23) If You Add 700 KJ Of Heat To 700 G Of Water Originally At 70.0C, How Much Water Is Left In The Container?

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Understanding the thermal behavior of water when heat is added is fundamental in fields such as thermodynamics, environmental science, and engineering. This question explores the impact of adding a specific amount of heat—700 kilojoules (kJ)—to a known mass of water initially at a certain temperature (70.0°C). The core inquiry is: How much water remains in the container after this heat addition? To answer this, we need to analyze the phase changes, energy requirements, and the properties of water, including its specific heat capacity and latent heats of vaporization and fusion.

Fundamentals of Heat Transfer and Water Properties

Specific Heat Capacity of Water

The specific heat capacity (c) is a property that indicates how much energy is needed to raise the temperature of a substance per unit mass per degree Celsius. For water:
- c = 4.186 J/g°C

This means that to increase the temperature of 1 gram of water by 1°C, 4.186 joules are required.

Latent Heats of Water

Water undergoes phase changes that involve latent heats:
- Latent heat of vaporization (L_v): approximately 2260 J/g at 100°C
- Latent heat of fusion (L_f): approximately 334 J/g at 0°C

These heats are necessary for water to change phases without temperature change, such as from liquid to vapor (boiling/evaporation) or from solid to liquid (melting).

Step-by-Step Solution Approach

To determine how much water remains after adding heat, the process involves:

1. Calculating the initial energy in the water.
2. Determining the temperature change if no phase change occurs.
3. Assessing whether the added heat causes boiling (vaporization).
4. Calculating the amount of water vaporized if boiling occurs.
5. Estimating the remaining water in the container.

Initial Conditions and Given Data

Parameter	Value
Mass of water (m)	700 g
Initial temperature (T_initial)	70.0°C
Heat added (Q)	700 kJ = 700,000 J

Step 1: Calculate the energy required to raise the water from 70.0°C to 100°C

Since water's boiling point is at 100°C, and the initial temperature is 70.0°C, the temperature increase needed is:

$$ \Delta T = 100.0°C - 70.0°C = 30.0°C $$

Energy required for this heating:

$$ Q_{heat} = m \times c \times \Delta T $$

$$ Q_{heat} = 700\,g \times 4.186\,J/g°C \times 30.0°C $$

$$ Q_{heat} \approx 700 \times 4.186 \times 30 $$

$$ Q_{heat} \approx 700 \times 125.58 $$

$$ Q_{heat} \approx 88,006\,J $$

Approximately 88 kJ are needed to raise the water's temperature from 70.0°C to 100°C.

Step 2: Determine energy remaining after reaching 100°C

Total heat added: 700,000 J

Energy used to heat the water to boiling point:

$$ Q_{to\ 100°C} \approx 88,006\,J $$

Remaining energy:

$$ Q_{remaining} = 700,000\,J - 88,006\,J \approx 611,994\,J $$

This remaining energy can go into vaporizing water at 100°C.

Step 3: Calculate how much water can be vaporized with remaining energy

Using the latent heat of vaporization:

$$ m_{vaporized} = \frac{Q_{vaporization}}{L_v} $$

$$ m_{vaporized} = \frac{611,994\,J}{2260\,J/g} $$

$$ m_{vaporized} \approx 271\,g $$

This means approximately 271 grams of water can be vaporized with the remaining energy.

Step 4: Determine the amount of water left in the container

Initial mass of water: 700 g

Vaporized mass: ~271 g

Remaining water:

$$ m_{remaining} = 700\,g - 271\,g = 429\,g $$

Summary: Final State of Water in the Container

- Remaining liquid water: approximately 429 grams
- Vaporized water: approximately 271 grams vaporized into the air

The temperature of the remaining water remains at 100°C during vaporization, as energy is used for phase change rather than temperature increase.

Additional Considerations and Real-World Factors

While the calculations above provide a theoretical estimate, real-world scenarios may vary due to factors such as:

- Heat losses: in actual systems, heat might dissipate into surroundings.
- Pressure conditions: these calculations assume atmospheric pressure; higher pressures raise the boiling point.
- Container properties: the material and heat transfer efficiency influence the process.

Implications and Applications of the Calculation

Understanding how much water vaporizes with a given heat input is crucial in:

- Designing heating systems: to prevent overboiling or to control evaporation rates.
- Environmental modeling: predicting water loss from bodies of water due to heat exposure.
- Industrial processes: such as distillation, where precise control of phase change is necessary.

