When 3 Mol Of O_2(g) Is Heated At Constant Pressure Of 3.25 Atm. The Temperature Increases From 260 To

Introduction

When 3 mol of $O_2(g)$ is heated at constant pressure of 3.25 atm, the temperature increases from 260°C to a higher value, leading to various thermodynamic changes in the system. This scenario provides an excellent opportunity to explore the principles of thermodynamics, including concepts like heat transfer, work done, and the relationship between temperature and other state variables. Understanding these processes is fundamental in fields such as chemical engineering, physical chemistry, and environmental science.

Fundamentals of the System

Initial Parameters

- Number of moles of oxygen gas, n = 3 mol
- Initial temperature, $T_{initial}$ = 260°C = 260 + 273.15 = 533.15 K
- Pressure, P = 3.25 atm
- Gas involved: $O_2(g)$

Final Temperature

The problem states that the temperature increases from 260°C to a higher value, which we need to determine. To do so, we need to analyze the thermodynamic process involved, assuming the process is ideal and at constant pressure.

Thermodynamics of Heating at Constant Pressure

Heat Transfer and Enthalpy

When a gas is heated at constant pressure, the heat added to the system (Q) is related to the change in enthalpy (ΔH). For an ideal gas, the relation simplifies to:

- $Q = n C_p \Delta T$

Where:

- n = number of moles
- C_p = molar heat capacity at constant pressure
- $\Delta T = T_{final} - T_{initial}$

Specific Heat Capacity of Oxygen Gas

Oxygen, as a diatomic gas, has well-established molar heat capacity values:

1. At constant pressure (C_p): approximately 29.4 J mol^{-1} K^{-1}
2. At constant volume (C_v): approximately 20.8 J mol^{-1} K^{-1}

Since the process occurs at constant pressure, we focus on C_p.

Determining the Final Temperature

Calculating the Heat Added

If the amount of heat supplied is known or can be calculated, the final temperature can be derived. However, in the absence of explicit heat input data, other methods such as relating work done or phase change considerations can be used, depending on problem context.

Assuming an Ideal Gas Behavior

For an ideal gas subjected to heating at constant pressure, the change in temperature is directly proportional to the heat supplied:

- $Q = n C_p \Delta T$

Thus, if we know Q, then:

$$T_{final} = T_{initial} + (Q / (n C_p))$$

Work Done During Heating

Expansion Work

Heating a gas at constant pressure often results in expansion, which involves work done by the system. The work done (W) during an expansion from an initial volume V_i to a final volume V_f is:

$$W = P \Delta V$$

For an ideal gas, volume and temperature are related by the ideal gas law:

$$PV = nRT$$

Calculating Change in Volume

Initial volume, V_i:

$$V_i = (n R T_{initial}) / P$$

Final volume, V_f:

$$V_f = (n R T_{final}) / P$$

Change in volume:

$$\Delta V = V_f - V_i = (n R / P) (T_{final} - T_{initial})$$

Where R = 0.08206 $L \cdot atm \cdot mol^{-1} \cdot K^{-1}$

Energy Accounting: First Law of Thermodynamics

Applying the First Law

The first law relates the change in internal energy (ΔU) to heat added and work done:

$$\Delta U = Q - W$$

For an ideal gas, the internal energy depends only on temperature:

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

Combining the equations allows us to analyze the energy flow and determine the final temperature based on heat input, work done, and initial conditions.

Summary of Key Equations

- Initial temperature: $T_{initial} = 533.15\ K$
- Final temperature: $T_{final} = ?$
- $V_i = (n\ R\ T_{initial}) / P$
- $V_f = (n\ R\ T_{final}) / P$
- $\Delta V = (n\ R / P)\ (T_{final} - T_{initial})$
- Work done: $W = P\ \Delta V = n\ R\ (T_{final} - T_{initial})$
- Heat added: $Q = n\ C_p\ (T_{final} - T_{initial})$
- Change in internal energy: $\Delta U = n\ C_v\ (T_{final} - T_{initial})$

Practical Implications and Applications

Industrial Heating Processes

Understanding how gases like oxygen respond to heating at constant pressure is vital in designing reactors,

engines, and other thermal systems. Accurate calculations of temperature changes and work done enable engineers to optimize energy efficiency and safety.

Environmental and Atmospheric Science

Oxygen plays a crucial role in atmospheric processes. Modeling how oxygen behaves under various temperature conditions helps in understanding phenomena such as combustion, pollutant formation, and climate change.

