In A Constant-volume Process, 210 J Of Energy Is Transferred By Heat To 1.01 Mol Of An Ideal Monatomic

In A Constant-volume Process, 210 J Of Energy Is Transferred By Heat To 1.01 Mol Of An Ideal Monatomic substance, presenting a fascinating scenario in thermodynamics that allows us to explore the principles governing energy transfer, heat, and work in ideal gases. Understanding this process requires a grasp of fundamental concepts such as internal energy, heat transfer, work done during processes, and the properties of ideal monatomic gases. This article delves into these aspects, providing a comprehensive analysis of what occurs during such a thermodynamic event.

Understanding the Process: An Overview

The process described involves the transfer of heat to a specific amount of an ideal monatomic gas at constant volume. Since the volume remains unchanged, no work is done by the gas during this process. Instead, all the energy transfer manifests as an increase in the internal energy of the gas, which correlates directly with the temperature change.

Key Concepts in the Process

- Constant-volume process (Isochoric process)
- Heat transfer (Q)
- Change in internal energy (ΔU)
- Amount of substance (number of moles, n)

In thermodynamics, when a gas undergoes a process at constant volume, any heat added or removed affects only the internal energy, since work done (W) is zero ($W = P\Delta V = 0$). The first law of thermodynamics simplifies to:

$\Delta U = Q$

where ΔU is the change in internal energy, and Q is the heat transferred.

Thermodynamic Foundations

To analyze this process thoroughly, it’s essential to understand the underlying thermodynamic principles, especially for an ideal monatomic gas.

Internal Energy of an Ideal Monatomic Gas

The internal energy (U) of an ideal monatomic gas depends solely on temperature and can be expressed as:

$U = (3/2)\ nRT$

where:
- n = number of moles
- R = universal gas constant (8.314 J/(mol·K))
- T = absolute temperature in Kelvin

The change in internal energy when the temperature changes from T_1 to T_2 is:

$\Delta U = U_2 - U_1 = (3/2)\ nR\ (T_2 - T_1)$

Since no work is done at constant volume, the heat added directly increases the internal energy.

Heat Transfer and Temperature Change

Given the heat transferred (Q), the temperature change of the gas can be determined:

$Q = \Delta U = (3/2)\ nR\ (T_2 - T_1)$

Rearranged to find the temperature change:

$T_2 - T_1 = (2/3)\ (Q)\ /\ (nR)$

Applying the specific values provided ($Q = 210$ J, $n \approx 1.01$ mol):

$T_2 - T_1 = (2/3)\ 210\ \text{J}\ /\ (1.01\ \text{mol}\ 8.314\ \text{J/(mol·K)})$
$T_2 - T_1 \approx (140)\ /\ (8.39614)$
$T_2 - T_1 \approx 16.68\ \text{K}$

This indicates the temperature of the gas increases by approximately 16.68 Kelvin during the process.

Calculating the Initial and Final Temperatures

Since only the temperature change is known, the actual initial and final temperatures depend on the initial temperature T_1, which is not specified. However, understanding the relationship allows us to analyze the process's implications.

Example Calculation with Assumed Initial Temperature

Suppose the initial temperature T_1 is 300 K:

- Final temperature $T_2 = T_1 + 16.68 \approx 316.68$ K

This provides a concrete understanding of how the heat transfer affects the gas's temperature.

Implications of the Process

Analyzing the energy transfer and thermodynamic changes in this process reveals several important implications.

Energy Conservation and Internal Energy

Since the process involves only heat transfer at constant volume, the internal energy increases by 210 J. This signifies that the gas gains energy, raising its temperature, but does not perform work on the surroundings because volume remains fixed.

Work Done During the Process

Because the volume is constant:

$$W = P\Delta V = 0$$

No work is performed during this process, which simplifies the analysis but also emphasizes the role of heat in changing internal energy.

Pressure and Temperature Relationship

For an ideal gas, the ideal gas law applies:

$$PV = nRT$$

At constant volume (V), pressure and temperature are directly proportional:

$$P = (nRT) / V$$

As temperature increases, so does pressure proportionally:

$$\Delta P / P = \Delta T / T$$

This means that at constant volume, an increase in temperature results in a proportional increase in pressure.