Conclusion

Adding 700 kJ of heat to 700 grams of water initially at 70.0°C results in approximately 429 grams of water remaining in the container as liquid, with the rest vaporized into the air. This calculation underscores the significant energy required for phase changes in water and illustrates the importance of understanding thermal properties and phase transitions in practical applications.

Summary of Key Points

- Heating water from 70.0°C to 100°C requires about 88 kJ.
- Remaining energy after heating is approximately 611.994 kJ.
- This energy can vaporize roughly 271 grams of water.
- Remaining water in the container is approximately 429 grams.

This detailed analysis demonstrates how thermodynamic principles can predict the behavior of water under heat input, providing valuable insights across multiple scientific and engineering disciplines.

Frequently Asked Questions

What is the initial temperature of the water before adding heat?

The initial temperature of the water is 70.0°C.

How much heat energy is added to the water?

700 KJ of heat energy is added to the water.

What is the specific heat capacity of water used in calculations?

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

How do you calculate the temperature change after adding heat?

Temperature change (ΔT) is calculated by dividing the heat added (Q) by the product of mass (m) and specific heat capacity (c): $\Delta T = Q / (m c)$.

What is the temperature of the water after adding 700 kJ of heat?

The temperature increases by approximately 250.6°C, reaching about 320.6°C, which exceeds water's boiling point, indicating boiling occurs.

Does the water boil during this process, and what is the significance?

Yes, the temperature surpasses 100°C, so the water will boil, causing some of it to convert to vapor and reducing the amount of liquid water remaining.

How much water remains in the container after boiling?

The amount of remaining water depends on how much vaporized during boiling; calculations show that only a fraction of the original 700 g remains liquid after reaching the boiling point and vaporization.

How can we estimate the mass of water remaining after boiling?

By calculating the energy required to vaporize the water (using latent heat of vaporization) and subtracting the energy used for heating, we can estimate the remaining water mass.

What is the key assumption in these calculations?

The key assumption is that all the added heat goes into raising the temperature and vaporizing water without heat losses to the surroundings.

Additional Resources

Understanding the Impact of Adding Heat to Water: A Detailed Analysis of the Scenario Involving 700 kJ of Energy and 700 g of Water at 70.0°C

Introduction

In thermodynamics, understanding how heat transfer affects the state and quantity of water is fundamental, especially when considering practical applications like heating systems, environmental processes, or industrial operations. The scenario posed—adding 700 kilojoules (kJ) of heat to 700 grams of water initially at 70.0°C—serves as an excellent case study to explore concepts such as specific heat capacity, phase changes, and energy calculations. The central question: How much water remains in the container after absorbing this heat? To answer this comprehensively, we need to analyze the heat transfer process, phase change thresholds, and the thermodynamic properties of water.

Fundamental Concepts and Parameters

Before diving into calculations, it's important to establish some key data points and physical principles:

- Mass of water (m): 700 g = 0.700 kg
- Initial temperature (Tinitial): 70.0°C
- Heat added (Q): 700 kJ = 700,000 Joules
- Specific heat capacity of water (cwater): approximately 4,186 J/(kg·°C)
- Latent heat of vaporization of water (Lv): approximately 2,260 kJ/kg (or 2,260,000 J/kg)
- Boiling point of water at standard atmospheric pressure: 100°C
- Assumption: No heat losses to surroundings, and the container can withstand the temperature changes without constraints.

Step 1: Calculating the Temperature Increase Without Phase Change

The first step is to determine how much the temperature of the water will rise before reaching boiling point, given the heat input.

Calculation:

$$
Q = m \times c_{water} \times \Delta T
$$

Where:

- ΔT is the temperature change

Rearranged for ΔT:

$$
\Delta T = \frac{Q}{m \times c_{water}}
$$

Plugging in the values:

$$
\Delta T = \frac{700,000\, \text{J}}{0.700\, \text{kg} \times 4186\, \text{J/(kg·°C)}}
$$

$$
\Delta T = \frac{700,000}{0.700 \times 4186} \approx \frac{700,000}{2,930.2} \approx 239.03\,^\circ \text{C}
$$

Interpretation:

- The temperature increase of approximately 239°C exceeds the boiling point at standard atmospheric pressure.
- Since the initial temperature is 70.0°C, the final temperature would be:

$$
T_{final} = T_{initial} + \Delta T \approx 70.0^\circ \text{C} + 239.03^\circ \text{C} \approx
$$

$$
309.03^\circ \text{C}
$$

This is physically impossible for water at atmospheric pressure because water cannot exist as a liquid above 100°C without pressure adjustments; it will vaporize.

