1 Kg Of Water At 100c Is Poured Into A Bucket That Contains 4 Kg Of Water At 0c. Find The Equilibrium

1 Kg Of Water At 100°C Is Poured Into A Bucket That Contains 4 Kg Of Water At 0°C. Find The Equilibrium

When a small quantity of hot water is added to a larger quantity of cold water, understanding the resulting temperature at equilibrium is essential in thermodynamics. This scenario involves heat transfer between two bodies of water with different initial temperatures, ultimately reaching a common temperature where no further heat transfer occurs. In this article, we will explore the principles behind this process, calculate the equilibrium temperature, and discuss related concepts in thermal physics.

Understanding the Problem: Water at Different Temperatures

To analyze this situation, it is critical to understand the initial parameters:

Initial Conditions

- Mass of hot water, m_1 = 1 kg
- Initial temperature of hot water, T_1 = 100°C
- Mass of cold water, m_2 = 4 kg
- Initial temperature of cold water, T_2 = 0°C

The goal is to determine the final equilibrium temperature, T_f, after the hot water is poured into the cold water and the system reaches thermal equilibrium.

Principles of Heat Transfer and Conservation of

Energy

The core principle governing this problem is the conservation of energy, which states that heat lost by the hot water will be equal to the heat gained by the cold water (assuming no heat loss to the surroundings).

Assumptions

- Perfect thermal insulation: no heat exchange with the environment
- Water has a specific heat capacity, $c \approx 4.18$ J/g°C or 4180 J/kg°C, which remains constant over the temperature range
- No phase change occurs during the process
- Mixing is instantaneous and uniform

Heat Transfer Equation

The heat gained or lost is given by:

$$ Q = mc\Delta T $$

where:
- m = mass of water
- c = specific heat capacity
- ΔT = change in temperature

Since the system is isolated:

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

which leads to:

$$ m_1 c (T_1 - T_f) = m_2 c (T_f - T_2) $$

Calculating the Equilibrium Temperature

Given the above, we can set up the equation to isolate T_f:

$$ m_1 (T_1 - T_f) = m_2 (T_f - T_2) $$

Plugging in the known values:

$$ 1 \times (100 - T_f) = 4 \times (T_f - 0) $$

Simplify:

$$100 - T_f = 4 T_f$$

Combine like terms:

$$100 = 5 T_f$$

Solve for T_f:

$$T_f = \frac{100}{5} = 20^\circ C$$

Result: The water reaches an equilibrium temperature of approximately 20°C.

Implications and Real-World Applications

Understanding such heat transfer scenarios has practical significance in various fields, including environmental science, engineering, and everyday life.

Applications in Engineering and Environmental Science

- Designing efficient cooling or heating systems
- Estimating temperature changes in mixing of fluids in industrial processes
- Assessing thermal comfort in building climate control

Factors Affecting Actual Results

Although the theoretical calculation assumes perfect insulation and no heat loss, real-world conditions may differ due to:

- Heat exchange with surroundings
- Heat capacity variations with temperature
- Incomplete mixing or temperature gradients within the water

In practical scenarios, the equilibrium temperature might be slightly lower or higher depending on these factors.

Related Concepts in Thermodynamics

This problem relates to several fundamental thermodynamic principles:

Specific Heat Capacity

The ability of a substance to store heat per unit mass per degree temperature change. Water's high specific heat capacity makes it an excellent medium for thermal energy storage.

Conservation of Energy

The total energy in an isolated system remains constant, which is the foundation for calculating temperature changes during heat exchange.

Heat Exchange in Mixing

The process of mixing substances at different temperatures involves transferring heat until thermal equilibrium is established, following the principle of energy conservation.

Step-by-Step Summary for Solving Similar Problems

To analyze similar heat transfer problems, follow these steps:

1. Identify masses (m_1, m_2, etc.) and initial temperatures (T_1, T_2, etc.)
2. Assume no heat loss to surroundings and perfect mixing
3. Use the heat transfer equation \(m c (T_{initial} - T_{final}) \) for each body
4. Set heat lost by hot object equal to heat gained by cold object
5. Solve for the unknown final temperature T_f

Conclusion: Final Equilibrium Temperature of Water Mixture

In the specific scenario where 1 kg of water at 100°C is poured into 4 kg of water at 0°C, the system reaches a thermal equilibrium at approximately 20°C. This calculation illustrates the fundamental principles of heat transfer and conservation of energy, offering insights into both theoretical and practical applications in thermodynamics.

Understanding such processes enables engineers and scientists to design better thermal systems, optimize energy efficiency, and deepen our comprehension of heat exchange phenomena in natural and industrial contexts.

Frequently Asked Questions

What is the initial temperature of the water being poured into the bucket?

The water being poured into the bucket has an initial temperature of 100°C.

How much water is initially in the bucket at 0°C?

The bucket initially contains 4 kg of water at 0°C.

What is the total mass of water after pouring 1 kg of water at 100°C into the bucket?

The total mass becomes 5 kg (4 kg + 1 kg).

What assumption is typically made about heat transfer in this type of problem?

It is assumed that heat transfer occurs until thermal equilibrium is reached, with no heat loss to the surroundings.

How can the final temperature of the water be calculated?

By applying the principle of conservation of energy: heat lost by hot water equals heat gained by cold water, using specific heat capacities.

What is the specific heat capacity of water used in

calculations?

The specific heat capacity of water is approximately 4.18 J/g°C or 4180 J/kg°C.

What is the formula to find the equilibrium temperature in this problem?

T_final = (m_hot T_hot + m_cold T_cold) / (m_hot + m_cold), assuming equal specific heat capacities.

Calculate the equilibrium temperature of the water.

