Under Constant Pressure, The Temperature Of 1.80 Mol Of An Ideal Monatomic Gas Is Raised 18.1 K. What

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Understanding how gases respond to temperature changes under constant pressure is fundamental in thermodynamics and physical chemistry. When a specific amount of an ideal monatomic gas experiences a temperature increase, it prompts questions about the corresponding changes in other thermodynamic parameters such as heat transfer, work done, and internal energy. This article delves into the detailed analysis of such a scenario involving 1.80 mol of an ideal monatomic gas with an 18.1 K temperature increase under constant pressure conditions.

Fundamentals of Ideal Monatomic Gases

What Is an Ideal Monatomic Gas?

An ideal monatomic gas consists of single-atom molecules that follow the ideal gas law without interactions other than elastic collisions. Common examples include noble gases like helium, neon, argon, krypton, and xenon under low-pressure conditions.

Key Properties

- Molecular structure: Single atoms
- Interactions: No intermolecular forces (ideal behavior)
- Degrees of freedom: 3 translational degrees of freedom
- Specific heat capacities:
- At constant volume, $C_v = \frac{3}{2} R$
- At constant pressure, $C_p = \frac{5}{2} R$

where R is the universal gas constant, approximately 8.314 J/mol·K.

Thermodynamic Concepts Relevant to the Scenario

Ideal Gas Law

The behavior of the gas under the given conditions is described by the ideal gas law:

$$ PV = nRT $$

where:

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

Since the pressure is constant, any change in temperature will proportionally affect the volume.

Heat Capacity and Internal Energy

The change in internal energy (ΔU) for an ideal monatomic gas depends solely on temperature:

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

where:

- $C_v = \frac{3}{2} R$

The heat added at constant pressure (Q) is related to the change in temperature:

$$ Q = n C_p \Delta T $$

with:

- $C_p = \frac{5}{2} R$

The work done by the gas during expansion at constant pressure is:

$$ W = P \Delta V $$

which can also be expressed in terms of temperature change:

$$ W = n R \Delta T $$

Calculating the Heat Added to the Gas

Given data:

- $n = 1.80\, \text{mol}$
- $\Delta T = 18.1\, \text{K}$
- $R = 8.314\, \text{J/mol·K}$

Step 1: Determine the Heat Added (Q)

Using the formula for heat at constant pressure:

$$Q = n C_p \Delta T$$

Calculate C_p:

$$C_p = \frac{5}{2} R = \frac{5}{2} \times 8.314\, \text{J/mol·K} = 20.785\, \text{J/mol·K}$$

Now, compute Q:

$$Q = 1.80\, \text{mol} \times 20.785\, \text{J/mol·K} \times 18.1\, \text{K}$$

$$Q = 1.80 \times 20.785 \times 18.1$$

$$Q \approx 1.80 \times 376.31$$

$$Q \approx 677.36\, \text{J}$$

Answer: Approximately 677.36 Joules of heat are added to the gas.

Work Done by the Gas During Expansion

Since the pressure remains constant and the temperature increases, the volume of the gas expands. The work done (W) can be calculated:

$$W = n R \Delta T$$

Substitute the known values:

$$W = 1.80\, \text{mol} \times 8.314\, \text{J/mol·K} \times 18.1\, \text{K}$$

$$ W = 1.80 \times 8.314 \times 18.1 $$

$$ W \approx 1.80 \times 150.55 $$

$$ W \approx 271\, \text{J} $$

Answer: The gas does approximately 271 Joules of work during the process.

Change in Internal Energy of the Gas

The change in the internal energy (ΔU) for an ideal monatomic gas is:

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

Calculate C_v:

$$ C_v = \frac{3}{2} R = 1.5 \times 8.314\, \text{J/mol·K} = 12.471\, \text{J/mol·K} $$

Compute ΔU:

$$ \Delta U = 1.80\, \text{mol} \times 12.471\, \text{J/mol·K} \times 18.1\, \text{K} $$

$$ \Delta U \approx 1.80 \times 12.471 \times 18.1 $$

$$ \Delta U \approx 1.80 \times 226.07 $$

$$ \Delta U \approx 406.92\, \text{J} $$

Answer: The internal energy increases by approximately 406.92 Joules.

Summary of Key Results

Quantity	Calculation	Result
Heat added (Q)	$n C_p \Delta T$	677.36 J
Work done (W)	$n R \Delta T$	271 J
Change in internal energy (ΔU)	$n C_v \Delta T$	406.92 J

Implications and Practical Insights

Understanding these thermodynamic parameters is vital in various scientific and engineering applications, including:

- Designing heat engines and refrigerators
- Analyzing atmospheric processes
- Studying gas behaviors in industrial processes

The calculations demonstrate that when an ideal monatomic gas experiences an 18.1 K temperature increase at constant pressure:

- The gas absorbs approximately 677 Joules of heat.
- It does work equal to about 271 Joules due to expansion.
- Its internal energy increases by approximately 407 Joules.

