A Gas Expands From A Volume Of 3.0 Dm3 To 5.0 Dm3 Against A Constant Pressure Of 3.0 Atm. The Work Done

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Introduction

Understanding the work done during the expansion of a gas is fundamental in thermodynamics. When a gas expands or compresses, it exchanges energy with its surroundings, and this exchange can be quantified as work. In this article, we explore a specific scenario where a gas expands from a volume of 3.0 dm³ to 5.0 dm³ against a constant pressure of 3.0 atm. We will analyze how to calculate the work done during this process, interpret the physical significance, and relate the calculation to thermodynamic principles.

Basic Concepts in Gas Expansion and Work

What is Work in Thermodynamics?

In thermodynamics, work (W) is defined as the energy transferred when a force acts over a distance. For gases, work is often associated with volume change when the gas expands or compresses against an external pressure. Mathematically, the work done by the gas during expansion or compression at constant pressure is expressed as:

\[W = P \Delta V \]

where:
- \(W \) = work done by the gas (in joules, J)
- \(P \) = external (or constant) pressure (in pascals, Pa)
- \(\Delta V \) = change in volume (in cubic meters, m³)

Units and Conversion Factors

Since in the problem, volumes are given in cubic decimeters (dm³) and pressure in atmospheres (atm), it is necessary to convert these units into SI units for consistent calculations:
- 1 dm³ = 0.001 m³
- 1 atm = 101,325 Pa

Understanding these conversions ensures accurate calculation of work done.

The Scenario: Gas Expansion at Constant Pressure

Initial and Final Conditions

Given:
- Initial volume, \(V_i = 3.0 \, \text{dm}^3 \)
- Final volume, \(V_f = 5.0 \, \text{dm}^3 \)
- External pressure, \(P = 3.0 \, \text{atm} \)

The process involves the gas expanding from the initial to the final volume against a constant external pressure.

Significance of Constant Pressure Process

A constant pressure expansion is a common thermodynamic process called an isobaric process. It simplifies calculations because the work done depends solely on the change in volume and the constant pressure.

Calculating the Work Done During Expansion

Step 1: Convert Units

Convert volumes from dm³ to m³:
- $V_i = 3.0 \, \text{dm}^3 = 3.0 \times 0.001 = 0.003 \, \text{m}^3$
- $V_f = 5.0 \, \text{dm}^3 = 5.0 \times 0.001 = 0.005 \, \text{m}^3$

Convert pressure from atm to Pa:
- $P = 3.0 \, \text{atm} = 3.0 \times 101,325 = 303,975 \, \text{Pa}$

Step 2: Calculate Change in Volume

$$\Delta V = V_f - V_i = 0.005 \, \text{m}^3 - 0.003 \, \text{m}^3 = 0.002 \, \text{m}^3$$

Step 3: Use the Work Formula

$$W = P \times \Delta V$$

Plugging in the values:

$$W = 303,975 \, \text{Pa} \times 0.002 \, \text{m}^3 = 607.95 \, \text{J}$$

Step 4: Interpret the Result

Since the gas is expanding, the work done by the gas on the surroundings is positive:

$$
\boxed{
W \approx 608 \, \text{J}
}
$$

This indicates that approximately 608 joules of work are done by the gas during the expansion process.

Significance of the Work Done in Thermodynamic Context

Work and Energy Transfer

The work done during expansion signifies energy transferred from the gas to the surroundings. This is crucial in understanding how gases perform work in engines, turbines, and various thermodynamic systems.

Relationship with Heat and Internal Energy

In an idealized process, the work done is often coupled with heat transfer (Q) and change in internal energy (ΔU). The first law of thermodynamics states:

\[

$$
\Delta U = Q - W
$$

Understanding the work component helps in analyzing the energy balance in thermodynamic systems.

Additional Considerations

Non-Ideal Gas Behavior

The calculation above assumes ideal gas behavior, where pressure, volume, and temperature are related via the ideal gas law. In real gases, deviations might occur, but for many practical purposes, ideal assumptions are sufficient.

Effect of Temperature

While the problem specifies constant pressure and volume change, temperature may change during expansion. However, since work depends only on the pressure and volume change, temperature variations do not affect the work calculation directly in this idealized scenario.

Expansion Against Variable Pressure

If the pressure were not constant, calculating work would require integration:

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

where $P(V)$ is the pressure as a function of volume. For constant pressure, integration simplifies to the straightforward product shown above.

Practical Applications of Gas Expansion and Work Calculation

Internal Combustion Engines

Understanding the work done during gas expansion helps in analyzing engine efficiency, where gases expand during combustion to produce mechanical work.

