In A Cylinder, 1.20mol Of An Ideal Monatomic Gas, Initially At 3.6010^5pa And 300k, Expands Until Its

In A Cylinder, 1.20mol Of An Ideal Monatomic Gas, Initially At 3.60×10^5 Pa And 300 K, Expands Until Its state changes, offering a fascinating insight into thermodynamic processes involving ideal gases. Understanding such expansions is fundamental in thermodynamics, with applications spanning engines, refrigerators, and various industrial processes. This comprehensive article explores the principles governing the expansion of an ideal monatomic gas in a cylinder, detailing the physics, calculations, and implications involved.

Understanding the Basics: Ideal Monatomic Gases

What Is an Ideal Gas?

An ideal gas is a theoretical gas composed of many randomly moving point particles that interact only through elastic collisions. These particles are considered to have negligible volume, and the interactions between them are assumed to be nonexistent except during collisions.

Characteristics of Monatomic Gases

Monatomic gases consist of single-atom particles, such as helium, neon, or argon. Their simplicity allows for straightforward analysis using kinetic theory and thermodynamics. Key properties include:

- Degrees of freedom: 3 (translation in x, y, z)
- Specific heat capacities: $C_v = \frac{3}{2} R$, $C_p = \frac{5}{2} R$
- Internal energy: depends solely on temperature, given by $U = \frac{3}{2} nRT$

Initial Conditions of the Gas

Given Data

- Number of moles, $n = 1.20\, mol$
- Initial pressure, $P_i = 3.60 \times 10^5\, Pa$
- Initial temperature, $T_i = 300\, K$

Initial State Calculations

Using the ideal gas law: $PV = nRT$

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

Plugging in values:

$$
V_i = \frac{(1.20)(8.314)(300)}{3.60 \times 10^5} \approx 8.28 \times 10^{-3}\, m^3
$$

This initial volume provides the starting point for analyzing the expansion.

Types of Thermodynamic Processes in Gas Expansion

Understanding how the gas expands involves recognizing the process type, which could be one of the following:

Isothermal Expansion

- Temperature remains constant ($T = T_i = T_f$)
- Heat exchange occurs to maintain temperature
- Work done by the gas equals the heat absorbed

Adiabatic Expansion

- No heat exchange ($Q = 0$)
- Temperature decreases as the gas expands
- Governed by the adiabatic process equations

Polytropic Expansion

- General process where $PV^n = \text{constant}$
- The value of n determines the nature of the process:
- $n=1$: Isothermal
- $n=\gamma = \frac{5}{3}$ for monatomic gases: Adiabatic

Determining which process occurs depends on experimental or specified conditions, which are often part of thermodynamic problems.

Analyzing the Expansion: Key Thermodynamic Principles

Work Done During Expansion

The work done by the gas during expansion from initial to final volume:

$$
W = \int_{V_i}^{V_f} P\, dV
$$

For specific process types, formulas vary:

- Isothermal:

$$
W_{iso} = nRT \ln \frac{V_f}{V_i}
$$

- Adiabatic:

$$
W_{ad} = \frac{P_i V_i - P_f V_f}{\gamma - 1}
$$

where $\gamma = \frac{C_p}{C_v} = \frac{5}{3}$ for monatomic gases.

Change in Internal Energy

The internal energy change:

$$
\Delta U = \frac{3}{2} n R (T_f - T_i)
$$

Since internal energy depends only on temperature for ideal gases, knowing the temperature change is crucial.

Heat Transfer

Depending on the process:

- Isothermal: $Q = W$
- Adiabatic: $Q = 0$
- Polytropic: Q varies and can be calculated if process parameters are known.

Final State of the Gas: Calculation Scenarios

Depending on the nature of the expansion process, different outcomes are possible.

Scenario 1: Isothermal Expansion

- Temperature remains constant at 300 K.
- Final volume:

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

- Final pressure:

$$
P_f = \frac{nRT}{V_f}
$$

If the gas expands until the pressure drops to a specified final pressure P_f, calculations can be made accordingly.

Scenario 2: Adiabatic Expansion

- Final temperature:

$$
T_f = T_i \left(\frac{V_i}{V_f}\right)^{\gamma - 1}
$$

- Final pressure:

$$
P_f = P_i \left(\frac{V_i}{V_f}\right)^\gamma
$$

- Final volume:

$$
V_f = V_i \left(\frac{P_i}{P_f}\right)^{1/\gamma}
$$

These equations assume the process is adiabatic and reversible.

Calculations for a Typical Expansion

Suppose the gas expands adiabatically until its pressure drops to $1.0 \times 10^5\, Pa$.