Conclusion

The scenario of heating 3 mol of $O_2(g)$ at a constant pressure of 3.25 atm, with an initial temperature of 260°C, encompasses important thermodynamic principles. By applying the concepts of heat capacity, ideal gas law, work done during expansion, and the first law of thermodynamics, one can determine the final temperature and associated energy changes. Although precise calculation of the final temperature requires specific information about the heat input, the theoretical framework outlined here provides a comprehensive understanding of the process. Such analyses are foundational in both academic research and practical engineering applications, emphasizing the importance of thermodynamics in real-world systems.

Frequently Asked Questions

What is the initial temperature of the oxygen gas when 3 mol of O_2 is heated at constant pressure?

The initial temperature is 260°C.

How does heating 3 mol of O_2 at constant pressure affect its temperature?

Heating causes the temperature of the oxygen gas to increase from 260°C to a higher value.

What is the significance of constant pressure in this heating process?

Constant pressure ensures that the volume of the gas can change, and the heat added relates directly to the change in temperature via the ideal gas law.

How can we determine the final temperature of the oxygen gas after

heating?

By knowing the amount of heat added and using the specific heat capacity or the ideal gas law, we can calculate the final temperature.

What is the role of the ideal gas law in analyzing this heating process?

The ideal gas law (PV = nRT) relates pressure, volume, and temperature, allowing us to calculate temperature changes when other variables are known.

If the temperature increases from 260°C to a higher temperature, what is the final temperature in Kelvin?

Convert 260°C to Kelvin (260 + 273.15 = 533.15 K), and add the temperature increase in Kelvin to find the final temperature.

Why is it important to specify the pressure when analyzing the heating of gases?

Pressure influences the volume and temperature relationship per the ideal gas law; keeping it constant simplifies calculations of temperature change.

Additional Resources

Understanding the Behavior of 3 Mol of O_2(g) When Heated at Constant Pressure of 3.25 atm: A Comprehensive Analysis

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Introduction

In the realm of thermodynamics and physical chemistry, the behavior of gases under various conditions provides foundational insights into their properties and interactions. The scenario where 3 mol of oxygen gas (O_2) is heated at a constant pressure of 3.25 atm, with its temperature rising from 260 K to a higher temperature, serves as an excellent case study to understand concepts such as ideal gas behavior, heat transfer, work done by gases, and the thermodynamic principles governing these processes. This detailed review aims to dissect this process meticulously, exploring theoretical foundations, calculations, implications, and real-world applications.

Fundamental Concepts Involved

Before delving into the specifics of the scenario, it's essential to revisit the core principles involved:

1. Ideal Gas Law

- The behavior of gases under many conditions can be approximated by the ideal gas law:

$$
PV = nRT
$$

where:
- P = pressure,
- V = volume,
- n = number of moles,
- R = universal gas constant,
- T = temperature in Kelvin.

- For this problem, since pressure and the amount of gas are constant, the relation simplifies to a direct proportionality between volume and temperature:

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

2. Thermodynamic Processes at Constant Pressure (Isobaric Process)

- When a gas is heated at constant pressure, the process is termed isobaric.
- Work done by the gas during expansion is given by:

$$
W = P \Delta V
$$

- Heat transfer (Q) for an ideal gas during an isobaric process can be expressed as:

$$
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$$
Q = n C_p \Delta T
$$

where:
- C_p = molar heat capacity at constant pressure (~29 J/mol·K for O_2).

3. Specifics for Oxygen Gas (O_2)

- Oxygen is a diatomic molecule, and at room temperature and moderate conditions, it behaves approximately as an ideal gas.
- Molar mass of O_2 = 32 g/mol.

Initial Conditions and Assumptions

The problem states:
- Number of moles, $n = 3$ mol,
- Initial temperature, $T_1 = 260\, \text{K}$,
- Final temperature, $T_2 = ?$ (to be determined),
- Pressure, $P = 3.25\, \text{atm}$.

Assumptions:
- Gas behaves ideally throughout the process.
- The process occurs reversibly and at constant pressure.
- No phase change or chemical reactions occur.
- Heat transfer is conducted quasi-statically, ensuring the system remains in equilibrium.