Broader Context and Applications

Understanding such processes is crucial in various scientific and engineering fields, including thermodynamic cycle analysis, heating systems, and internal combustion engines.

Real-World Applications

- Designing heat engines and refrigerators
- Analyzing energy efficiency in industrial processes
- Studying atmospheric phenomena involving gas temperature changes

Relevance to Thermodynamic Cycles

Constant-volume heating is a key step in cycles like the Otto cycle (used in gasoline engines), where understanding heat addition at constant volume aids in optimizing performance and efficiency.

Summary and Key Takeaways

- In a constant-volume process, heat transfer directly increases the internal energy of an ideal monatomic gas.
- The amount of heat transferred (210 J) results in a temperature increase that depends on the number of moles and the gas constant.
- No work is performed during the process because the volume remains unchanged.
- The process provides insight into fundamental thermodynamic principles, illustrating how heat transfer affects internal energy and temperature.

Conclusion

The scenario of transferring 210 J of heat to 1.01 mol of an ideal monatomic gas at constant volume exemplifies core thermodynamic concepts. By analyzing the relationship between heat, internal energy, temperature, and pressure, we gain a clearer understanding of how energy flows influence the behavior of gases. Such knowledge is essential in designing efficient thermal systems and understanding natural phenomena involving gases. Whether in engineering applications or academic research, mastering these principles enables scientists and engineers to optimize processes and innovate solutions in energy management and thermodynamics.

Frequently Asked Questions

In a constant-volume process, how is the heat transferred related to the change in internal energy?

In a constant-volume process, the heat transferred (Q) equals the change in internal energy (ΔU) because work done (W) is zero, so Q = ΔU.

What is the significance of transferring 210 J of heat in this ideal monatomic gas process?

Transferring 210 J of heat indicates the amount of energy added to or removed from the gas, which affects its internal energy and temperature.

How can we determine the change in internal energy for 1.01 mol of an ideal monatomic gas with 210 J heat transfer?

Using the relation $\Delta U = n C_v \Delta T$, where for a monatomic ideal gas, $C_v = (3/2) R$, and knowing $Q = \Delta U$, we can find ΔT accordingly.

What is the molar heat capacity at constant volume (C_v) for an ideal monatomic gas?

$C_v = (3/2) R$, which is approximately 12.5 J/(mol·K), since $R \approx 8.314$ J/(mol·K).

How does the energy transfer of 210 J relate to the temperature change of the gas?

The temperature change ΔT can be calculated using $\Delta U = n C_v \Delta T = 210$ J; thus, $\Delta T = 210 \text{ J} / (n C_v)$.

What is the initial internal energy change of the gas in this process?

The initial internal energy change is 210 J, equal to the heat transferred, assuming no work done and ideal gas behavior.

Can work be done in this constant-volume process? Why or why not?

No, work cannot be done because work in thermodynamics is related to volume change ($W = P\Delta V$), which is zero at constant volume.

How would the temperature of the gas change after transferring 210 J of heat?

The temperature increase ΔT can be calculated as $\Delta T = Q / (n C_v)$; plugging in the values gives the specific temperature change.

Is the process described an adiabatic process? Why or why not?

No, because heat is transferred to or from the gas ($Q = 210$ J), so it is not adiabatic, which involves no heat transfer.

What is the significance of using an ideal monatomic gas in this analysis?

Using an ideal monatomic gas simplifies calculations because its internal energy depends solely on temperature and has a known heat capacity ($C_v = 3/2 R$).

Additional Resources

In A Constant-volume Process, 210 J Of Energy Is Transferred By Heat To 1.01 Mol Of An Ideal Monatomic — this statement encapsulates a fundamental thermodynamic scenario that offers rich insights into the behavior of ideal gases under specific conditions. Such processes are pivotal in understanding energy transfer mechanisms, especially in systems where volume remains unchanged, and heat exchange plays a dominant role. This analysis aims to dissect the core principles, implications, and educational significance of this process, providing a comprehensive review suitable for students, educators, and professionals interested in thermodynamics.