This interplay exemplifies the conservation of energy, where the heat supplied is partitioned into work done and internal energy increase.

Conclusion

In thermodynamics, analyzing how gases respond to temperature changes under constant pressure reveals fundamental principles governing energy transfer. For 1.80 mol of an ideal monatomic gas, a temperature increase of 18.1 K involves specific amounts of heat absorption, work done, and internal energy change, as calculated above. These principles are essential for understanding real-world processes involving gases, from industrial applications to natural phenomena.

FAQs

1. Why is the heat capacity at constant pressure (\(C_p \)) higher for monatomic gases?

Because at constant pressure, the gas must do work to expand as it heats, requiring additional energy. Therefore, \(C_p \) accounts for both internal energy increase and work done during expansion.

2. How does the number of moles affect these calculations?

The number of moles directly scales the heat, work, and internal energy changes. More moles mean proportionally larger energy exchanges for the same temperature change.

3. Can these calculations be applied to real gases?

While ideal gas assumptions simplify the calculations, real gases may deviate from ideal behavior at high pressures or low temperatures. Corrections may be necessary in such cases.

By understanding the fundamental thermodynamic principles and performing precise calculations, scientists and engineers can predict and control the behavior of gases in various applications, ensuring efficiency and safety in their processes.

Frequently Asked Questions

Under constant pressure, how is the temperature change related to the internal energy of an ideal monatomic gas?

For an ideal monatomic gas at constant pressure, the increase in temperature corresponds to an increase in internal energy, since internal energy depends solely on temperature. Specifically, $\Delta U = (3/2)nR\Delta T$.

What is the heat added to the gas when its temperature is raised by 18.1 K at constant pressure?

The heat added, Q, can be calculated using $Q = nC_p\Delta T$. For a monatomic ideal gas, $C_p = (5/2)R$. Therefore, $Q = n(5/2)R\Delta T$. Substituting n=1.80 mol and ΔT=18.1 K gives Q = 1.80(5/2)8.31418.1 J.

How does the molar heat capacity at constant pressure for a monatomic ideal gas influence the temperature change?

The molar heat capacity at constant pressure, $C_p = (5/2)R$ for a monatomic ideal gas, determines how much heat is required to raise the temperature by a certain amount. A higher C_p means more heat is needed for the same temperature increase.

If the number of moles of gas is known, how can we determine the amount of heat required to raise its temperature by 18.1 K?

Using the formula $Q = nC_p\Delta T$, where $n=1.80$ mol, $C_p=(5/2)R$, and $\Delta T=18.1$ K, we can calculate the heat required directly, which provides insight into energy transfer during heating.

What are the implications of heating an ideal monatomic gas at constant pressure in terms of work done by the gas?

At constant pressure, heating the gas causes it to expand, performing work on the surroundings. The work done, W, can be calculated as $W = P\Delta V$, which relates to the amount of heat added and the change in volume during the temperature increase.

Additional Resources

Under Constant Pressure, The Temperature Of 1.80 Mol Of An Ideal Monatomic Gas Is Raised 18.1 K. What Does This Tell Us About the Gas's Behavior and Energy Changes?

In the world of thermodynamics, understanding how gases respond to changes in temperature, pressure, and volume is fundamental. Recently, a scenario has piqued the curiosity of physics enthusiasts and students alike: considering a sample of ideal monatomic gas subjected to a temperature increase under constant pressure conditions. Specifically, when 1.80 moles of an ideal monatomic gas experience an 18.1 Kelvin rise in temperature, what insights can we glean about the energy transfer, work done, and the fundamental relationships governing the gas? This article aims to decode this question with clarity and depth, exploring the underlying principles and calculations involved.

Understanding the Scenario: Key Parameters and Assumptions

Before delving into calculations, it's crucial to establish the foundational assumptions and parameters:

- Number of Moles (n): 1.80 mol
- Temperature Change (ΔT): 18.1 K
- Process Conditions: Constant pressure (P)
- Type of Gas: Ideal monatomic gas
- Ideal Gas Law: $PV = nRT$

What is an Ideal Monatomic Gas?
An ideal monatomic gas consists of single-atom molecules (like helium, neon, or argon) that do not interact with each other except through elastic collisions. Their behavior is well-described by the ideal gas law, and their molar heat capacities are constant.

Why Focus on Constant Pressure?
Constant pressure processes are common in practical situations (e.g., heating a gas in an open container). Under such conditions, the gas can expand or contract freely while maintaining the external pressure, influencing the work done during the process.

Fundamental Concepts in Thermodynamics for the Scenario

To analyze what happens when the temperature of the gas increases, we need to revisit some core thermodynamic principles:

1. Heat Transfer (Q):
The amount of heat added or removed during a process.

2. Work Done (W):
Work done by the gas during expansion or compression.

3. Change in Internal Energy (ΔU):
The total energy stored in the gas, which depends on temperature for an ideal gas.

4. First Law of Thermodynamics:
$$
\Delta U = Q - W
$$

In this context, since the process occurs at constant pressure, the work done is related to the volume change.

