What Is The Temperature, In K, Of 8.70 Moles Of Helium In A 3.00 L Vessel At 7.69 Atm?

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Understanding the temperature of a gas in a confined space is fundamental in chemistry and physics, especially when dealing with ideal gases. This question involves calculating the temperature in Kelvin (K) for a specified amount of helium gas under certain conditions, which combines principles from the ideal gas law and molar calculations. In this article, we will explore how to determine the temperature of 8.70 moles of helium contained within a 3.00-liter vessel at an external pressure of 7.69 atmospheres, providing a thorough explanation of the concepts and formulas involved.

Introduction to Gas Laws and Their Significance

Gases are unique among states of matter because their particles are widely spaced and in constant, random motion. The behavior of gases under different conditions of pressure, volume, and temperature can be described mathematically using the ideal gas law. This law provides a foundation for understanding how gases respond to changes in these parameters and allows us to calculate unknown properties when some variables are known.

The ideal gas law is expressed as:
$$ PV = nRT $$

Where:
- P = pressure in atmospheres (atm)
- V = volume in liters (L)
- n = number of moles (mol)
- R = ideal gas constant, approximately 0.082057 L·atm/(mol·K)
- T = temperature in Kelvin (K)

By rearranging this formula, we can solve for the temperature:
$$ T = \frac{PV}{nR} $$

This equation allows us to find the temperature when the pressure, volume, amount of gas, and the gas constant are known.

Understanding the Context of the Problem

Before delving into calculations, let's clearly understand the parameters involved:

- Number of moles of helium, n: 8.70 mol

- Volume of the vessel, V: 3.00 L
- Pressure of the helium gas, P: 7.69 atm

It's important to note that the pressure given (7.69 atm) is the external or gauge pressure inside the vessel. Since the problem states these conditions, we assume the gas behaves ideally, and the vessel is rigid and sealed, meaning the volume remains constant during the process.

The goal is to find the temperature of the helium in Kelvin under these conditions.

Step-by-Step Calculation of the Temperature

To determine the temperature, we will apply the ideal gas law directly, substituting the known values.

Step 1: Write down the ideal gas law formula for T:

$$ T = \frac{PV}{nR} $$

Step 2: Plug in the known values:

$$
T = \frac{(7.69\, \text{atm}) \times (3.00\, \text{L})}{8.70\, \text{mol} \times 0.082057\, \text{L·atm/(mol·K)}}
$$

Step 3: Calculate numerator and denominator separately:

- Numerator:
$$ 7.69\, \text{atm} \times 3.00\, \text{L} = 23.07\, \text{L·atm} $$
- Denominator:
$$ 8.70\, \text{mol} \times 0.082057\, \text{L·atm/(mol·K)} \approx 0.7134\, \text{L·atm/K} $$

Step 4: Compute T:

$$
T = \frac{23.07}{0.7134} \approx 32.33\, \text{K}
$$

Thus, the temperature of the helium gas under these conditions is approximately 32.33 Kelvin.

Understanding the Implications of the Results

The calculated temperature of approximately 32.33 K indicates that the helium gas is at a very low temperature, close to the temperature of outer space. This low temperature results from the high pressure exerted on a small volume with a finite amount of gas, leading to a significant cooling effect in the context of the ideal gas law.

It's essential to recognize that this calculation assumes ideal behavior, which is a reasonable approximation for helium under these conditions because helium is a noble gas with minimal intermolecular interactions, and the pressure is not excessively high.

Additional Considerations and Real-World Applications

While the ideal gas law provides an excellent approximation, real gases can deviate slightly from ideal behavior, especially under high pressures or low temperatures. For helium, deviations are minimal due to its inert nature.

Applications of such calculations include:

- Designing pressurized gas containers
- Understanding the behavior of gases in cryogenic systems
- Calculating thermodynamic properties in scientific experiments
- Engineering applications involving helium, such as cooling systems in MRI machines

Important factors to consider in practical scenarios:

- Actual pressure inside the vessel may differ due to temperature changes
- The vessel's material properties and safety considerations
- Potential for non-ideal behavior at different temperature and pressure ranges

Summary of Key Points

- The ideal gas law is a fundamental tool for calculating the temperature of gases under known conditions.
- In this problem, 8.70 moles of helium in a 3.00 L vessel at 7.69 atm pressure results in a temperature of approximately 32.33 K.
- The calculation assumes ideal behavior, which is valid for helium under these conditions.
- Understanding gas laws is crucial in various scientific and engineering applications.

