from the hot granite to the cooler water, resulting in a decrease in the granite's temperature and an increase in the water's temperature until equilibrium.

How would the final temperature change if the water's initial

temperature were higher than 24.7°C?

If the water were initially hotter, the granite would lose more heat, and the final temperature would be higher than if the water were cooler, but the same heat transfer principles still apply.

What assumptions are typically made in solving such heat transfer problems involving a hot object and water?

Assumptions include no heat loss to surroundings, uniform temperature within each substance (thermal equilibrium within each), and constant specific heats over the temperature range.

Additional Resources

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Introduction

The interaction between a hot solid object and a cooler liquid medium offers a fascinating window into thermodynamic principles, specifically heat transfer, energy conservation, and entropy changes. In this investigative review, we analyze the scenario where a 126.1-gram block of granite at 92.6°C is dropped into a tub of water at 24.7°C in an isolated system. This setup, while seemingly straightforward, encompasses complex processes that warrant detailed examination, including heat exchange dynamics, thermal equilibrium, and entropy considerations.

Background and Context

Heat transfer scenarios like the one described are foundational in thermodynamics, applicable across fields such as geology, engineering, environmental science, and material science. The specific choice of granite—a common, thermally inert mineral—and water—a fluid with well-characterized thermal properties—serves as an ideal model for studying conduction, convection, and thermal equilibrium.

Key parameters:

- Mass of granite, m_g = 126.1 g = 0.1261 kg
- Initial temperature of granite, $T_{g\_initial}$ = 92.6°C
- Initial temperature of water, $T_{w\_initial}$ = 24.7°C
- Final equilibrium temperature, T_{final} (unknown)

The system is assumed isolated, meaning no heat exchange with the environment or other external sources/sinks. This assumption simplifies the analysis to internal energy redistribution between the granite and water.

Thermodynamic Foundations

Conservation of Energy

In an isolated system, the total energy remains constant. As the granite cools and the water warms, the heat lost by the granite equals the heat gained by the water:

$$ Q_{lost} + Q_{gained} = 0 $$

Expressed mathematically:

$$ m_g c_g (T_{g\_initial} - T_{final}) = m_w c_w (T_{final} - T_{w\_initial}) $$

where:

- c_g = specific heat capacity of granite (~790 J/kg·K)
- c_w = specific heat capacity of water (~4184 J/kg·K)
- m_w = mass of water (unknown, but for analysis, can be varied or assumed)

The final temperature T_{final} can be derived from this energy balance.

Analyzing Heat Transfer Dynamics

Step 1: Estimating the Final Equilibrium Temperature

Assuming a known mass of water, for example, 1 kg of water, the energy balance yields:

$$ 0.1261 \times 790 \times (92.6 - T_{final}) = 1 \times 4184 \times (T_{final} - 24.7) $$

Calculating:

$$ 99.539 \times (92.6 - T_{final}) = 4184 \times (T_{final} - 24.7) $$

Expanding:

$$ 99.539 \times 92.6 - 99.539 \times T_{final} = 4184 \times T_{final} - 4184 \times 24.7 $$

$$ 9219.07 - 99.539 T_{final} = 4184 T_{final} - 103,434.8 $$

Bringing like terms together:

$$ 9219.07 + 103,434.8 = 4184 T_{final} + 99.539 T_{final} $$

$$ 112,653.87 = 4283.539 T_{final} $$

$$ T_{final} = \frac{112,653.87}{4283.539} \approx 26.3°C $$

This result indicates that, with 1 kg of water, the final temperature stabilizes around 26.3°C, slightly above the initial water temperature, as expected.

Note: If the water mass differs, the final temperature shifts accordingly.

Deep Dive: Heat Transfer Mechanisms

Conduction and Convection

- Initial contact: When the hot granite is introduced into water, heat transfer begins immediately at the interface via conduction.
- Fluid motion: Natural convection currents develop within the water, enhancing heat transfer.
- Thermal boundary layers: A thin layer of water near the granite absorbs heat rapidly, facilitating the transfer process.

Time Scale to Equilibrium

The duration to reach thermal equilibrium depends on:

- The thermal conductivity of granite (~2.4 W/m·K)
- The surface area of contact
- The water's convection efficiency
- The initial temperature difference

Modeling this precisely requires solving transient heat conduction equations, often employing numerical methods such as finite element analysis.

Entropy and Irreversibility

In any real process, entropy increases due to irreversibilities such as:

- Finite temperature gradients
- Turbulent mixing within water
- Non-instantaneous heat transfer

The total entropy change in the system can be expressed as:

$$ \Delta S_{total} = \Delta S_{water} + \Delta S_{granite} $$

Where:

$$ \Delta S = m c \ln \left(\frac{T_{final}}{T_{initial}} \right) $$

Calculations show that entropy increases overall, consistent with the second law of thermodynamics, indicating irreversibility and the natural tendency towards equilibrium.

Practical Considerations and Real-World Implications

Experimental Constraints

- Material properties: Variations in granite composition alter specific heat and thermal conductivity.
- System isolation: Perfect insulation is theoretical; in practice, minor heat losses occur.
- Water volume and agitation: Affect the rate of heat transfer and uniformity of temperature distribution.

Applications

- Geothermal studies: Understanding heat exchange between rocks and groundwater.
- Material testing: Thermal response of mineral specimens.
- Engineering design: Insulation and cooling systems where phase change or temperature regulation is critical.

Advanced Topics: Non-Equilibrium Thermodynamics and Modeling

Transient Heat Transfer Models

- Use of heat conduction equations (Fourier's law)
- Numerical simulations to predict temperature evolution over time
- Incorporation of convective heat transfer coefficients

Multi-Component Systems

- Considering phase changes, if the temperature approaches water's boiling point
- Effects of dissolved minerals or impurities in water on heat transfer

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Summary and Conclusions

The scenario of a 126.1-gram block of granite at 92.6°C dropped into a tub of water at 24.7°C in an isolated system encapsulates key principles of thermodynamics:

- Energy conservation dictates the final equilibrium temperature, which depends on the mass and specific heat capacities of the involved substances.
- Heat transfer mechanisms—conduction and convection—govern the rate at which thermal equilibrium is achieved.
- Irreversibility and entropy increase are inherent in real processes, aligning with the second law of thermodynamics.
- Practical modeling requires detailed knowledge of material properties and system conditions, often necessitating numerical approaches for accurate predictions.

This analysis underscores the fundamental interconnectedness of thermodynamic concepts and their relevance across scientific disciplines. Whether studying geological phenomena, designing thermal systems, or exploring material behaviors, understanding such heat exchange processes is vital for both theoretical insight and practical application.

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