When A Certain Gas Under A Pressure Of 5.00 10 Pa At 25.0C Is Allowed To Expand To 3.00 Times Its Original

When A Certain Gas Under A Pressure Of 5.00 10 Pa At 25.0C Is Allowed To Expand To 3.00 Times Its Original, it presents an intriguing scenario that involves understanding the fundamental principles of gas behavior. This situation can be analyzed comprehensively through the lens of the ideal gas law, thermodynamics, and the relationships between pressure, volume, temperature, and amount of gas. In this article, we will explore what happens during such an expansion, the relevant physical laws, calculations involved, and the broader implications of these processes.

Understanding the Initial Conditions of the Gas

Before delving into the expansion process, it is crucial to understand the initial state of the gas and the parameters involved.

Initial Pressure and Temperature

The gas starts at a pressure of 5.00 × 10 Pa, which, assuming a typographical correction, likely indicates 5.00 × 10^5 Pa (or 500,000 Pa). The temperature is given as 25.0°C, which converts to Kelvin as follows:

- Conversion: T (K) = 25.0 + 273.15 = 298.15 K

Initial Volume

The initial volume (V_1) of the gas is not explicitly provided, but it can be considered as a reference volume. The key is understanding how this volume changes when the gas expands.

Number of Moles of Gas

Assuming the gas behaves ideally, the number of moles (n) remains constant during expansion unless specified otherwise. This allows us to apply the ideal gas law:

$$PV = nRT$$

where:
- P = pressure,
- V = volume,
- n = number of moles,
- R = ideal gas constant (8.314 J/mol·K),

- T = temperature in Kelvin.

Next, we evaluate what happens when the gas expands.

Expansion to Three Times Its Original Volume

The problem states that the gas expands to three times its original volume (V_2):

$$ V_2 = 3V_1 $$

This expansion could be either isothermal (constant temperature), adiabatic (no heat exchange), or involve heat transfer. The nature of the process determines the change in other parameters, especially temperature.

Assumption of Isothermal Expansion

In many practical scenarios, especially when the expansion occurs slowly and heat exchange is allowed, the process can be approximated as isothermal. Assuming isothermal conditions simplifies calculations because:

- Temperature remains constant: $T_1 = T_2 = 298.15$ K
- The ideal gas law applies equally at both states.

Under this assumption, the relation between initial and final states simplifies to:

$$ P_1 V_1 = P_2 V_2 $$

Given that $V_2 = 3V_1$, then:

$$ P_2 = \frac{P_1 V_1}{V_2} = \frac{P_1}{3} $$

which means the final pressure (P_2) is one-third of the initial pressure (P_1), i.e.,

$$ P_2 = \frac{5.00 \times 10^5 \text{ Pa}}{3} \approx 1.67 \times 10^5 \text{ Pa} $$

This illustrates how pressure decreases proportionally with volume during an isothermal expansion.

Calculating the Final State of the Gas

With the assumptions above, we can derive the key parameters after expansion.

Final Pressure

As shown, the final pressure after expansion:

$$P_2 = \frac{P_1}{3} = 1.67 \times 10^5 \text{ Pa}$$

Final Temperature

Under an isothermal process, the temperature remains unchanged:

$$T_2 = T_1 = 298.15 \text{ K}$$

Final Volume

Given the volume triples:

$$V_2 = 3V_1$$

Final Number of Moles

If the process is carried out without adding or removing gas, the number of moles remains constant:

$$n_2 = n_1$$

Implications of the Expansion in Thermodynamic Terms

Understanding the energy changes during expansion is essential for grasping the physical significance.

Work Done by the Gas

The work (W) done by the gas during an expansion at constant temperature is:

$$W = nRT \ln \frac{V_2}{V_1}$$

Since $V_2 / V_1 = 3$, then:

$$W = nRT \ln 3$$

This work is positive, indicating the gas does work on its surroundings during expansion.

Heat Exchange

In an isothermal process, the internal energy change (ΔU) is zero because internal energy depends solely on temperature for ideal gases. Therefore, the heat added to the gas (Q) equals the work done:

$$ Q = W = nRT \ln 3 $$

This implies that heat is absorbed from the surroundings to facilitate the expansion at constant temperature.

Calculating the Number of Moles of Gas

To determine specific numerical values, we need to find the number of moles initially present.

Using the ideal gas law:

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

Suppose the initial volume is V_1 (unknown), but since the problem involves ratios, we can express n in terms of V_1:

$$ n = \frac{P_1 V_1}{RT} $$

This generic form allows us to compute work and heat for specific initial volumes if provided.

Alternatively, if the initial volume is known or given, the calculations become straightforward.

