A Sealed 1.50-L Chamber Filled With Helium Gas Initially At 20C And 1.00 Atm Is Heated Until The Gas

A Sealed 1.50-L Chamber Filled With Helium Gas Initially At 20C And 1.00 Atm Is Heated Until The Gas is a compelling scenario often encountered in physics and thermodynamics studies. This situation exemplifies fundamental principles such as gas laws, temperature effects on gases, and the behavior of ideal gases under changing conditions. Understanding how helium behaves when heated in a sealed environment not only deepens our grasp of thermodynamic principles but also has practical applications in fields ranging from industrial gas storage to scientific research. In this comprehensive article, we will explore the process step-by-step, analyze the key concepts involved, and discuss the real-world implications of heating a sealed helium-filled chamber.

Understanding the Initial Conditions of the Helium Gas Chamber

Before delving into the effects of heating, it is essential to understand the initial state of the helium gas within the chamber. The given parameters are:

- Volume (V): 1.50 liters
- Temperature (T_1): 20°C (which converts to 293.15 K)
- Pressure (P_1): 1.00 atm

These values provide a baseline for analyzing how the system responds as it is heated.

Key Properties of Helium Gas

Helium is a noble gas characterized by:

- Very low atomic mass (approximately 4 g/mol)
- Nearly ideal gas behavior under standard conditions
- Monatomic nature, meaning it has a single atom per molecule
- High thermal conductivity, facilitating rapid temperature changes

Because of its properties, helium often serves as a model gas in thermodynamic studies.

Principles of the Ideal Gas Law

The initial state of the helium can be described by the ideal gas law:

$$ PV = nRT $$

Where:

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

Since the chamber volume is fixed and the gas is sealed, the amount of helium (n) remains constant during heating.

The Process of Heating the Sealed Chamber

When the chamber is heated, several thermodynamic changes occur:

- The temperature of the helium increases.
- The pressure inside the chamber rises.
- The volume remains constant because the chamber is sealed.

Key Point: The process is considered constant volume heating, which simplifies analysis using the ideal gas law.

Calculating the Final Temperature

If the initial temperature is $T_1 = 293.15 \, K$, and the final temperature after heating is T_2, the relationship between initial and final states in a sealed, constant volume system is:

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

Because the volume and number of moles are constant, the pressure and temperature are directly proportional:

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

To determine T_2, consider the heating process:

- If the final pressure or temperature is specified, we can compute the unknowns.

- If only the heating process is described without specific final conditions, we analyze the general behavior.

Effects of Heating on Helium Gas in a Sealed Chamber

Heating helium in a sealed chamber results in several observable and measurable effects:

Increase in Pressure

Since the volume and the number of moles remain constant, the pressure increases proportionally with temperature:

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

For example, if the temperature is increased to 100°C (373.15 K):

$$ P_2 = 1.00\, \text{atm} \times \frac{373.15\, K}{293.15\, K} \approx 1.273\, \text{atm} $$

This demonstrates a significant increase in pressure due to heating.

Increase in Internal Energy

The internal energy (U) of an ideal monatomic gas like helium depends solely on temperature:

$$ U = \frac{3}{2} nRT $$

Thus, as temperature increases:

- The internal energy increases linearly with temperature.
- The amount of energy added to the gas can be calculated if the number of moles and temperature change are known.

Work Done by the Gas

In a sealed rigid chamber (constant volume), the gas does no work during the heating process because work in thermodynamics is defined as:

$$ W = P \Delta V $$

Since $\Delta V = 0$, no work is performed by the gas during heating in this scenario.

Potential Physical Consequences

- Risk of structural failure if the pressure exceeds the chamber's design limits.
- The necessity of pressure relief mechanisms in real-world applications.

Calculations and Key Formulas Involved

To analyze the heating process quantitatively, several formulas are relevant:

1. Final Pressure After Heating

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

Where:

- P_1: initial pressure (1 atm)
- T_1: initial temperature in Kelvin (293.15 K)
- T_2: final temperature in Kelvin

2. Internal Energy Change

$$ \Delta U = \frac{3}{2} n R (T_2 - T_1) $$

- n: number of moles of helium

3. Number of Moles of Helium

Given initial conditions:

$$ n = \frac{P V}{RT} $$

Using initial parameters:

$$ n = \frac{(1.00\, \text{atm})(1.50\, \text{L})}{(0.082057\, \text{L·atm/(mol·K)})(293.15\, K)} $$

Calculating gives:

$$ n \approx 0.0624\, \text{mol} $$

Real-World Applications and Implications

Understanding the behavior of helium in a sealed environment under heating conditions is crucial in various fields:

Industrial Gas Storage

- Helium tanks are designed to withstand high pressures resulting from thermal variations.
- Proper pressure relief mechanisms are essential to prevent accidents.

Scientific Research

- Precise control of temperature and pressure in experiments involving helium.
- Use in low-temperature physics, cryogenics, and quantum mechanics studies.

