A Gas Occupies A Volume Of 60 L At A Temperature Of 0.5 K. What Will The Volume Be At 4 K?

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Understanding how gases behave under different temperature conditions is fundamental in fields like chemistry, physics, engineering, and environmental science. When a gas's temperature changes, its volume also changes, provided the pressure remains constant. In this article, we will explore the relationship between temperature and volume for gases, apply the ideal gas law to solve the problem of determining the new volume at 4 K, and explain the concepts involved in detail. Whether you're a student preparing for exams or a professional seeking a refresher, this guide will clarify the principles behind this interesting question.

Fundamental Principles: The Ideal Gas Law

What Is the Ideal Gas Law?

The ideal gas law is a fundamental equation that describes the relationship between the pressure (P), volume (V), temperature (T), and amount of gas (n). It is expressed as:

- **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

This law assumes the gas behaves ideally—meaning the particles do not interact and occupy negligible volume. While real gases deviate from ideal behavior at high pressures and low temperatures, for many practical purposes, the ideal gas law provides an excellent approximation.

Temperature and Volume Relationship at Constant Pressure

When the pressure and number of moles remain constant, the ideal gas law simplifies to Charles's Law:

- **$V \propto T$**

which indicates that volume is directly proportional to temperature in Kelvin:

- $V_1 / T_1 = V_2 / T_2$

This relationship allows us to calculate the new volume of a gas when the temperature changes, assuming pressure and the amount of gas do not change.

Applying the Concepts to the Problem

Given Data:

- Initial volume, $V_1 = 60$ L
- Initial temperature, $T_1 = 0.5$ K
- Final temperature, $T_2 = 4$ K

Our goal:
- Find the final volume, V_2, when the temperature increases from 0.5 K to 4 K.

Step-by-Step Calculation

Since the pressure and the amount of gas are constant, we use Charles's Law:

- $V_1 / T_1 = V_2 / T_2$

Rearranged to solve for V_2:

- $V_2 = V_1 \times (T_2 / T_1)$

Plugging in the values:

- $V_2 = 60 \text{ L} \times (4 \text{ K} / 0.5 \text{ K}) = 60 \text{ L} \times 8 = 480 \text{ L}$

Therefore, the volume of the gas at 4 K will be 480 liters.

Implications and Considerations

Significance of the Temperature Change

The dramatic increase in volume from 60 L to 480 L illustrates how sensitive gas volume is to temperature changes, especially at very low temperatures like 0.5 K. In this case, the temperature increases eightfold, leading to an eightfold increase in volume, consistent with the direct proportionality described by Charles's Law.

Limitations and Real-World Factors

While the calculations assume ideal behavior, real gases may deviate at extremely low temperatures or high pressures. For example:

- At temperatures approaching absolute zero, gases tend to liquefy or solidify, and the ideal gas law no longer applies accurately.
- Interactions between particles and their finite volume become significant, causing deviations from ideality.

However, for most practical purposes, especially in controlled laboratory conditions, the ideal gas law provides reliable estimates.

Additional Related Concepts

Effect of Pressure Changes

If pressure were to change alongside temperature, Boyle's Law would come into play, which states that:

- $P_1V_1 / T_1 = P_2V_2 / T_2$

but since the problem specifies constant pressure, our calculation remains straightforward.

Importance of Kelvin Scale

Temperature must be measured in Kelvin for gas law calculations because Kelvin is an absolute scale. Using Celsius or Fahrenheit would lead to incorrect results because the relationships depend on absolute temperatures.

Summary

To summarize:

- When a gas's temperature increases at constant pressure, its volume increases proportionally.
- Applying Charles's Law allows us to compute the new volume based on initial and final temperatures.
- In this specific case, increasing the temperature from 0.5 K to 4 K causes the volume to expand from 60 L to 480 L.

Key Takeaways:
- Gas volume and temperature are directly proportional at constant pressure.
- Even small temperature changes at low temperatures can lead to significant volume changes.
- Always use Kelvin for temperature in gas law calculations.

Final Thoughts

Understanding the relationship between temperature and volume in gases is essential for numerous applications, from designing chemical reactors to understanding atmospheric phenomena. The problem of determining the volume of a gas at different temperatures exemplifies the practical use of the ideal gas law and Charles's Law. By grasping these principles, scientists and engineers can predict and control gas behaviors effectively across various industries and research fields.

Whether you're studying thermodynamics, working in laboratory settings, or exploring the fundamentals of physical chemistry, mastering the concepts behind gas laws will enhance your ability to analyze and solve complex problems related to gases. Remember to always consider the assumptions underlying these laws and recognize the conditions under which they apply most accurately.

End of Article

Frequently Asked Questions

What is the initial volume and temperature of the gas in the problem?

The initial volume is 60 L and the initial temperature is 0.5 K.

What is the final temperature of the gas in the problem?

The final temperature is 4 K.

Which law relates the volume and temperature of a gas at constant pressure?

Charles's Law relates the volume and temperature of a gas at constant pressure.

How do you calculate the new volume of the gas when temperature changes according to Charles’s Law?

Use the formula V1/T1 = V2/T2, then solve for V2: V2 = V1 (T2 / T1).

What is the value of the final volume of the gas at 4 K?

V2 = 60 L (4 K / 0.5 K) = 60 L 8 = 480 L.

Why does the volume increase when the temperature increases?

Because gases expand when heated at constant pressure, increasing their volume according to Charles’s Law.

Are there any assumptions made in solving this problem?

Yes, it assumes the gas behaves ideally and pressure remains constant during the temperature change.

Is the temperature in Kelvin or Celsius important in this calculation?

Kelvin is important because Charles’s Law requires absolute temperature measurements.

What would happen if the temperature approached absolute zero?

