A Constant Volume And Mass Of Helium Gas At 77C Is Heated So That The Pressure Of The Gas Doubles. What

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Understanding the behavior of gases under various conditions is a fundamental aspect of physics and chemistry. When dealing with gases like helium, the relationship between pressure, volume, temperature, and mass is described by the ideal gas law. In scenarios where the volume and mass of a gas are held constant—such as in a sealed container—any change in temperature can significantly impact pressure. This article explores what happens when a fixed amount of helium gas at 77°C is heated until its pressure doubles, analyzing the underlying principles and calculations involved.

Fundamentals of Gas Laws

Before diving into the specific scenario, it's essential to understand the core principles governing gases:

The Ideal Gas Law

The ideal gas law is expressed as:

$$PV = nRT$$

Where:
- P = pressure of the gas
- V = volume
- n = number of moles of gas
- R = universal gas constant (~8.314 J/(mol·K))
- T = temperature in Kelvin

This law assumes gases behave ideally, which is a good approximation under many conditions, especially for helium, which is a noble gas with minimal interactions.

Key Variables in the Scenario

In the problem at hand:
- Mass (m) of helium remains constant.
- Volume (V) remains constant.
- Initial temperature (T_1) = 77°C = 77 + 273.15 = 350.15 K
- Final pressure (P_2) = 2 × P_1 (pressure doubles)

- Final temperature (T_2) = ?

Analyzing the Scenario

Given the conditions:
- The volume of the container is fixed.
- The mass of helium remains unchanged.
- The initial temperature is 77°C.
- The pressure doubles upon heating.

Question: What will be the final temperature of the helium gas after the pressure doubles?

Applying the Ideal Gas Law in a Fixed Volume and Mass Context

Since both the volume and the amount of gas are constant, the ideal gas law simplifies to a direct relationship between pressure and temperature:

$$ \frac{P_1}{T_1} = \frac{P_2}{T_2} $$

This is derived from rearranging the ideal gas law:

$$ P = \frac{nRT}{V} $$

Because n and V are constant, the ratio of pressure to temperature remains constant:

$$ \frac{P}{T} = \text{constant} $$

Therefore:

$$ P_1 / T_1 = P_2 / T_2 $$

Rearranged to find T_2:

$$ T_2 = T_1 \times \frac{P_2}{P_1} $$

Given that $P_2 = 2 P_1$:

$$ T_2 = T_1 \times 2 = 350.15 \, \text{K} \times 2 = 700.3 \, \text{K} $$

Converting back to Celsius:

$$ T_2^\circ C = T_2 - 273.15 = 700.3 - 273.15 \approx 427.15^\circ C $$

Result: The temperature must be increased to approximately 427.15°C for the pressure to double at constant volume and mass.

Understanding the Physical Implications

This calculation highlights a fundamental concept: pressure is directly proportional to temperature when volume and amount of gas are fixed. Doubling the pressure requires doubling the absolute temperature.

Key Takeaways:
- Heating a fixed amount of helium increases its pressure proportionally.
- To double the pressure, the gas must be heated to twice its initial absolute temperature.
- The initial temperature in Kelvin was 350.15 K at 77°C.
- The final temperature needed for doubling pressure is approximately 700.3 K (~427°C).

Additional Considerations and Real-World Applications

While the ideal gas law provides a good approximation, real gases exhibit deviations at high pressures or low temperatures. Helium, being a noble gas with weak intermolecular forces, behaves very similarly to an ideal gas under typical conditions.

Practical scenarios where this understanding applies include:

- Designing pressurized helium tanks for balloons or scientific instruments.
- Understanding temperature limits for helium in cryogenic applications.
- Predicting pressure changes in closed systems during heating or cooling.

Safety note: In real-world applications, exceeding certain temperature or pressure limits could compromise the integrity of the container or lead to dangerous conditions.

Mathematical Summary and Key Equations

For clarity, here is a summary of the key equations used:

1. Ideal Gas Law: $PV = nRT$
2. At constant V and n: $\frac{P_1}{T_1} = \frac{P_2}{T_2}$
3. Final temperature when pressure doubles: $T_2 = 2 \times T_1$ (Kelvin)
4. Conversion between Celsius and Kelvin: $T(K) = T(°C) + 273.15$

Conclusion

In conclusion, if a fixed amount of helium gas at 77°C (350.15 K) is heated so that its pressure doubles, the temperature must be increased from 350.15 K to approximately 700.3 K, which is about 427°C. This direct proportionality between pressure and temperature at constant volume underscores the importance of understanding gas laws in practical applications, from industrial processes to scientific experiments.