Medical and Technological Uses

- Helium is used in MRI machines, requiring careful management of pressure and temperature.
- In aerospace, helium is used for pressurizing fuel tanks and other systems.

Safety Considerations When Heating Sealed Gas Chambers

- Overpressure Risks: As temperature rises, pressure can exceed safe limits.
- Structural Integrity: Ensure the chamber material can withstand increased internal pressure.
- Pressure Relief Valves: Incorporate safety valves to vent excess pressure.
- Monitoring: Use sensors to continuously monitor internal pressure and temperature.

Summary and Conclusion

Heating a sealed 1.50-L chamber filled with helium gas from 20°C (293.15 K) to a higher temperature significantly impacts the internal pressure, internal energy, and overall behavior of the gas. The ideal gas law provides a straightforward way to predict these changes, emphasizing the proportional relationship between temperature and pressure in a constant volume system. For example, heating helium from 20°C to 100°C results in a pressure increase from 1 atm to approximately 1.273 atm, illustrating the importance of considering thermal effects in the design and use of sealed gas containers.

Understanding these principles is vital for engineers, scientists, and safety professionals to ensure the safe and efficient handling of helium and similar gases under varying thermal conditions. Proper safety measures, including pressure relief systems and material considerations, are essential to prevent accidents and maintain operational integrity in applications involving heated sealed chambers.

In essence, the study of heating helium in a sealed chamber combines fundamental thermodynamic principles with practical considerations, serving as a cornerstone for innovations in gas storage, scientific experiments, and industrial processes.

Frequently Asked Questions

What happens to the pressure of the helium gas when the sealed 1.50-L chamber is heated from 20°C?

The pressure increases because, according to Gay-Lussac's Law, pressure is directly proportional to temperature when volume and moles are constant.

How does the temperature change affect the volume of the helium gas in the sealed chamber?

Since the chamber is sealed, the volume remains constant; heating only increases the gas's pressure and temperature.

What is the initial number of moles of helium in the chamber?

Using the ideal gas law, initial moles $n = (P \times V) / (R \times T)$. At 20°C (293 K), $P = 1$ atm, $V = 1.50$ L, $R = 0.0821$ L·atm/(mol·K), so $n \approx 0.0624$ mol.

If the temperature is increased to 100°C, what will be

the new pressure inside the chamber?

At 100°C (373 K), the new pressure $P_2 = P_1 \times (T_2 / T_1) = 1 \text{ atm} \times (373 / 293) \approx 1.27 \text{ atm}$.

Does heating helium in a sealed chamber cause any change in its volume?

No, since the chamber is sealed and rigid, the volume remains constant regardless of temperature changes.

What law describes the relationship between pressure and temperature for helium in this scenario?

Gay-Lussac's Law describes this relationship: $P \propto T$ at constant volume and amount of gas.

Is the ideal gas law applicable in this situation, and why?

Yes, because helium behaves as an ideal gas under these conditions, allowing the use of the ideal gas law to predict pressure and temperature changes.

What safety considerations should be taken into account when heating a sealed gas chamber?

Heating increases pressure, which can compromise the integrity of the chamber. Proper safety measures, such as pressure relief valves and avoiding excessive heating, are essential.

How would the pressure change if the volume of the chamber were to double while heating at 20°C?

If the volume doubles at constant temperature, the pressure halves according to Boyle's Law; combined with heating, the final pressure would depend on both effects, but at constant T, P would be halved.

Additional Resources

Helium Gas Expansion in a Sealed 1.50-L Chamber: An In-Depth Analysis

When examining the behavior of gases under changing thermal conditions, few scenarios are as illustrative and practical as heating a sealed chamber filled with helium. This case study—featuring a 1.50-liter sealed container initially at 20°C and 1.00 atm—provides rich insights into thermodynamics, ideal gas law applications, and real-world implications for scientific and industrial processes. In this expert review, we will explore each phase of the heating process, the underlying principles, and what occurs as the gas responds to temperature increases.

Understanding the Initial Conditions

Before delving into the effects of heating, it’s crucial to understand the initial state of the helium gas within the chamber.

Initial Parameters

- Volume (V): 1.50 liters (L)
- Temperature (T_1): 20°C
- Pressure (P_1): 1.00 atm

In thermodynamic terms, these parameters set the stage for applying the ideal gas law, which states:

$$ PV = nRT $$

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

Converting the initial temperature to Kelvin:

$$ T_1 = 20°C + 273.15 = 293.15\,K $$

Calculating the Number of Moles of Helium

Using the ideal gas law:

$$
n = \frac{PV}{RT}
$$

Plugging in the initial conditions:

$$
n = \frac{(1.00\,atm)(1.50\,L)}{(0.082057\,L\,atm/(mol\,K))(293.15\,K)}
$$

Calculating:

$$
n \approx \frac{1.50}{0.082057 \times 293.15} \approx \frac{1.50}{24.055} \approx 0.0624\,mol
$$

This stable number of moles indicates that the chamber is perfectly sealed, with no gas exchange occurring during heating.