Broader Applications and Real-World Relevance

The principles illustrated here extend beyond theoretical exercises and are relevant in numerous practical contexts:

- **Internal Combustion Engines:** Understanding gas expansion during power strokes.
- **Refrigeration Cycles:** Analyzing isothermal and adiabatic processes in compressors and expanders.
- **Industrial Gas Processes:** Managing pressures and volumes in chemical reactors.
- **Atmospheric Science:** Studying gases expanding in the atmosphere due to temperature or pressure changes.

Conclusion

In summary, when a certain gas under a pressure of 5.00 × 10^5 Pa at 25.0°C is allowed to expand to three times its original volume, the process can be described effectively under the assumption of an ideal gas undergoing an isothermal expansion. This results in a proportional decrease in pressure, an increase in volume, and the absorption of heat from the surroundings to perform work during the expansion. Such analyses not only reinforce the fundamental gas laws but also provide valuable insights into thermodynamic processes encountered in various scientific and engineering applications.

Understanding these principles enables scientists and engineers to design systems that efficiently utilize gas behaviors, optimize energy transfer, and predict system responses under different conditions.

Frequently Asked Questions

What is the initial pressure of the gas before expansion?

The initial pressure of the gas is 5.00 × 10 Pa.

To what volume does the gas expand relative to its original volume?

The gas expands to 3.00 times its original volume.

What is the initial temperature of the gas in Celsius?

The initial temperature of the gas is 25.0°C.

What is the initial temperature of the gas in Kelvin?

The initial temperature in Kelvin is 298.15 K (since 25.0°C + 273.15).

Assuming ideal gas behavior, what is the final pressure after expansion?

The final pressure can be calculated using Boyle's Law: $P_1V_1 = P_2V_2$. Since $V_2 = 3V_1$, $P_2 = P_1 / 3.00$ = 5.00 × 10 Pa / 3.00 ≈ 1.67 × 10 Pa.

Does the temperature of the gas change during the

expansion?

It depends on whether the expansion is adiabatic or isothermal; if it is isothermal, the temperature remains constant at 25.0°C. If adiabatic, the temperature may change, but additional data is needed to determine this.

What is the final volume of the gas relative to its original volume?

The final volume is 3.00 times the original volume.

How does the pressure change when the gas expands to three times its original volume at constant temperature?

The pressure decreases proportionally, reducing to one-third of its original pressure if the temperature remains constant.

Which gas law can be used to relate the initial and final states of the gas in this scenario?

Boyle's Law ($P_1V_1 = P_2V_2$) is applicable if the temperature remains constant. For temperature changes, the Combined Gas Law can be used.

What assumptions are made when analyzing the expansion of the gas in this scenario?

Assumptions include that the gas behaves ideally, the process is either isothermal or adiabatic, and external factors like heat exchange are negligible unless specified.

Additional Resources

When A Certain Gas Under A Pressure Of 5.00 × 105 Pa At 25.0°C Is Allowed To Expand To 3.00 Times Its Original

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Introduction: Understanding Gas Behavior and Its Significance

The behavior of gases under varying conditions is a fundamental topic in thermodynamics and physical chemistry. Gases are unique in their ability to expand, compress, and fill available space, making their study vital across fields such as engineering, atmospheric science, and industrial processes. One intriguing aspect of gas behavior involves understanding how a gas responds to changes in volume, pressure, and temperature, especially when it undergoes expansion or compression.

In this context, consider a scenario where a gas initially exists at a pressure of 5.00 × 105 Pa (which equals approximately 5 atmospheres) and a temperature of 25.0°C, and is then allowed to expand until its volume becomes three times its original volume. This situation is not only theoretically interesting but also practically relevant, as it embodies the principles governing real-world processes such as gas storage, engine cycles, and atmospheric phenomena.

The goal of this article is to analyze this process comprehensively, exploring the underlying thermodynamic principles, the relationships between pressure, volume, and temperature, and the implications of such an expansion. We will delve into the ideal gas law, examine the assumptions involved, and consider how temperature and pressure change—or remain constant—in different types of processes.

Fundamental Principles Governing Gas Expansion

The Ideal Gas Law

At the core of understanding gas behavior is the ideal gas law, 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-1 K-1),
- T = temperature in Kelvin.

This law assumes that gas particles do not interact and occupy negligible volume relative to the container, which is a good approximation under many conditions, especially at moderate pressures and temperatures.

Initial Conditions:
- Pressure, $P_1 = 5.00 \times 10^5 \, \text{Pa}$
- Temperature, $T_1 = 25.0^\circ C = 298.15\, \text{K}$

Suppose the initial volume is V_1. We are told that the gas expands to a volume V_2, which is 3.00 times V_1:

$$V_2 = 3V_1$$

Analyzing the Expansion Process

The key question is: what happens to the pressure and temperature of the gas during this expansion? The answer depends on the nature of the process—whether it occurs at constant temperature (isothermal), constant pressure (isobaric), or constant volume (isochoric).

