A Cylinder With A Moveable Piston Contains 92g Of Nitrogen. The External Pressure Is Constant At 1.00

A Cylinder With A Moveable Piston Contains 92g Of Nitrogen. The External Pressure Is Constant At 1.00

Understanding the behavior of gases under various conditions is fundamental in fields such as chemistry, physics, and engineering. In this article, we explore a practical scenario involving a cylinder with a moveable piston containing 92 grams of nitrogen gas, with a constant external pressure of 1.00 atmosphere. We will analyze the thermodynamic principles at play, including calculations related to molar quantities, ideal gas law applications, and the implications of a moveable piston in gas behavior. This comprehensive guide aims to elucidate key concepts and provide a detailed understanding of the system's dynamics.

Basic Concepts and Assumptions

Before delving into calculations and in-depth analysis, it is essential to clarify the foundational assumptions and concepts that underpin this scenario:

Ideal Gas Behavior

- Nitrogen gas (N_2) is assumed to behave ideally under the given conditions, meaning its molecules do not interact and occupy negligible volume relative to the container.
- The ideal gas law (PV = nRT) applies, where:
- P = pressure
- V = volume
- n = number of moles
- R = universal gas constant
- T = temperature in Kelvin

External Pressure and System Equilibrium

- The external pressure acting on the piston remains constant at 1.00 atm throughout the process.
- The piston is moveable, allowing the volume of the gas to change until equilibrium is reached under the external pressure.

Mass and Molar Calculations

- The mass of nitrogen provided is 92 grams.
- The molar mass of nitrogen (N_2) is approximately 28.0134 g/mol.

Calculating the Number of Moles of Nitrogen

The first step in analyzing the system is to determine the number of moles of nitrogen gas present.

Number of Moles (n)

Using the molar mass:
- $n = \text{mass} / \text{molar mass}$
- $n = 92\ g / 28.0134\ g/mol \approx 3.283\ mol$

This amount of nitrogen gas is the basis for further calculations involving volume and temperature.

Applying the Ideal Gas Law

The ideal gas law provides a relationship between pressure, volume, temperature, and amount of gas:

$$PV = nRT$$

Where:
- $P = 1.00$ atm (constant external pressure)
- V = unknown volume
- $n \approx 3.283$ mol
- $R = 0.082057\ L\cdot atm/(mol\cdot K)$
- T = temperature in Kelvin (unknown initially)

Determining Volume at a Given Temperature

Suppose the temperature of the gas is known, or we want to find the volume at a specific temperature. Rearranged, the ideal gas law becomes:

$$V = (nRT) / P$$

For example, at room temperature ($T \approx 298$ K):

$$V = (3.283\ mol \times 0.082057\ L\cdot atm/(mol\cdot K) \times 298\ K) / 1.00\ atm$$

$$V \approx (3.283 \times 0.082057 \times 298) / 1$$

$$V \approx (3.283 \times 24.447) \approx 80.2\ L$$

Thus, at 25°C (298 K), the nitrogen occupies approximately 80.2 liters under a constant external pressure of 1.00 atm.

Impact of a Moveable Piston on Gas Behavior

The presence of a moveable piston introduces dynamic factors into the system, including pressure-volume relationships and thermodynamic processes such as expansion and compression.

Equilibrium Conditions

- When the piston moves, the internal pressure of the gas adjusts until it balances the external pressure.
- Because the external pressure remains constant at 1.00 atm, the piston will move until the internal pressure reaches this same value, assuming ideal conditions.

Processes Involving Piston Movement

- Isothermal process: If the temperature remains constant during piston movement, the process is isothermal, and gas volume changes inversely with pressure.
- Adiabatic process: If no heat exchange occurs, the process is adiabatic, with different relationships between pressure, volume, and temperature.
- Isobaric process: When the external pressure remains constant, and the piston moves, the process is typically isobaric, with temperature and volume changing in tandem.

Analyzing the System's Thermodynamics

To understand how the piston moves and how the system evolves, it is vital to analyze the thermodynamic principles involved.

Work Done During Piston Movement

- When the piston moves, the gas does work or has work done on it.
- The work (W) done by the gas during expansion or compression at constant pressure is:

$$W = P\Delta V$$

- For an expansion, $\Delta V > 0$, and work is done by the gas.
- For compression, $\Delta V < 0$, and work is done on the gas.