Understanding these principles allows engineers, scientists, and students to predict and control the behavior of gases in various scenarios, ensuring safety, efficiency, and precision in their work.

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- Helium gas pressure and temperature
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- Gas law calculations
- Doubling gas pressure
- Heating gases at constant volume
- Helium properties
- Gas law applications
- Physics of gases
- Thermodynamics of gases
- Pressure-temperature relationship

Frequently Asked Questions

What happens to the temperature of helium gas when its pressure doubles at constant volume and mass?

The temperature of the helium gas increases, approximately doubling, according to Gay-Lussac's law.

Which law explains the relationship between pressure and temperature for helium gas at constant volume?

Gay-Lussac's law explains that pressure is directly proportional to temperature when volume and mass are constant.

If the initial pressure of helium gas is P and its temperature is 77°C, what is the new temperature after pressure doubles?

The new temperature is approximately $2 \times 77°C + 273.15\ K \approx 427.15\ K$, considering Kelvin scale, the temperature roughly doubles.

What is the initial temperature of helium in Kelvin?

The initial temperature is $77°C + 273.15 = 350.15\ K$.

How does the ideal gas law relate to this scenario?

The ideal gas law ($PV=nRT$) shows that at constant volume and mass, pressure is directly proportional to temperature ($P \propto T$).

What is the significance of constant volume and mass in this problem?

Constant volume and mass mean that any change in pressure must be due to a change in temperature, as per the ideal gas law.

If the pressure doubles, by what factor does the temperature increase?

The temperature increases by a factor of two, assuming ideal behavior and constant volume.

Why is helium used in this type of thermodynamic problem?

Helium is an ideal gas in many conditions, making it suitable for studying pressure-temperature relationships without complex interactions.

What assumptions are made in solving this problem?

Assumptions include ideal gas behavior, constant volume, constant mass, and no heat loss or additional energy transfer.

What is the final pressure of helium gas if the initial pressure was 1 atm?

The final pressure would be 2 atm, since the pressure doubles as specified in the problem.

Additional Resources

A Constant Volume And Mass Of Helium Gas At 77°C Is Heated So That The Pressure Of The Gas Doubles. What Happens Next?

Understanding the behavior of gases under varying conditions is fundamental to fields ranging from physics and chemistry to engineering and atmospheric science. When a constant volume and mass of helium gas at 77°C is heated so that the pressure of the gas doubles, it offers a compelling scenario to explore the principles of gas laws, thermodynamics, and the physical properties of helium. This article provides a comprehensive breakdown of what occurs in this situation, highlighting the underlying principles, calculations, and implications.

Introduction to the Scenario

Imagine a sealed, rigid container filled with helium gas, initially at a temperature of 77°C. Since the volume is fixed and the mass of helium remains unchanged, any change in pressure or temperature must follow the fundamental laws of gases. The key event here is that the pressure of the helium doubles after heating.

This scenario is an excellent example to understand how pressure, temperature, and volume relate through the ideal gas law, and how these relationships manifest in real-world conditions.

Fundamental Principles: The Ideal Gas Law

At the heart of this analysis lies the ideal gas law, which states:

$$PV = nRT$$

Where:
- P = pressure of the gas
- V = volume of the gas
- n = number of moles of gas
- R = universal gas constant (8.314 J/mol·K)
- T = temperature in Kelvin

Given that the volume (V) and number of moles (n) of helium are constant, the ideal gas law simplifies to:

$$P \propto T$$

or

$$ \frac{P}{T} = \text{constant} $$

This proportionality indicates that pressure and temperature are directly related when volume and amount of gas are held constant.