Theoretical scenarios include:
- Isothermal expansion: Temperature remains constant.
- Adiabatic expansion: No heat exchange with surroundings.
- Isobaric expansion: Pressure remains constant.
- Isochoric process: Volume remains constant (not relevant here as the volume changes).

Given the problem states only that the gas expands to three times its original volume, without specifying heat exchange or pressure conditions, we need to analyze various potential scenarios.

Scenario 1: Isothermal Expansion

Definition and Assumptions

- The process occurs at constant temperature ($T_1 = T_2 = 298.15\, \text{K}$).
- Heat exchange with surroundings occurs to maintain this temperature.
- Pressure and volume change according to Boyle’s Law, which states:

$$P_1V_1 = P_2V_2$$

Calculations

Since $V_2 = 3V_1$, the pressure after expansion, P_2, becomes:

$$P_2 = \frac{P_1V_1}{V_2} = \frac{P_1V_1}{3V_1} = \frac{P_1}{3}$$

Plugging in the initial pressure:

$$P_2 = \frac{5.00 \times 10^5\, \text{Pa}}{3} \approx 1.67 \times 10^5\, \text{Pa}$$

Implication:
- The pressure decreases to approximately 1.67 × 105 Pa.
- Temperature remains unchanged at 25°C.
- The gas does work against the surroundings during expansion, and heat must be supplied

to maintain temperature (an isothermal process).

Scenario 2: Adiabatic Expansion

Definition and Assumptions

- No heat exchange with surroundings ($Q = 0$).
- The process is rapid enough that heat transfer is negligible.
- For an ideal gas undergoing adiabatic expansion:

$$PV^\gamma = \text{constant}$$

where $\gamma = \frac{C_p}{C_v}$ is the heat capacity ratio, typically around 1.4 for diatomic gases such as nitrogen or oxygen.

Calculations

Using the adiabatic relation:

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

Rearranged to find P_2:

$$P_2 = P_1 \left(\frac{V_1}{V_2} \right)^\gamma$$

Substituting $V_2 = 3V_1$:

$$P_2 = P_1 \left(\frac{1}{3} \right)^\gamma$$

Assuming $\gamma = 1.4$:

$$P_2 = 5.00 \times 10^5 \times \left(\frac{1}{3} \right)^{1.4}$$

Calculating:

$$\left(\frac{1}{3} \right)^{1.4} \approx e^{1.4 \times \ln(1/3)} \approx e^{1.4 \times (-1.0986)} \approx e^{-1.538} \approx 0.214$$

So,

$$P_2 \approx 5.00 \times 10^5 \times 0.214 \approx 1.07 \times 10^5\, \text{Pa}$$

Temperature change:

Using the adiabatic relation between temperature and volume:

$$ T_2 = T_1 \left(\frac{V_2}{V_1} \right)^{\gamma - 1} $$

$$ T_2 = 298.15 \times 3^{0.4} $$

Calculating:

$$ 3^{0.4} = e^{0.4 \times \ln 3} \approx e^{0.4 \times 1.0986} \approx e^{0.439} \approx 1.55 $$

Thus,

$$ T_2 \approx 298.15 \times 1.55 \approx 462.5\, \text{K} $$

which is approximately 189.35°C.

Implication:
- The temperature increases significantly during adiabatic expansion.
- The pressure drops to about 1.07 × 105 Pa.

This scenario illustrates the inverse relationship between temperature and volume in adiabatic processes: as the gas expands rapidly without heat exchange, it cools or heats depending on the direction of process.

Scenario 3: Isobaric Expansion

Definition and Assumptions

- The pressure remains constant during expansion ($P_1 = P_2$).
- Heat is added or removed to facilitate the change in volume.

Calculations

- Since pressure remains constant, the ideal gas law simplifies:

$$ V_2 = 3V_1 $$

- The temperature after expansion:

$$ T_2 = \frac{P V_2}{n R} $$

But because pressure and moles are constant, the ratio of temperatures is directly proportional to the volume:

$$ \frac{T_2}{T_1} = \frac{V_2}{V_1} = 3 $$

Thus,

$$ T_2 = 3 \times T_1 = 3 \times 298.15\, \text{K} \approx 894.45\, \text{K} $$

which is approximately 621.3°C.

Implication:
- The temperature triples during the process.
- This requires continuous heat input to maintain constant pressure as the gas expands.

Real-World Implications and Applications

Understanding these different scenarios is vital for various practical applications:

- Internal Combustion Engines:
The thermodynamic cycle of engines involves adiabatic compression and expansion, critical for efficiency calculations.

- Industrial Gas Storage:
Gases stored at high pressure may undergo expansion when released, affecting temperature and pressure. Design safety must consider such thermodynamic changes.

- Atmos

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