Step 2: Understanding Phase Changes and Energy Requirements

Given the above, the actual process involves multiple stages:

1. Heating Water from 70.0°C to 100°C:
The water absorbs a certain amount of heat to reach boiling temperature.

2. Vaporization (Phase Change):
Once at 100°C, additional heat causes water to convert from liquid to vapor.

3. Post-Vaporization Heating (if any):
After vaporization, if heat continues to be added, the vapor's temperature would increase, but this depends on the container's ability to contain vapor and whether the vapor remains at 100°C or heats further.

Calculating heat needed to reach boiling point:

$$
Q_{to\,boil} = m \times c_{water} \times (100^\circ C - 70^\circ C) = 0.700\, \text{kg} \times 4186\, \text{J/(kg·°C)} \times 30^\circ C
$$

$$
Q_{to\,boil} = 0.700 \times 4186 \times 30 \approx 0.700 \times 125,580 \approx 87,906\, \text{J}
$$

Result:

- To bring the 700 g of water from 70°C to 100°C, approximately 87.9 kJ is needed.

Step 3: Determining the Remaining Heat for Vaporization

- Total heat supplied: 700 kJ = 700,000 J
- Heat used to reach boiling point: ~87.9 kJ
- Remaining heat for vaporization:

$$
Q_{vaporization} = 700,000\, \text{J} - 87,906\, \text{J} \approx 612,094\, \text{J}
$$

- Amount of water vaporized:

$$
m_{vaporized} = \frac{Q_{vaporization}}{L_v} = \frac{612,094\, \text{J}}{2,260,000\, \text{J/kg}} \approx 0.271\, \text{kg}
$$

\]

- Mass remaining as liquid:

$$
m_{liquid} = 0.700\, \text{kg} - 0.271\, \text{kg} \approx 0.429\, \text{kg}
$$

Conclusion:

- After adding 700 kJ of heat, approximately 271 grams of water vaporize, leaving about 429 grams of liquid water at 100°C.

Step 4: Final State of the System

- The water initially at 70°C is heated to boiling point, consuming ~87.9 kJ.
- The excess heat (roughly 612 kJ) vaporizes about 271 g of water.
- The vaporization occurs at 100°C, so the vapor formed is at saturation temperature, assuming standard atmospheric pressure.
- The remaining water in the container is at boiling point, in equilibrium with vapor.

Important considerations:

- Pressure conditions:
This analysis assumes atmospheric pressure. If the pressure is increased, the boiling point would shift, affecting the calculations.

- Container constraints:
If the container is sealed, pressure might increase during vaporization, changing the boiling point and the amount of water vaporized.

- Heat transfer efficiency:
The calculations assume perfect heat transfer with no losses, which is idealized.

Additional Considerations and Real-World Implications

1. Effect of Pressure Variations:

In real scenarios, the pressure within the container influences the boiling point:

- Increased pressure:
Raises boiling point, meaning more heat is required to vaporize water at higher temperatures.

- Decreased pressure (vacuum):
Lowers boiling point, leading to vaporization at temperatures below 100°C.

2. Practical Applications:

- Steam generation:
The amount of water vaporized is critical in designing boilers and steam turbines.

- Climatic and environmental processes:
Understanding how heat affects water bodies helps in modeling weather patterns and climate change.

- Industrial heating:
Precise calculations ensure efficient energy use in processes like distillation, sterilization, or cooking.

3. Limitations of the Model:

- Assumes ideal conditions; real systems experience heat loss, non-uniform heating, and pressure variations.

- Water's specific heat capacity varies slightly with temperature; at higher temperatures, it decreases marginally.

- The latent heat of vaporization also varies with temperature, generally decreasing as temperature approaches the critical point.

Summary and Final Answer

Based on the detailed thermodynamic analysis:

- The initial 70°C water is heated to boiling point (100°C) using approximately 87.9 kJ.
- The remaining energy (approximately 612 kJ) vaporizes about 271 g of water.
- Consequently, after adding 700 kJ of heat to 700 g of water initially at 70°C, roughly 429 grams of water remain in the container as liquid water at 100°C, with the rest converted into vapor.

This comprehensive calculation underscores the importance of understanding phase changes, heat capacities, and energy requirements, which are fundamental in many scientific and engineering contexts.

Final Remarks

The scenario illustrates a classic thermodynamic problem that emphasizes the principles of heat transfer, phase change, and energy conservation. Mastery of these concepts is essential for engineers, physicists, and anyone involved in processes where temperature and phase transformations are critical. Accurate modeling requires considering real-world factors like pressure, container design, and heat losses, but the idealized analysis provides a solid foundation for understanding the fundamental physics involved.

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