Step 1: Calculate the final volume:

$$
V_f = V_i \left(\frac{P_i}{P_f}\right)^{1/\gamma}
$$

$$
V_f = 8.28 \times 10^{-3} \times \left(\frac{3.60 \times 10^5}{1.0 \times 10^5}\right)^{3/5} \approx 8.28 \times 10^{-3} \times (3.6)^{0.6}
$$

$$
V_f \approx 8.28 \times 10^{-3} \times 2.11 \approx 0.0175\, m^3
$$

Step 2: Calculate the final temperature:

$$
T_f = T_i \left(\frac{V_i}{V_f}\right)^{\gamma - 1} = 300 \times \left(\frac{8.28 \times 10^{-3}}{0.0175}\right)^{2/3}
$$

$$
T_f = 300 \times (0.473)^{0.666} \approx 300 \times 0.597 \approx 179\, K
$$

Step 3: Calculate work done:

$$
W = \frac{P_i V_i - P_f V_f}{\gamma - 1}
$$

$$
W = \frac{(3.60 \times 10^5)(8.28 \times 10^{-3}) - (1.0 \times 10^5)(0.0175)}{2/3}
$$

$$
W = \frac{2978 - 1750}{0.666} \approx \frac{1228}{0.666} \approx 1844\, J
$$

This work is done by the gas during expansion.

Implications and Applications of Gas Expansion

Understanding the thermodynamics of gas expansion is vital in various engineering and scientific fields:

- **Engine Cycles:** Internal combustion engines rely on adiabatic expansion of gases to do work.
- **Refrigeration:** Compression and expansion cycles involve similar principles to transfer heat.
- **Industrial Processes:** Gas turbines, jet engines, and turbines operate on controlled expansions of gases.
- **Energy Efficiency:** Analyzing work and heat during expansion helps optimize energy conversion processes.

Environmental considerations also play a role, as efficient gas expansions can reduce energy consumption and mitigate environmental impact.

Conclusion

The expansion of an ideal monatomic gas in a cylinder encapsulates fundamental thermodynamic principles and highlights the importance of understanding process types—whether isothermal, adiabatic, or polytropic. By applying the ideal gas law, equations for work, heat transfer, and internal energy change, engineers and scientists can predict and optimize these processes for practical applications. The scenario considered—initial conditions, process type, and final states—serves as a foundation for more complex thermodynamic analyses and real-world system design. Whether in engines, refrigerators, or energy systems, mastering the principles of gas expansion remains essential for advancing technology and efficiency.

Keywords: ideal gas, monatomic gas, thermodynamics, adiabatic process,

Frequently Asked Questions

What is the initial state of the ideal monatomic gas in the cylinder?

The initial state has 1.20 mol of the gas at a pressure of 3.6×10^5 Pa and a temperature of 300 K.

How can the work done by the gas during expansion be calculated?

For an ideal gas expanding at constant pressure, the work done is $W = P\Delta V$, where ΔV is the change in volume, which can be found using the ideal gas law.

What is the significance of the gas being monatomic in thermodynamic calculations?

Monatomic gases have specific heat capacities (C_v and C_p) that are lower compared to polyatomic gases, influencing calculations of heat transfer and internal energy during expansion.

How do you determine the final temperature of the gas after expansion if the process is adiabatic?

In an adiabatic process for a monatomic ideal gas, the final temperature T_2 can be found using $T_2 = T_1 (V_1/V_2)^{(\gamma - 1)}$, where $\gamma = 5/3$.

What is the role of the ideal gas law in understanding the expansion process?

The ideal gas law (PV = nRT) relates pressure, volume, and temperature, allowing calculation of changes in state variables during expansion.

How does the number of moles (1.20 mol) influence the thermodynamic calculations of the gas expansion?

The number of moles determines the total amount of substance involved, directly affecting calculations of internal energy, work, and heat exchange during the expansion.

Additional Resources

In A Cylinder, 1.20 mol Of An Ideal Monatomic Gas, Initially At 3.6010^5 Pa And 300 K, Expands Until Its

Understanding the thermodynamics of gases is fundamental to many fields of science and engineering, from designing engines to predicting atmospheric phenomena. When analyzing the behavior of gases contained within a cylinder, especially during expansion processes, it is crucial to consider the properties of the gas, the nature of the process, and how various parameters change. In this article, we will undertake a comprehensive exploration of a scenario involving In A Cylinder, 1.20 mol Of An Ideal Monatomic Gas, Initially At 3.6010^5 Pa And 300 K, Expands Until Its — delving into the thermodynamic principles, calculations, and implications of such an expansion.

Setting the Stage: The Scenario and Its Significance

Imagine a cylinder sealed with a movable piston containing 1.20 mol of an ideal monatomic gas. The initial conditions are a pressure of approximately 3.6 × 10^5 Pa and a temperature of 300 K. The gas undergoes an expansion process—possibly isothermal, adiabatic, or otherwise—until certain final conditions are reached. Such analyses are not mere academic exercises; they model practical situations like the operation of internal combustion engines, refrigeration cycles, and even natural phenomena.

At the core of this scenario lies the question: What happens during the expansion? To answer this, we need to:

- Identify the nature of the process (is it isothermal, adiabatic, isobaric, or a polytropic process?)
- Calculate the work done by or on the gas
- Determine the heat exchanged with the surroundings

- Find the change in internal energy
- Understand the implications for entropy and other thermodynamic properties

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Thermodynamic Foundations: Key Concepts and Equations

Before diving into calculations, it's essential to review the fundamental thermodynamic principles and equations applicable to ideal monatomic gases.