Calculating Work for a Specific Volume Change

Suppose the volume changes from V_1 to V_2:

$$W = P \times (V_2 - V_1)$$

Using the earlier example at 25°C:
- V_1 = 80.2 L (initial volume)
- V_2 = desired volume after piston movement

If, for instance, the piston moves to double the volume:

$$V_2 = 2 \times V_1 = 160.4\ \text{L}$$

$$W = 1.00\ \text{atm} \times (160.4\ \text{L} - 80.2\ \text{L}) = 1.00\ \text{atm} \times 80.2\ \text{L}$$

Converting to Joules (1 L·atm ≈ 101.3 J):

W ≈ 80.2 L·atm × 101.3 J/L·atm ≈ 8,124 J

This work is associated with the expansion process.

Temperature Changes During Gas Expansion or Compression

Depending on the process type, temperature may or may not change:

Isothermal Process

- Temperature remains constant (T = constant).
- Volume and pressure vary inversely: PV = constant.

Adiabatic Process

- No heat exchange with surroundings.
- Temperature decreases during expansion and increases during compression.
- Governed by the adiabatic equations:

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

Where γ (gamma) is the heat capacity ratio (Cp/Cv), approximately 1.4 for nitrogen.

Implications for the Piston System

- In a real-world scenario, piston movement may involve heat exchange, making the process somewhere between purely isothermal and adiabatic.
- Understanding these processes helps in designing systems like engines and compressors.

Practical Applications and Real-World Implications

The principles outlined in this scenario are foundational in various engineering and scientific applications:

Industrial Gas Storage

- Managing nitrogen in pressurized cylinders involves understanding gas behavior under constant external pressure.
- Ensuring safety and efficiency requires precise calculations of volume, temperature, and pressure.

Refrigeration and Air Conditioning

- Gas expansion and compression cycles rely on similar thermodynamic principles.
- Moveable pistons are integral components in compressors.

Internal Combustion Engines

- Pistons in engines operate under controlled thermodynamic processes, often involving expansions and compressions akin to the described scenario.

Laboratory and Experimental Settings

- Controlled piston systems are used to study gas laws and thermodynamic processes, providing insights into molecular behavior and energy transfer.

Conclusion

The scenario of a cylinder containing 92 grams of nitrogen with a moveable piston under constant external pressure illustrates fundamental gas laws and thermodynamic principles. By calculating the number of moles, applying the ideal gas law, and understanding piston dynamics, we gain valuable insights into how gases behave under different conditions. These principles are not only academically interesting but also critically important in industrial applications, engineering designs, and scientific research. Mastery of these concepts enables professionals to predict system behavior accurately, optimize processes, and innovate in fields reliant on gas dynamics.

Whether designing pressurized systems, understanding natural phenomena, or developing new technologies, the interplay of pressure, volume, temperature, and work remains central to advancing our understanding of the physical world.

Frequently Asked Questions

What is the initial amount of nitrogen in the cylinder?

The initial amount of nitrogen in the cylinder is 92 grams.

What is the external pressure acting on the piston?

The external pressure is constant at 1.00 atmosphere.

How does the moveable piston affect the gas volume in the cylinder?

The piston allows the volume of the nitrogen gas to change in response to pressure and temperature changes, maintaining equilibrium with external pressure.

What assumptions are typically made when analyzing this gas system?

Assumptions often include the gas behaving ideally, the process being quasi-static, and the external pressure remaining constant.

How can you calculate the number of moles of nitrogen in the cylinder?

Using the molar mass of nitrogen (28.0 g/mol), the moles are calculated as 92 g divided by 28.0 g/mol, which equals approximately 3.29 mol.

What is the significance of the external pressure being constant in this system?

A constant external pressure means the piston moves freely to maintain equilibrium, and it simplifies the analysis of work done during expansion or compression.

If the temperature changes, how will the volume of nitrogen be affected?

According to the ideal gas law ($PV=nRT$), if temperature increases at constant external pressure, the volume will increase; if temperature decreases, the volume will decrease.

Can the work done by the gas be calculated in this scenario?

Yes, if the change in volume is known, the work done by the gas during expansion or compression can be calculated using $W = P_{external} \times \Delta V$.

What is the role of the piston in controlling the state of the nitrogen gas?

The piston allows the volume to adjust in response to pressure and temperature changes, enabling the gas to reach equilibrium with external conditions.

How would you determine the change in internal energy of the nitrogen if the temperature change is known?