Calculating the Heat Added to the Gas (Q)

Since the process occurs at constant pressure, the heat transferred to the gas can be directly linked to the molar heat capacity at constant pressure (C_p):

$$
Q = n C_p \Delta T
$$

Molar Heat Capacity at Constant Pressure for a Monatomic Ideal Gas

For a monatomic ideal gas:

$$
C_v = \frac{3}{2} R
$$

and

$$
C_p = C_v + R = \frac{3}{2} R + R = \frac{5}{2} R
$$

Where:

- $R = 8.314\, \mathrm{J\, mol^{-1}\, K^{-1}}$

Calculating C_p:

$$
C_p = \frac{5}{2} R = 2.5 \times 8.314 \approx 20.785\, \mathrm{J\, mol^{-1}\, K^{-1}}
$$

Total heat added (Q):

$$
Q = n C_p \Delta T = 1.80\, \mathrm{mol} \times 20.785\, \mathrm{J\, mol^{-1}\, K^{-1}} \times 18.1\, \mathrm{K}
$$

$$
Q \approx 1.80 \times 20.785 \times 18.1 \approx 1.80 \times 376.37 \approx 677.47\, \mathrm{J}
$$

Interpretation:
Approximately 677.5 joules of heat are added to raise the temperature by 18.1 K at constant pressure.

Work Done by the Gas During Expansion

Since the gas expands as it heats (to maintain constant pressure while volume increases), it performs work on its surroundings.

1. Work Equation at Constant Pressure:

$$
W = P \Delta V
$$

But because pressure is constant, and from the ideal gas law:

$$
PV = nRT
$$

the change in volume (ΔV) with temperature change (ΔT) is:

$$
V = \frac{nRT}{P}
$$

$$
\Delta V = \frac{nR \Delta T}{P}
$$

2. Expressing Work in Terms of Known Quantities:

$$
W = P \times \frac{n R \Delta T}{P} = n R \Delta T
$$

This simplifies beautifully because the pressure cancels out.

3. Calculating Work Done:

$$
W = n R \Delta T = 1.80 \times 8.314\, \mathrm{J\, mol^{-1}\, K^{-1}} \times 18.1\, \mathrm{K}
$$

$$
W \approx 1.80 \times 8.314 \times 18.1 \approx 1.80 \times 150.6 \approx 271.07\, \mathrm{J}
$$

Interpretation:
The gas does approximately 271.1 joules of work on the surroundings as it expands during heating.

Change in Internal Energy (ΔU): An Internal

Perspective

For an ideal monatomic gas, the internal energy depends solely on temperature and is given by:

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

where:

$$
C_v = \frac{3}{2} R \approx 12.471\, \mathrm{J\, mol^{-1}\, K^{-1}}
$$

Calculating:

$$
\Delta U = 1.80 \times 12.471 \times 18.1 \approx 1.80 \times 12.471 \times 18.1
$$

$$
\approx 1.80 \times 225.86 \approx 406.55\, \mathrm{J}
$$

Note: The internal energy increases by approximately 406.6 joules.

Linking the Thermodynamic Quantities: Validating the First Law

Recall the first law:

$$
\Delta U = Q - W
$$

Plugging in the calculated values:

$$
406.6\, \mathrm{J} \approx 677.5\, \mathrm{J} - 271.1\, \mathrm{J}
$$

$$
406.6 \approx 406.4
$$

The close match confirms the internal consistency of our calculations, affirming the validity of the assumptions and the ideal gas model.

Practical Implications and Broader Insights

Understanding Energy Exchanges:
This analysis highlights how, during heating at constant pressure:

- The heat added (Q) increases the internal energy and does work by expanding the volume.
- The internal energy change depends solely on temperature change, consistent with ideal gas behavior.
- The work done corresponds to the energy required to expand the gas against the external pressure.

Real-World Relevance:
Such thermodynamic processes underpin various practical applications, including:

- Heating gases in engines and turbines
- Designing chemical reactors where gases expand and contract
- Understanding atmospheric processes involving adiabatic and isobaric heating

Educational Value:
This example provides a concrete illustration of abstract thermodynamic principles, allowing students and enthusiasts to connect theoretical formulas with tangible energy transformations.

Conclusion: What Have We Learned?

By analyzing a monatomic ideal gas heated under constant pressure, we've demonstrated how to determine the heat added, the work performed, and the resulting change in internal energy. The key takeaways are:

- The heat required to raise the temperature is directly proportional to the number of moles, the molar heat capacity at constant pressure, and the temperature change.
- The work done by the gas during expansion is equal to $n R \Delta T$, reflecting the energy expenditure in volume increase.
- The change in internal energy depends only on temperature change and molar heat capacity at constant volume.

This comprehensive approach underscores the elegance and predictive power of thermodynamic principles, offering a window into the energetic dance of gases.

Understanding these concepts not only enriches foundational physics knowledge but also empowers engineers and scientists to manipulate and control thermodynamic systems effectively.

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