Calculating the Final Temperature

Since the pressure is held constant, and the process involves heating the gas:

Step 1: Use the ideal gas law to determine the change in volume:

$$
V_1 = \frac{nRT_1}{P}
$$

$$
V_2 = \frac{nRT_2}{P}
$$

Because n, R, and P are constant, the ratio of volumes directly relates to the ratio of temperatures:

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

Step 2: To find T_2, we need additional information such as the amount of heat supplied or the work done. Since the problem emphasizes heating at constant pressure, let's consider typical scenarios:

- If the heat supplied is known, the final temperature can be calculated directly.
- Alternatively, if the problem is designed to understand the change in volume or work done, we proceed with calculations based on thermodynamic relations.

Example Calculation:

Suppose the problem states that the gas is heated until a certain temperature, say 500 K, then:

$$
T_2 = 500\, \text{K}
$$

The change in temperature:

$$
\Delta T = T_2 - T_1 = 500\, \text{K} - 260\, \text{K} = 240\, \text{K}
$$

Quantitative Analysis of the Process

1. Volume Change

Using the ideal gas law:

$$
$$

$$
V_1 = \frac{nRT_1}{P}
$$

Convert pressure to SI units:

$$
P = 3.25\, \text{atm} = 3.25 \times 101.325\, \text{kPa} \approx 329.7\, \text{kPa}
$$

Universal gas constant:

$$
R = 8.314\, \text{J/mol·K}
$$

Calculate initial volume:

$$
V_1 = \frac{3 \times 8.314 \times 260}{329700} \approx \frac{6481.92}{329700} \approx 0.01966\, \text{m}^3
$$

Similarly, for final temperature T_2:

$$
V_2 = \frac{3 \times 8.314 \times T_2}{329700}
$$

If $T_2 = 500\, \text{K}$:

$$
V_2 \approx \frac{3 \times 8.314 \times 500}{329700} \approx \frac{12471}{329700} \approx 0.0378\, \text{m}^3
$$

2. Work Done by the Gas

The work done during the isobaric expansion:

$$
W = P \Delta V = 329.7\, \text{kPa} \times (V_2 - V_1)
$$

$$
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$$
W \approx 329700\, \text{Pa} \times (0.0378 - 0.01966)\, \text{m}^3 \approx 329700 \times 0.01814 \approx 5984\, \text{J}
$$

3. Heat Supplied

The heat added:

$$
Q = n C_p \Delta T
$$

For diatomic gases like O_2:

$$
C_p \approx 29\, \text{J/mol·K}
$$

Therefore:

$$
Q = 3 \times 29 \times 240 \approx 3 \times 6960 \approx 20{,}880\, \text{J}
$$

Alternatively, from the first law:

$$
Q = \Delta U + W
$$

where:

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

and for diatomic gases:

$$
C_v \approx 20.8\, \text{J/mol·K}
$$

Thus,

$$
\Delta U = 3 \times 20.8 \times 240 \approx 3 \times 4992 \approx 14,976\, \text{J}
$$

Adding work:

$$
Q = \Delta U + W \approx 14,976 + 5984 \approx 20,960\, \text{J}
$$

which closely matches the heat calculated via $n C_p \Delta T$, confirming the internal consistency.

Implications and Further Insights

1. Effect of Heating on Volume and Pressure

- Since the pressure is held constant at 3.25 atm, heating causes the gas to expand.
- The volume increase is directly proportional to the temperature increase, based on the ideal gas law.
- This expansion can be visualized as the gas "pushing" against the surroundings, doing work.

2. Thermodynamic Work and Energy Transfer

- The work done by the gas during expansion is significant (~6 kJ in the example), highlighting the energy involved in physical expansion.
- The heat supplied not only raises the internal energy but also accounts for the work done.

3. Real-World Applications

- This principle is fundamental in engines, turbines, and chemical reactors where gases are heated under constant pressure.
- Understanding the relationship between temperature, volume, and work helps in designing efficient thermal systems.

4. Limitations of Ideal Gas Assumption

- At higher pressures or lower temperatures, real gases deviate from ideal behavior.
- For oxygen, at high pressures or very low temperatures, corrections like Van der Waals equations become necessary.

Additional Considerations and Advanced Topics

1. Specific Heat Capacities and Temperature Dependence

- While C_p and C_v are often treated as constants, they can vary with temperature.
- For precise calculations, temperature-dependent heat capacities should be used.

2. Thermodynamic Cycles Involving O_2

- The process described can be part of larger thermodynamic cycles such as Carnot, Otto, or Stirling engines.
- Analyzing such cycles involves understanding the heat exchange, work done, and efficiency under various conditions.

3. Non-Ideal

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