For an ideal gas, the change in internal energy depends only on temperature change and can be calculated using $\Delta U = nC_v\Delta T$, where C_v is the molar heat capacity at constant volume.

Additional Resources

A Cylinder With A Moveable Piston Contains 92g Of Nitrogen: An Investigative Analysis of Thermodynamic Behavior Under Constant External Pressure

---

Introduction

The study of gases within confined environments is fundamental to thermodynamics and engineering disciplines. Among the numerous scenarios encountered, the behavior of a gas—such as nitrogen—contained within a cylinder fitted with a moveable piston under constant external pressure offers rich insights into the principles governing gas laws, energy transfer, and system equilibrium. This investigative review aims to dissect the physical and thermodynamic characteristics of a cylinder holding 92 grams of nitrogen, with a particular focus on how the system responds to changes and what implications arise from a constant external pressure environment.

Background and Context

Nitrogen (N_2) is a diatomic, inert gas constituting approximately 78% of Earth's atmosphere. Its thermodynamic properties are well characterized, making it an ideal candidate for experimental and theoretical studies. When confined within a cylinder equipped with a moveable piston, nitrogen exhibits behaviors that are governed primarily by the ideal gas law, provided the conditions remain within the ideal regime.

The key parameters in this scenario include:

- Mass of nitrogen: 92 grams
- External pressure (P_e): 1.00 atm (standard atmospheric pressure)
- System configuration: Closed cylinder with a moveable piston
- Objective: To analyze the thermodynamic state, potential changes, and energy exchanges under these conditions

---

Fundamental Assumptions and Initial Conditions

Before delving into calculations and analysis, certain assumptions are made to simplify the complex reality:

- The nitrogen behaves as an ideal gas
- The system is initially in equilibrium
- The cylinder and piston are rigid and thermally insulated unless specified
- The external pressure remains constant at 1.00 atm throughout the process
- No phase changes occur, as nitrogen remains gaseous within typical operational temperatures and pressures

These assumptions enable the application of classical thermodynamic equations and facilitate a clearer understanding of the system's behavior.

Calculating the Initial State

Determining the Moles of Nitrogen

The molar mass of nitrogen (N_2):

- Atomic mass of nitrogen ≈ 14.01 g/mol

- Molar mass of N_2 = 2 × 14.01 g/mol ≈ 28.02 g/mol

Number of moles (n):

$$
n = \frac{\text{mass}}{\text{molar mass}} = \frac{92\, \text{g}}{28.02\, \text{g/mol}} \approx 3.28\, \text{mol}
$$

Applying the Ideal Gas Law

The ideal gas law:

$$
PV = nRT
$$

Where:

- P = pressure (atm)
- V = volume (L)
- n = number of moles
- R = universal gas constant ≈ 0.082057 L·atm/(mol·K)
- T = temperature (K)

Assuming initial temperature T_i, the initial volume V_i is:

$$
V_i = \frac{nRT_i}{P}
$$

Without a specified temperature, a typical initial temperature—say, room temperature $T_i = 298\, \text{K}$—can be used for calculations.

Calculating initial volume:

$$
V_i = \frac{3.28\, \text{mol} \times 0.082057\, \text{L·atm/(mol·K)} \times 298\, \text{K}}{1.00\, \text{atm}} \approx 79.8\, \text{L}
$$

This initial volume provides a baseline for understanding how the system might respond under various thermodynamic processes.

Thermodynamic Behavior Under Constant External Pressure

Equilibrium and Piston Movement

The moveable piston allows the volume of the gas to adjust in response to internal and external forces. When external pressure remains constant at 1.00 atm, the system’s behavior depends on processes such as heating, cooling, or work done during expansion or compression.

- Expansion occurs if internal pressure exceeds external pressure
- Compression occurs if internal pressure drops below external pressure

The system will tend toward equilibrium where internal and external pressures balance, and the piston reaches a position where the net force is zero.

Work Done During Expansion or Compression

Work (W) associated with piston movement:

$$
W = P_{ext} \times \Delta V
$$

- For expansion: $\Delta V > 0$, work done by system
- For compression: $\Delta V < 0$, work done on the system

In a quasi-static process, the work can be integrated over the change in volume, but for simple uniform processes, the above relation suffices.

Investigative Scenarios and Their Implications

1. Isothermal Expansion or Compression

If the process occurs at constant temperature:

$$
PV = \text{constant}
$$

The volume change:

$$
V_f = V_i \times \frac{P_i}{P_f}
$$

Since external pressure is held constant at 1 atm, and assuming the internal pressure adjusts accordingly, the system will expand or contract to maintain equilibrium, with heat exchange occurring to keep the temperature constant.