Conclusion

Determining the temperature of gases under specific conditions is critical in both theoretical and applied sciences. By applying the ideal gas law, we can accurately estimate the temperature in Kelvin for helium gas confined in a vessel. In this case, the temperature is about 32.33 K, highlighting the low-energy state of helium under high pressure and small volume. This calculation underscores the importance of understanding gas behavior for practical applications, from industrial processes to scientific research.

Remember: Always verify your units and assumptions when performing such calculations, and consider real-world deviations for precise engineering or scientific purposes.

Frequently Asked Questions

How do you calculate the temperature in Kelvin for a given amount of helium gas using the ideal gas law?

You can calculate the temperature in Kelvin (T) using the ideal gas law: PV = nRT. Rearranged, T = (PV) / (nR). Substitute the given pressure (P), volume (V), moles (n), and the gas constant (R = 0.0821 L·atm/(mol·K)) to find T.

What is the temperature in Kelvin of 8.70 moles of helium in a 3.00 L vessel at 7.69 atm?

Using the ideal gas law T = (PV) / (nR): T = (7.69 atm × 3.00 L) / (8.70 mol × 0.0821 L·atm/(mol·K)) ≈ 30.18 K.

Why is it important to use Kelvin when calculating temperature in gas law problems?

Kelvin is an absolute temperature scale starting at absolute zero, ensuring that calculations involving gases are physically meaningful and proportional, as the gas laws are based on absolute temperature.

If the pressure or volume changes, how does that affect the temperature of the helium gas?

According to the ideal gas law, if pressure or volume increases while moles and the gas constant remain constant, the temperature will increase. Conversely, decreasing pressure or volume will decrease the temperature.

What assumptions are made when applying the ideal gas law to calculate the temperature of helium gas?

The assumptions include that the gas particles do not interact with each other and occupy negligible volume compared to the container, which is valid at low pressures and high temperatures for helium.

Additional Resources

Understanding the Temperature of Helium in a 3.00 L Vessel at 7.69 atm—A Comprehensive Analysis

When delving into the realm of gases and thermodynamics, one of the fundamental questions often encountered is: What is the temperature of a given amount of gas under specific conditions? In this case, we are examining 8.70 moles of helium contained within a 3.00-liter vessel at a pressure of 7.69 atm, and our goal is to determine the temperature in Kelvin (K). This problem embodies core concepts in gas laws, particularly the Ideal Gas Law, and offers a rich context to explore thermodynamics, units conversion, and the behavior of noble gases such as helium.

Fundamental Concepts and Equations

Before jumping into calculations, it's essential to understand the fundamental principles involved.

The Ideal Gas Law

The Ideal Gas Law is the cornerstone of many gas-related calculations:

$$PV = nRT$$

Where:
- P is the pressure (in atmospheres, atm)
- V is the volume (in liters, L)
- n is the number of moles (mol)
- R is the ideal gas constant
- T is the temperature (in Kelvin, K)

This law assumes that gases behave ideally—that is, the particles do not interact and occupy negligible volume. For helium, a noble gas with minimal interactions, this approximation is quite accurate at typical conditions.

Constants and Conversion Factors

- $R = 0.082057 \, \text{L·atm/(mol·K)}$

This value of R aligns with units in atmospheres, liters, moles, and Kelvin, making calculations straightforward.

Step-by-Step Calculation of Temperature

The problem provides the following data:
- $n = 8.70 \, \text{mol}$

- $V = 3.00 \, \text{L}$
- $P = 7.69 \, \text{atm}$

Our goal: Find T in Kelvin.

Rearranged Ideal Gas Law

Rearranged to solve for temperature:

$$T = \frac{PV}{nR}$$

Substituting the known values:

$$T = \frac{(7.69 \, \text{atm}) \times (3.00 \, \text{L})}{8.70 \, \text{mol} \times 0.082057 \, \text{L·atm/(mol·K)}}$$

Performing the Calculation

Calculating numerator:

$$7.69 \times 3.00 = 23.07 \, \text{L·atm}$$

Calculating denominator:

$$8.70 \times 0.082057 \approx 0.713 \, \text{L·atm/(K)}$$

Finally, calculating temperature:

$$T = \frac{23.07}{0.713} \approx 32.36 \, \text{K}$$

Result: The temperature of the helium gas in the vessel is approximately 32.36 Kelvin.