Refrigeration Cycles

In refrigeration cycles, gases undergo expansion and compression, and calculating work is essential for energy efficiency analysis.

Industrial Gas Processes

Designing processes such as gas turbines or pneumatic systems hinges on precise calculations of work during gas expansion or compression.

Summary

- The expansion of a gas from 3.0 dm^3 to 5.0 dm^3 against a constant pressure of 3.0 atm results in approximately 608 joules of work done by the gas.
- The calculation involves converting units to SI, applying the formula $W = P \times \Delta V$, and understanding the physical context.

- This process exemplifies fundamental thermodynamic principles, illustrating how energy transfer manifests as work during volume changes.

Conclusion

Calculating the work done during gas expansion is a vital aspect of thermodynamics, providing insights into energy transfer and system efficiency. In the scenario discussed, the straightforward application of the work formula under constant pressure conditions offers a clear understanding of how gases perform work during volume changes. Such calculations are indispensable across various scientific and engineering disciplines, underpinning the design and analysis of numerous thermal systems.

Frequently Asked Questions (FAQs)

1. Why is the work done positive during expansion?

Because the gas is doing work on the surroundings as it expands, energy leaves the gas, resulting in positive work output.

2. Can work be negative during gas compression?

Yes. During compression, the surroundings do work on the gas, and the work done by the gas is negative, indicating energy transfer into the gas.

3. How does temperature affect the work done?

In an ideal gas at constant pressure, temperature changes are related to volume change via the ideal gas law. However, the work depends only on pressure and volume change, not directly on temperature.

4. What if the pressure were not constant?

If pressure varies during expansion, the work calculation requires integrating the pressure over the volume change, which could involve more complex calculations depending on the process specifics.

By mastering these principles and calculations, students and professionals can better analyze thermodynamic systems involving gas expansion, leading to more efficient designs and a deeper understanding of energy transfer processes.

Frequently Asked Questions

What is the formula to calculate the work done during gas expansion at constant pressure?

The work done (W) is given by $W = P \times \Delta V$, where P is the constant pressure and ΔV is the change in volume.

How do you convert the volume from dm^3 to liters in this problem?

Since 1 dm^3 equals 1 liter, the volumes are already in liters: initial volume = 3.0 L, final volume = 5.0 L.

What is the change in volume (ΔV) during the expansion?

ΔV = final volume - initial volume = 5.0 dm^3 - 3.0 dm^3 = 2.0 dm^3.

How do you convert the pressure from atm to SI units for work calculation?

Since work is typically calculated in liter·atm units, and pressure is given in atm, no conversion is needed for units involving atm and liters.

Calculate the work done during the gas expansion.

Work done $W = P \times \Delta V$ = 3.0 atm × 2.0 dm^3 = 6.0 liter·atm.

What is the significance of the work done in the context of thermodynamics?

The work done represents the energy transferred by the gas as it expands against the constant pressure.

How can the work done be expressed in joules?

Using the conversion 1 liter·atm ≈ 101.3 joules, W = 6.0 liter·atm × 101.3 J/liter·atm ≈ 607.8 J.

What assumptions are made in calculating work done in this scenario?

Assumptions include that the process is quasi-static (reversible), the pressure remains constant, and the gas behaves ideally.

If the pressure was not constant, how would the work calculation change?

The work would need to be calculated using the integral $W = \int P \, dV$ over the volume change, accounting for how pressure varies during expansion.

Why is understanding work done important in thermodynamics and practical applications?

It helps quantify energy transfer during processes like expansion and compression, essential for engines, refrigerators, and other thermodynamic systems.

Additional Resources

Work Done in a Gas Expansion at Constant Pressure: An In-Depth Analysis

Understanding the work done during the expansion of a gas is fundamental to grasping the principles of thermodynamics, a cornerstone of physical science that explains how energy transforms and transfers in various systems. In this article, we delve into a specific scenario where a gas expands from a volume of 3.0 dm^3 to 5.0 dm^3 against a constant pressure of 3.0 atm. We will explore the concepts involved, the calculations required, and the significance of this process both theoretically and practically.

Introduction to Gas Expansion and Work

The process of gas expansion occurs when a gas increases its volume, often doing work on its surroundings. The work done by a gas during expansion is a crucial concept, especially in engines, refrigerators, and various thermodynamic cycles. It reflects the energy transferred from the gas to its environment due to its change in volume under a certain pressure.

In our case, the key parameters are:
- Initial volume, $V_i = 3.0\, \text{dm}^3$
- Final volume, $V_f = 5.0\, \text{dm}^3$
- Constant pressure, $P = 3.0\, \text{atm}$

Our goal: To determine the work done by the gas during this expansion, considering the process occurs at constant pressure.