The gas would theoretically contract to a very small volume, but real gases deviate from ideal behavior near absolute zero.

Additional Resources

A Gas Occupies A Volume Of 60 L At A Temperature Of 0.5 K. What Will The Volume Be At 4 K? This question presents an intriguing scenario that taps into the principles of thermodynamics and the behavior of gases under varying temperature conditions. Understanding how a gas's volume changes with temperature is fundamental in fields ranging from physics and chemistry to engineering and atmospheric science. In this comprehensive guide, we'll explore the underlying concepts, the relevant gas laws, and the step-by-step process to determine the new volume of the gas at 4 K, starting from its initial conditions at 0.5 K.

Understanding the Scenario

Imagine a container holding a certain amount of gas, initially occupying a volume of 60 liters at an extremely low temperature of 0.5 Kelvin. The question posed is: What will be the volume of this same gas when the temperature is increased to 4 Kelvin?

At first glance, the change in temperature from 0.5 K to 4 K might seem minimal—less than an order of magnitude—but the principles governing the behavior of gases, especially at low temperatures, require careful consideration.

The Ideal Gas Law: The Foundation of Our Analysis

To analyze the problem, we need to turn to the Ideal Gas Law, which expresses the relationship between pressure (P), volume (V), temperature (T), and amount of gas (n):

$$PV = nRT$$

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

Key assumptions:

- The gas behaves ideally.
- The pressure remains constant during the temperature change.
- The amount of gas remains unchanged.

In most practical scenarios, these assumptions hold true at low pressures and moderate temperatures. However, at ultra-low temperatures such as 0.5 K, real gases may deviate from ideal behavior because of quantum effects and intermolecular forces. For the sake of this analysis, and because the problem is posed in a straightforward manner, we'll assume ideal behavior.

Applying the Law: Volume and Temperature Relationship

Since pressure and amount of gas are assumed constant, the Ideal Gas Law simplifies to:

$$ V \propto T $$

which implies:

$$ \frac{V_1}{T_1} = \frac{V_2}{T_2} $$

where:

- $V_1 = 60 \, \text{L}$
- $T_1 = 0.5 \, \text{K}$
- $T_2 = 4 \, \text{K}$
- $V_2 = ?$

Rearranged, the formula becomes:

$$ V_2 = V_1 \times \frac{T_2}{T_1} $$

Step-by-Step Calculation

Let's perform the calculation with the given values:

$$ V_2 = 60 \, \text{L} \times \frac{4\, \text{K}}{0.5\, \text{K}} $$

$$ V_2 = 60 \times 8 $$

$$ V_2 = 480 \, \text{L} $$

Result: The volume of the gas at 4 Kelvin would be approximately 480 liters.

Critical Considerations and Potential Deviations

While this straightforward calculation provides a clear answer based on the ideal gas law, real-life scenarios, especially at such low temperatures, involve several nuances:

1. Deviations from Ideal Gas Behavior

At temperatures approaching absolute zero (0 K), gases tend to deviate significantly from ideality due to:

- Quantum effects
- Intermolecular forces

- Phase changes (e.g., condensation)

In particular, at 0.5 K and 4 K, some gases may condense or liquefy, invalidating ideal gas assumptions.

2. Nature of the Gas

- Type of gas: Noble gases like helium or neon behave differently at low temperatures.
- Quantum gases: Helium-4 and helium-3 exhibit superfluidity or quantum degeneracy effects at cryogenic temperatures.

3. Constant Pressure Assumption

In real experimental setups, maintaining constant pressure during temperature variation is challenging. Changes in pressure can influence volume independently of temperature.

4. Experimental Constraints

- The container's material properties at low temperatures.
- Thermal contraction or expansion of the container.

When Are These Effects Significant?

Understanding when deviations matter is crucial:

- For gases at moderate temperatures and pressures, the ideal gas law is sufficiently accurate.
- At cryogenic temperatures (below 1 K), quantum effects dominate, and the behavior becomes more complex.
- For liquefied gases or near phase transitions, the ideal gas law no longer applies.

Practical Applications and Examples

Example 1: Estimating Volume Change in Laboratory Settings

Suppose a scientist is working with helium gas in a cryogenic environment. Knowing that the gas initially occupies 60 L at 0.5 K, they can estimate that raising the temperature to 4 K would increase the volume to approximately 480 L, assuming pressure remains constant.

Example 2: Engineering Design

Designers of cryogenic equipment need to anticipate volume changes due to temperature fluctuations. Applying the proportionality $V \propto T$ helps in sizing containers and understanding the stresses involved.

Summary of Key Points

- The relationship between volume and temperature for an ideal gas at constant pressure is linear: $V \propto T$.
- Given initial conditions (60 L at 0.5 K), increasing the temperature to 4 K results in a volume of approximately 480 L.
- Real gas behavior at cryogenic temperatures may deviate from ideal predictions, necessitating corrections or more complex models.
- Understanding the assumptions behind the ideal gas law is crucial when applying it to low-temperature physics.

Final Thoughts

While the calculation suggests that increasing the temperature from 0.5 K to 4 K results in a volume increase by a factor of 8, it's important to contextualize this within the physical realities of gas behavior at cryogenic temperatures. For most practical purposes, especially in well-controlled laboratory conditions, this proportionality provides a reliable estimate. However, for precise applications involving real gases or near phase transitions, more sophisticated models and experimental data are required.

In conclusion, the question of "A gas occupying 60 L at 0.5 K, what will its volume be at 4 K?" offers a compelling glimpse into thermodynamics and the importance of understanding the conditions and assumptions behind foundational gas laws. Whether for academic exploration, experimental design, or industrial processes, mastering these principles is essential for accurate predictions and effective application.

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