Ideal Gas Law

The initial state of the gas is characterized by the ideal gas law:

$$PV = nRT$$

where:
- P = pressure (Pa)
- V = volume (m^3)
- n = number of moles (mol)
- R = universal gas constant = 8.314 J/(mol·K)
- T = temperature (K)

Given initial conditions, the initial volume V_i can be calculated as:

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

Internal Energy of a Monatomic Gas

For an ideal monatomic gas, the internal energy U depends solely on temperature:

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

Thus, any change in internal energy ΔU during the process is:

$$\Delta U = U_f - U_i = \frac{3}{2} n R (T_f - T_i)$$

where T_f and T_i are the final and initial temperatures, respectively.

Work Done by the Gas

The work W done during expansion depends on the process path:

- Isothermal (constant T):

$$W = nRT \ln \frac{V_f}{V_i}$$

- Adiabatic (no heat exchange, $Q=0$):

$$W = \frac{P_i V_i - P_f V_f}{\gamma - 1}$$

where $\gamma = C_p/C_v$ (for monatomic gases, $\gamma = 5/3$).

- General polytropic process:

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

and the work:

$$W = \frac{P_f V_f - P_i V_i}{1 - n}$$

Step-by-Step Analysis of the Expansion Process

The nature of the expansion—whether it is isothermal, adiabatic, or a different kind—will determine the specific calculations. For the purpose of this guide, we'll analyze several common scenarios, providing formulas and reasoning for each.

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1. Isothermal Expansion

Assumption: The temperature remains constant at 300 K during the expansion.

Step 1: Calculate Initial Volume V_i

Using the ideal gas law:

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

Substitute the known values:

$$V_i = \frac{(1.20\, \text{mol})(8.314\, \text{J/(mol·K)})(300\, \text{K})}{3.601 \times 10^5\, \text{Pa}}$$

Calculations:

$$ V_i = \frac{(1.20)(8.314)(300)}{3.601 \times 10^5} $$

$$ V_i \approx \frac{2990.5}{360100} $$

$$ V_i \approx 8.30 \times 10^{-3}\, \text{m}^3 $$

Step 2: Determine Final Volume V_f

In an isothermal process, T remains constant, so:

$$ P_i V_i = P_f V_f $$

If the final pressure P_f is known, the final volume:

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

Alternatively, if the process ends at a certain volume or pressure, you can determine the other. Suppose the expansion ends at a lower pressure P_f, say $1.0 \times 10^5\, \text{Pa}$:

$$ V_f = \frac{3.601 \times 10^5 \times 8.30 \times 10^{-3}}{1.0 \times 10^5} $$

$$ V_f \approx 2.99 \times 10^{-2}\, \text{m}^3 $$

Step 3: Calculate Work Done

$$ W = nRT \ln \frac{V_f}{V_i} $$

$$ W = 1.20 \times 8.314 \times 300 \times \ln \left(\frac{V_f}{V_i} \right) $$

$$ W \approx 2990.5 \times \ln \left(\frac{2.99 \times 10^{-2}}{8.30 \times 10^{-3}} \right) $$

$$ W \approx 2990.5 \times \ln (3.60) $$

$$ W \approx 2990.5 \times 1.280 $$

$$ W \approx 3830\, \text{J} $$

Interpretation: The gas does approximately 3830 J of work during this expansion, which is supplied by an external source or results from the external work done during the process.

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2. Adiabatic Expansion

Assumption: No heat exchange with surroundings ($Q=0$).

For an adiabatic process involving an ideal monatomic gas:

$$TV^{\gamma -1} = \text{constant}$$
$$PV^{\gamma} = \text{constant}$$

where:

$$\gamma = \frac{5}{3} \approx 1.6667$$

Step 1: Find Final Temperature T_f

Using the adiabatic relation:

$$T_f = T_i \left(\frac{V_i}{V_f} \right)^{\gamma -1}$$

or equivalently, using pressure and volume:

$$T_f = T_i \left(\frac{P_f}{P_i} \right)^{(\gamma -1)/\gamma}$$

Suppose the final pressure is $1.0 \times 10^5\, \text{Pa}$, then:

$$T_f = 300 \left(\frac{1.0 \times 10^5}{3.601 \times 10^5} \right)^{(0.6667)/1.6667}$$

$$T_f = 300 \times (0.278)^{0.4}$$

$$T_f \approx 300 \times 0.606$$

$$T_f \approx 181.8\, \text{K}$$

The temperature drops during the expansion, as expected for adiabatic expansion.

Step 2: Calculate Work Done W

The work done during an adiabatic process:

$$W = \frac{P_i V_i - P_f V_f}{\gamma - 1}$$

Alternatively, using the relation:

$$W = \frac{n R (T_i - T_f)}{\gamma - 1}$$

Calculate T_f as above, then:

$$W = \frac{1.20 \times 8.314 \times (300 - 181.8)}{0.6667}$$

$$W \approx \frac{1.20 \times 8.314 \times 118.2}{0.6667}$$

$$W \approx \frac{1181.4}{0.6667}$$

$$W \approx 1772\, \text{J}$$

Since the process involves expansion, the work is done by the gas, totaling approximately 1772 J.

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