Effect of Heating: Theoretical Perspective

As the chamber is heated, the temperature of the helium gas increases, and according to the ideal gas law, this results in changes in pressure and possibly volume, depending on the chamber’s constraints.

Scenario 1: Rigid, Sealed Chamber

In this case, the chamber's volume remains constant at 1.50 L. Since the container is sealed and rigid, volume does not change. The key variables affected are pressure and temperature.

Applying the ideal gas law at the new temperature T_2:

$$
P_2 = \frac{nRT_2}{V}
$$

Given that n, R, and V are constants, the relationship simplifies to:

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

Thus,

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

This proportional relationship means that as temperature increases, pressure increases linearly.

Key Point:
Pressures can rise significantly in sealed environments, potentially approaching or exceeding safety limits if heating is substantial.

Scenario 2: Flexible Chamber Allowing Volume Change

If the chamber is flexible (e.g., a balloon or a piston), the volume can expand as the gas heats. Under such circumstances, the process can be considered an isobaric (constant pressure) process, or more generally, a process where both pressure and volume may change depending on constraints.

- If the chamber maintains constant pressure (e.g., connected to a pressure regulator): The volume will expand proportionally with temperature.

- If the chamber is completely rigid: The volume stays fixed, and pressure increases as temperature rises.

Calculating the Final Conditions After Heating

Suppose the chamber is rigid; the temperature is increased from 20°C to a higher temperature T_2. Let's examine a few practical examples:

Example 1: Heating to 100°C

Convert to Kelvin:

$$
T_2 = 100°C + 273.15 = 373.15\,K
$$

Calculate the new pressure:

$$
P_2 = P_1 \times \frac{T_2}{T_1} = 1.00\,atm \times \frac{373.15}{293.15} \approx 1.27\,atm
$$

Implication:
The pressure increases by approximately 27%. Since helium is a noble gas with low reactivity and high diffusivity, it can withstand these pressure changes without chemical alterations. However, the increased pressure could pose safety concerns if the chamber’s rated maximum pressure is exceeded.

Example 2: Heating to 200°C

Convert:

$$
T_2 = 200 + 273.15 = 473.15\,K
$$

Calculate:

$$
P_2 = 1.00\,atm \times \frac{473.15}{293.15} \approx 1.61\,atm
$$

Implication:
At 200°C, pressure increases by approximately 61%. This underscores the importance of knowing the chamber’s maximum pressure rating to prevent rupture or failure.

Real-World Implications and Safety Considerations

Understanding the thermodynamic response of helium in a sealed chamber is critical for various practical applications:

- Balloon and Aerostat Design:
Helium-filled balloons expand as temperature increases, which can lead to bursting if not properly vented or designed with safety margins.

- Scientific Experimentation:
Precise control of pressure and temperature is essential for experiments involving helium, especially in low-temperature physics or high-precision measurements.

- Industrial Gas Storage:
Ensuring the integrity of storage vessels under temperature fluctuations is vital to prevent accidents.

Safety Tips:

- Always verify the maximum rated pressure of the chamber before heating.
- Use controlled heating environments to prevent rapid temperature increases.
- Incorporate pressure relief valves if possible to mitigate overpressure risks.
- Consider the thermal expansion properties of the chamber material.

Impact of Non-Ideal Gas Behavior

While the ideal gas law provides a robust approximation, real gases deviate under certain conditions, especially at high pressures or low temperatures where interactions between particles become significant.

Helium's Behavior:

- At typical laboratory conditions, helium closely follows ideal behavior.
- Under extreme heating leading to high pressures, deviations may occur, requiring correction factors like Van der Waals constants.
- For most practical purposes, these deviations are negligible in the described temperature and pressure ranges.

Concluding Remarks

The process of heating a sealed 1.50-L chamber filled with helium from 20°C involves predictable yet critical changes primarily in pressure. The linear relationship between temperature and pressure in rigid containers underscores the importance of understanding thermodynamic principles for safety and efficiency.

Key takeaways include:

- The pressure of helium in a sealed chamber increases proportionally with temperature.
- The volume remains constant in rigid chambers, leading to increased pressure.
- Safety considerations are paramount when heating gases under confinement.
- Real-world applications demand precise calculations and safety margins.

By leveraging the ideal gas law and understanding the properties of helium, engineers, scientists, and safety professionals can design and operate systems that harness helium’s unique characteristics while minimizing risks associated with thermal expansion and pressure buildup.

In summary, heating helium in a sealed chamber exemplifies fundamental thermodynamic concepts with direct implications across scientific, industrial, and recreational domains. Proper comprehension of these principles ensures safe operation and optimal utilization of helium’s properties in various applications.

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