Interpreting the Result

Understanding what this temperature implies involves considering the physical state of helium and the conditions within the vessel.

Is 32.36 K Realistic?

- Helium's boiling point: Helium remains a gas down to extremely low temperatures, with its boiling point at atmospheric pressure being about 4.22 K. Since our calculated temperature is

approximately 32.36 K, it is comfortably above helium's boiling point, confirming it would exist as a gas under these conditions.
- Physical implications: At this temperature, helium atoms possess relatively low kinetic energy, but the gas behavior remains ideal at these conditions, especially given helium's inertness and minimal interactions.

Implications for Gas Behavior

- Low temperature: The low Kelvin temperature indicates the gas particles are moving relatively slowly compared to higher temperatures, but they still exhibit significant kinetic energy.
- Density considerations: Given the volume and moles, the density of helium can be calculated, providing insights into the physical state and potential applications.

Additional Aspects to Consider

While the calculation is straightforward, several nuanced factors can influence the interpretation and practical understanding.

1. Validity of the Ideal Gas Law

- At the given conditions (pressure and temperature), helium behaves very closely to an ideal gas.
- Deviations from ideality become significant at very high pressures or low temperatures, but here, the low pressure (7.69 atm, which is moderate) and moderate temperature support the ideal gas approximation.

2. Real Gas Corrections

- If higher accuracy is required, especially at conditions near liquefaction, real gas models like Van der Waals equation could be used:

$$\left(P + \frac{a n^2}{V^2}\right)(V - nb) = nRT$$

where a and b are gas-specific constants accounting for intermolecular forces and finite molecular volume, respectively. For helium:
- a is very small, reflecting weak intermolecular forces.
- b is also small, due to the small size of helium atoms.

- Under typical laboratory conditions, these corrections are negligible for helium.

3. Temperature Units and Conversions

- Kelvin is the SI base unit for temperature in thermodynamics, making it essential for calculations involving the ideal gas law.
- Converting from Celsius or Fahrenheit to Kelvin involves:

$$ T(K) = T(^\circ C) + 273.15 $$

- However, since the problem directly involves Kelvin, no conversion was necessary.

4. Impact of Moles and Volume on Temperature

- Increasing the number of moles at constant pressure and volume would proportionally increase the temperature.
- Conversely, decreasing the volume at constant pressure and moles would increase the temperature, illustrating Boyle's Law and Charles's Law in action.

Real-World Applications and Significance

Understanding the temperature of helium under specific conditions has practical importance across multiple fields:

1. Cryogenics and Low-Temperature Physics

- Helium is extensively used in cryogenic applications, including MRI machines and superconductor cooling systems.
- Precise knowledge of temperature at given conditions ensures the safety and efficiency of these systems.

2. Gas Storage and Transportation

- Helium must be stored at specific pressures and temperatures to prevent liquefaction or loss.
- Calculations like the one above inform safety protocols and handling procedures.

3. Scientific Research

- Helium's properties at low temperatures are critical in research involving quantum fluids and superfluidity.

- Accurate thermodynamic data underpin experimental design and interpretation.

Summary and Key Takeaways

- The temperature of 8.70 moles of helium in a 3.00 L vessel at 7.69 atm pressure is approximately 32.36 Kelvin.
- The calculation hinges on the ideal gas law, which is sufficiently accurate for helium under the specified conditions.
- Understanding this temperature offers insights into the physical behavior of helium, including its state, kinetic energy, and suitability for various applications.
- Real gas effects are minimal here but should be considered at more extreme conditions.
- Mastery of units conversion and gas laws is essential for accurate thermodynamic calculations.

Final Thoughts

This problem exemplifies the elegant simplicity of the ideal gas law and its power in solving real-world questions about gases. Helium's unique properties, especially its inertness and low boiling point, make it a fascinating subject in thermodynamics. By carefully analyzing the given parameters and applying fundamental principles, we gain a clear understanding of the gas's temperature, which in turn informs practical applications, scientific research, and safety considerations.

Whether you're a student mastering the basics of thermodynamics or a professional working with gases in industrial settings, such calculations reinforce the importance of precise data and a deep understanding of physical laws. As you continue exploring the behavior of gases, remember that behind every straightforward formula lies a rich tapestry of physics waiting to be uncovered.

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