T_final = (1 kg 100°C + 4 kg 0°C) / (1 kg + 4 kg) = 100 / 5 = 20°C.

What does the final temperature tell us about the heat exchange process?

The final temperature of 20°C indicates that heat from the hot water has been distributed to the cold water, reaching thermal equilibrium without losses.

Additional Resources

1 Kg Of Water At 100°C Is Poured Into A Bucket That Contains 4 Kg Of Water At 0°C. Find The Equilibrium.

Investigating the Thermal Equilibrium of Mixed Water Systems: A Detailed Analysis

The problem of mixing water at different temperatures is a classic example used extensively in thermodynamics and heat transfer studies. It provides insight into the principles governing energy conservation, specific heat capacity, and temperature equilibrium. Specifically, the scenario where 1 Kg of water at 100°C is poured into a container holding 4 Kg of water at 0°C offers an intriguing case for analysis, blending theoretical physics with practical thermodynamic applications.

This article aims to critically examine this problem, exploring the concepts involved, deriving the solution systematically, and discussing the broader implications in thermodynamics. Our goal is to provide a comprehensive review suitable for academic, engineering, or scientific audiences.

Fundamental Concepts and Assumptions

Before delving into the calculations, it is essential to clarify the foundational principles and assumptions that underpin the problem:

Conservation of Energy

- The total heat lost by the hot water equals the heat gained by the cold water, assuming no heat exchange with the environment.
- No phase changes occur during the process; the water remains in the liquid phase throughout.

Specific Heat Capacity

- The specific heat capacity of water, c, is assumed to be constant at approximately 4.18 J/g°C or 4180 J/kg°C.
- It is assumed that this value remains constant over the temperature range involved.

Initial Conditions

- Hot water: mass $m_h = 1\,kg$, initial temperature $T_h = 100^\circ C$
- Cold water: mass $m_c = 4\,kg$, initial temperature $T_c = 0^\circ C$

Final Equilibrium Temperature

- Denoted as T_{f}. It is expected to be between 0°C and 100°C, given the heat exchange.

Additional Assumptions

- Perfect thermal insulation (no heat loss to surroundings).
- Instantaneous mixing, with no heat loss during the transfer.
- The system reaches thermal equilibrium, with both quantities of water at the same final temperature.

Step-by-Step Derivation of the Equilibrium Temperature

1. Establishing the Heat Balance Equation

The principle of conservation of energy states:

Heat lost by hot water = Heat gained by cold water

Expressed mathematically:

$$
m_h c (T_h - T_{f}) = m_c c (T_{f} - T_c)
$$

Since the specific heat capacity c is common and constant, it cancels out:

$$
m_h (T_h - T_{f}) = m_c (T_{f} - T_c)
$$

2. Substituting Known Values

$$
(1\,kg)(100^\circ C - T_{f}) = (4\,kg)(T_{f} - 0^\circ C)
$$

Simplify:

$$
100 - T_{f} = 4 T_{f}
$$

3. Solving for T_{f}

$$
100 = 5 T_{f}
$$

$$
T_{f} = \frac{100}{5} = 20^\circ C
$$

4. Interpretation of Results

The equilibrium temperature of the mixture is 20°C.

Critical Analysis of the Result

Physical Meaning

- The final temperature of 20°C indicates that the hot water cools down significantly, while the cold water warms up modestly.
- The larger mass of cold water (4 kg) acts as a thermal reservoir, absorbing heat without reaching boiling or vaporization points.

Validity of Assumptions

- The calculation assumes no heat loss to the environment, which is idealized. In practice, some heat would escape, slightly lowering the actual equilibrium temperature.
- The specific heat capacity of water can vary with temperature, but for most practical purposes, assuming a constant c is acceptable.

- No phase change occurs; thus, the water remains in the liquid phase.

Broader Implications

This simplified problem exemplifies key thermodynamic principles relevant in various fields such as:

- Climate modeling (temperature regulation)
- Industrial processes involving mixing of fluids
- Design of cooling systems and heat exchangers

Extending the Analysis: Real-World Considerations

While the idealized calculation provides a clear solution, real-world scenarios often involve complexities:

Heat Loss to Surroundings

- Using a thermally insulated container reduces heat loss.
- In practice, some heat dissipates, leading to a final temperature slightly below 20°C.

Phase Changes and Latent Heat

- If the hot water's temperature were above boiling point, vaporization could occur, complicating energy calculations.
- In such cases, latent heat calculations are necessary.

Viscosity and Convection

- Mixing involves convective currents, which influence the rate but not the final temperature in ideal cases.

Non-uniform Temperature Distribution

- Initially, temperature gradients exist; full mixing takes time.
- The calculation assumes instantaneous and uniform temperature after mixing.

Practical Applications and Educational Significance

This problem serves as an excellent educational tool for:

- Teaching conservation of energy principles
- Demonstrating the importance of mass ratios in thermal systems
- Illustrating how assumptions influence calculations
- Modeling real systems in engineering thermodynamics

It also underscores the importance of understanding the limitations of simplified models when applied to complex systems.

Conclusion

The scenario where 1 Kg of water at 100°C is poured into a bucket containing 4 Kg of water at 0°C results in a final equilibrium temperature of approximately 20°C. This conclusion derived from fundamental thermodynamics principles underscores how the distribution of mass and initial temperatures influence the thermal equilibrium.

While the calculation assumes ideal conditions, it provides a foundational understanding relevant across scientific and engineering disciplines. Recognizing the assumptions and limitations encourages the development of more nuanced models that incorporate heat losses, phase changes, and variable specific heats for advanced applications.

This detailed investigation exemplifies the power of fundamental physics in solving practical problems, reinforcing the importance of rigorous analysis and critical thinking in thermodynamics research and education.

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