Fundamental Concepts and Definitions

Work in Thermodynamics

In thermodynamics, work (W) is defined as the energy transferred when a system undergoes a change that involves a force acting through a distance. For gases expanding or compressing in a piston, the work done by the gas can be expressed as:

$$
W = \text{Force} \times \text{Displacement}
$$

However, in the context of a gas, this simplifies to:

\[

$$
W = P \Delta V
$$

where:
- P is the constant external pressure,
- $\Delta V = V_f - V_i$ is the change in volume.

It's important to note that:
- If the gas expands ($V_f > V_i$), the work done by the gas is positive.
- If the gas compresses ($V_f < V_i$), the work done on the gas is positive, but the work done by the gas is negative.

This sign convention is essential for correctly interpreting the results.

Units and Conversion Factors

Since the parameters are given in different units (dm^3 and atm), a consistent unit system is necessary. The standard SI unit of volume is cubic meters (m^3), and pressure is in pascals (Pa). The conversion factors are:

- 1 dm^3 = 1 liter = 10^{-3} m^3
- 1 atm = 101,325 Pa

These conversions enable us to compute work in joules (J), the SI unit of energy.

Step-by-Step Calculation of Work Done

Let's walk through the calculation process meticulously.

Step 1: Convert Volumes to Cubic Meters

$$
V_i = 3.0\, \text{dm}^3 = 3.0 \times 10^{-3}\, \text{m}^3
$$

$$
V_f = 5.0\, \text{dm}^3 = 5.0 \times 10^{-3}\, \text{m}^3
$$

Step 2: Convert Pressure to Pascals

$$
P = 3.0\, \text{atm} = 3.0 \times 101,325\, \text{Pa} = 303,975\, \text{Pa}
$$

Step 3: Calculate the Change in Volume ΔV

$$
\Delta V = V_f - V_i = (5.0 - 3.0) \times 10^{-3} \text{m}^3 = 2.0 \times 10^{-3} \text{m}^3
$$

Step 4: Compute the Work Done W

Using the formula:

$$
W = P \times \Delta V
$$

we substitute the values:

$$
W = 303,975\, \text{Pa} \times 2.0 \times 10^{-3}\, \text{m}^3
$$

$$
W = 607.95\, \text{J}
$$

Result: The gas does approximately 608 joules of work during this expansion.

Interpreting the Results

The positive value of work indicates that during the process, the gas performs energy transfer to the surroundings by expanding against the external pressure. This energy transfer can be harnessed in various practical applications, such as moving pistons in engines or powering turbines.

Significance of the Calculation:
- It quantifies the energy involved in the physical change.
- Provides insight into the efficiency of thermodynamic systems.
- Serves as a basis for calculating other thermodynamic properties, such as heat transfer and internal energy change.

Additional Considerations and Real-World Applications

Isothermal vs. Adiabatic Expansion

While our calculation assumes a constant external pressure, real-world processes can be more complex:

- Isothermal expansion occurs at constant temperature, which involves heat exchange with surroundings.
- Adiabatic expansion occurs without heat exchange, leading to different work calculations based on the adiabatic process equations.

Understanding these distinctions is vital for engineers and scientists designing systems like engines, refrigerators, or chemical reactors.

Practical Examples

- Internal Combustion Engines: Pistons undergo expansion strokes where work is performed by expanding gases.
- Refrigeration Cycles: Gas expansion at constant pressure can absorb heat, cooling the environment.
- Industrial Gas Processes: Controlled expansions are used in turbines and gas turbines for energy generation.

Limitations and Assumptions

- The calculation presumes ideal conditions with no losses or heat transfer.
- Real gases may deviate from ideal behavior, especially at high pressures or low temperatures.
- External factors like friction or heat exchange can alter actual work performed.

Conclusion and Key Takeaways

The process of a gas expanding from 3.0 dm^3 to 5.0 dm^3 against a constant pressure of 3.0 atm results in approximately 608 joules of work done by the gas. This value, derived through fundamental thermodynamic principles, underscores the importance of understanding energy transfer mechanisms in gases.

Summary of crucial points:

- The work done during expansion at constant pressure is \(W = P \times \Delta V \).
- Accurate unit conversions are essential for correct calculations.

- The sign of work indicates whether energy is transferred by or to the system.
- Real-world applications span engines, refrigeration, and energy systems.
- Assumptions made in calculations highlight the importance of considering actual conditions for practical scenarios.

By mastering these concepts, scientists and engineers can better analyze, optimize, and innovate systems that rely on gas expansion and thermodynamic principles, ensuring efficiency and sustainability in various technological domains.

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