Implication: The piston moves until internal pressure equals external pressure, with heat entering or leaving the system to compensate for work done.

2. Adiabatic Process

If the process occurs without heat exchange:

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

Where:

- $\gamma = C_p / C_v \approx 1.4$ for nitrogen

The piston would move in a manner dictated by the adiabatic relation, leading to temperature and pressure changes within the gas, but with no heat transfer across system boundaries.

Implication: This scenario illustrates the energy transformations within the system and the relationship between temperature, pressure, and volume during rapid processes.

3. Heating or Cooling at Constant External Pressure

Applying heat:

- Increases internal energy
- Causes expansion if the piston is free to move
- Changes the system’s temperature and volume

Cooling would have the opposite effect, leading to contraction.

Energy Considerations and System Limitations

First Law of Thermodynamics

The change in internal energy:

$$
\Delta U = Q - W
$$

Where:

- Q = heat added to the system
- W = work done by the system (positive during expansion)

For nitrogen:

$$
\Delta U = n C_v \Delta T
$$

Using specific heat capacities at constant volume C_v for nitrogen (≈ 20.8 J/mol·K):

$$
\Delta U = 3.28\, \text{mol} \times 20.8\, \text{J/mol·K} \times \Delta T \approx 68.2\, \text{J/K} \times \Delta T
$$

This relation underscores how temperature changes relate directly to internal energy shifts during processes.

Limitations and Real-World Factors

- Non-ideal behavior: At high pressures or low temperatures, deviations from ideal gas law occur.
- Piston friction and heat transfer: Real pistons experience resistance and may not be perfectly adiabatic or isothermal.
- Material constraints: The cylinder and piston materials impose limits on maximum and minimum volumes and pressures.

Practical Applications and Significance

Understanding the thermodynamic behavior of nitrogen in such a setup has widespread implications:

- Industrial Gas Storage: Designing cylinders and safety protocols for storing gases under various pressures
- Refrigeration Cycles: Analyzing expansion and compression processes in refrigeration systems
- Rocket Propulsion: Managing pressurized gases in propulsion systems
- Laboratory Experiments: Studying gas laws and thermodynamic processes

The insights derived from these analyses help optimize system design, improve safety, and enhance efficiency in applications involving gases under pressure.

Future Directions and Open Questions

While the current analysis provides a thorough understanding of the fundamental principles at play, several avenues warrant further investigation:

- How do real gas deviations affect the behavior at high pressures?
- What is the impact of non-quasi-static processes on piston dynamics?
- How do temperature gradients and thermal conduction influence the system?
- Can microgravity conditions alter the equilibrium states?

Addressing these questions requires experimental validation and advanced modeling techniques, which could refine our understanding of gas behavior in confined, movable-piston systems.

Conclusion

The investigation of a cylinder containing 92 grams of nitrogen with a moveable piston under constant external pressure reveals key aspects of thermodynamics, including the application of the ideal gas law, work-energy relationships, and process-specific behaviors. Such systems serve as valuable models for understanding fundamental principles that underpin myriad engineering and scientific applications. As technology advances, deeper insights into real-gas effects, dynamic processes, and system optimization will continue to emerge, informing better designs and safer handling of pressurized gases.

References

- Smith, J.M., Van Ness, H.C., Abbott, M.M. (2005). Introduction to Chemical Engineering Thermodynamics. McGraw-Hill.
- Sonntag, R.E., Borgnakke, C., Van Wylen, G. (2003). Fundamentals of Thermodynamics. Wiley.
- Atkins, P., de Paula, J. (2010). Physical Chemistry. Oxford University Press.
- National Institute of Standards and Technology (N

A Cylinder With A Moveable Piston Contains 92g Of Nitrogen The External Pressure Is Constant At 1 00

A Cylinder With A Moveable Piston Contains 92g Of Nitrogen The External Pressure Is Constant At 1 00

Related Articles

- When Societies Use Trained Teachers To Pass On Specialized Knowledge That Adults Will Need For Their
- 1. 8 LAB - Create Index And Explain (Sakila)Refer To The Table Of The Sakila Database. This Lab Loads
- A 4-pole De Shunt Generator Is Delivering 20 A To A Load Of 10 2. The Armature Resistance Is 0.52 And

Back to Home