Initial Conditions and Changes

Initial State:
- Temperature: $T_1 = 77°C = 77 + 273.15 = 350.15\,K$
- Pressure: P_1 (some initial pressure)

Final State:
- Pressure: $P_2 = 2 \times P_1$ (pressure doubles)
- Temperature: T_2 (unknown, to be determined)

Since volume and number of moles are constant, the relation between initial and final states simplifies to:

$$ \frac{P_1}{T_1} = \frac{P_2}{T_2} $$

or

$$ T_2 = T_1 \times \frac{P_2}{P_1} $$

Given that $P_2 = 2 P_1$:

$$ T_2 = T_1 \times 2 = 350.15\,K \times 2 = 700.3\,K $$

Converting back to Celsius:

$$ T_2 = 700.3\,K - 273.15 = 427.15°C $$

Thus, the temperature of the helium must increase from 77°C to approximately 427.15°C to double the pressure at constant volume and mass.

Detailed Analysis: What Happens When Helium Is Heated?

1. Temperature Increase

The immediate and most straightforward consequence is the significant rise in temperature—from 77°C to roughly 427°C. This temperature increase causes the helium atoms to move more rapidly, leading to increased kinetic energy.

2. Pressure Doubling

Since pressure is directly proportional to temperature (when volume is fixed), the pressure doubles. This means the molecules exert twice the force per unit area on the container walls compared to the initial state.

3. Kinetic Energy of Helium Atoms

According to kinetic theory:

$$KE_{avg} = \frac{3}{2} RT$$

- As T increases, the average kinetic energy of helium atoms increases proportionally.
- At higher temperatures, helium atoms move faster, resulting in more frequent and forceful collisions with the container walls, thereby increasing pressure.

4. Implications for the Container

- If the container is rigid and maintains constant volume, the increased pressure due to heating is borne by the container walls.
- If the container is flexible or capable of expanding (e.g., a balloon), the volume would increase to accommodate the rising pressure and temperature, following Charles's Law.

Exploring Real-World Implications

a. Practical Applications

- Gas Storage and Transportation: Understanding how helium behaves under heating is crucial for safely storing and transporting helium, especially in applications like cryogenics or scientific instrumentation.
- Pressure Vessels Design: Engineers must account for pressure changes when designing sealed containers that experience temperature fluctuations.
- Thermodynamic Cycles: Helium is used in various thermodynamic cycles; understanding how pressure and temperature correlate is key in efficiencies.

b. Limitations of the Ideal Gas Law

While the ideal gas law provides a good approximation, real gases deviate under high pressures or low temperatures. Helium, being a noble gas with weak intermolecular forces, closely follows ideal behavior but may exhibit slight deviations at extreme conditions.

Additional Considerations

1. Heat Energy Required

To increase the temperature from 77°C to 427°C, energy must be supplied:

$$Q = n C_v \Delta T$$

Where:
- C_v = molar heat capacity at constant volume for helium (~12.5 J/mol·K)
- $\Delta T = T_2 - T_1$

This energy input depends on the number of moles, which can be calculated if initial pressure, volume, and gas constants are known.

2. Behavior of Helium at High Temperatures

- Helium remains monatomic and retains its physical properties up to very high temperatures.
- Its inertness ensures chemical stability, so no reactions occur during heating under typical conditions.

3. Safety and Material Constraints

- Elevated temperatures and pressures can compromise container integrity.
- Materials used must withstand high thermal and pressure stresses to prevent failures.

Summary and Key Takeaways

- When a constant volume and mass of helium gas at 77°C is heated so that the pressure doubles, the temperature must increase from 77°C to approximately 427°C.
- This process exemplifies the direct proportionality between pressure and temperature in ideal gases.
- The kinetic energy of helium atoms increases with temperature, leading to more energetic collisions and higher pressure.
- Practical applications span from industrial gas storage to thermodynamic cycle design, emphasizing the importance of understanding gas behavior.
- While the ideal gas law offers a robust approximation, real-world scenarios should consider material limitations and potential deviations at extreme conditions.

Final Thoughts

This analysis underscores the elegance and utility of basic gas laws in predicting and understanding physical phenomena. The behavior of helium under heating conditions not only illustrates foundational physics principles but also informs practical engineering and scientific applications. Whether designing safer storage vessels or optimizing thermodynamic cycles, grasping how pressure, volume, and temperature interrelate is indispensable for scientists and engineers alike.

Disclaimer: All calculations assume ideal gas behavior and may slightly deviate when applied to real-world systems with complex interactions or under extreme conditions.

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