Understanding the Basics: What Is a Constant-volume Process?

Definition and Significance

A constant-volume process, also known as an isochoric process, is one in which the volume of a system remains unchanged during the transformation. In thermodynamics, this process is particularly straightforward because no work is done by the system due to volume change—work, in this context, is given by $W = P \Delta V$. When $\Delta V = 0$, the work done is zero, simplifying the energy balance equations.

This process is crucial in various practical applications, such as heating gases in rigid containers, internal combustion engines during certain phases, and laboratory experiments where volume control is essential. It also provides a clean theoretical framework to study heat transfer and internal energy changes without the complexity introduced by work interactions.

Characteristics of a Constant-volume Process

- No work done: Since volume is fixed, $W = 0$.
- Energy transfer via heat: The entire energy change is through heat addition or removal.
- Temperature change: For ideal gases, temperature typically varies with heat transfer at constant volume.
- Internal energy change: Directly related to heat added or removed, especially in ideal gases where internal energy depends solely on temperature.

Analyzing the Scenario: 210 J of Heat Transfer to an Ideal Monatomic Gas

Given Data Recap

- Heat transferred, $Q = 210 \, \mathrm{J}$
- Number of moles, $n = 1.01 \, \mathrm{mol}$
- Gas type: Ideal monatomic gas (e.g., helium, neon, argon)

Implications of the Data

In this scenario, the heat transfer occurs at constant volume, leading to an increase in the internal energy of the gas. Since the gas is ideal and monatomic, its internal energy depends only on temperature and can be expressed using the molar heat capacity at constant volume, C_v.

Internal energy change:
$$
\Delta U = n C_v \Delta T
$$

For a monatomic ideal gas,
$$
C_v = \frac{3}{2} R
$$
where $R = 8.314\, \mathrm{J/(mol \cdot K)}$.

The temperature change induced by the heat transfer can be derived as:
$$
\Delta T = \frac{\Delta U}{n C_v} = \frac{Q}{n C_v}
$$

Calculating the temperature change:
$$
\Delta T = \frac{210\, \mathrm{J}}{1.01\, \mathrm{mol} \times \frac{3}{2} \times 8.314\, \mathrm{J/(mol \cdot K)}}
$$

$$
\Delta T \approx \frac{210}{1.01 \times 12.471} \approx \frac{210}{12.595} \approx 16.68\, \mathrm{K}
$$

This indicates that the gas temperature increases by approximately 16.68 Kelvin due to the heat transfer.

Thermodynamic Analysis and Key Equations

First Law of Thermodynamics in Action

The first law states:
$$

$$
\Delta U = Q - W
$$

Since work done $W = 0$ in a constant-volume process,

$$
\boxed{\Delta U = Q}
$$

This confirms that all the heat energy supplied to the gas increases its internal energy.

Work Done and Heat Transfer

- Work done: $W = 0$
- Heat transferred: $Q = 210\, \mathrm{J}$
- Internal energy increase: $\Delta U = 210\, \mathrm{J}$

Temperature and Internal Energy Relationship

For an ideal monatomic gas, the internal energy change is:

$$
\Delta U = \frac{3}{2} n R \Delta T
$$

Rearranged to find ΔT:

$$
\Delta T = \frac{2}{3} \times \frac{\Delta U}{n R}
$$

Plugging in the given values:

$$
\Delta T = \frac{2}{3} \times \frac{210}{1.01 \times 8.314} \approx 16.68\, \mathrm{K}
$$

This confirms the earlier calculation and emphasizes the direct proportionality between heat transfer and temperature increase in an ideal monatomic gas at constant volume.

Features and Educational Significance

Features of the Process

- Simplicity: The absence of work simplifies energy calculations.
- Direct relationship: Between heat transferred and internal energy change.
- Predictability: For ideal gases, temperature change can be directly calculated from heat transfer, making it a valuable teaching model.
- Relevance: Applies to real-world scenarios like heating gases in sealed containers.

Educational Benefits

- Clarifies the distinction between heat, work, and internal energy.
- Demonstrates the use of thermodynamic equations in practical contexts.
- Provides insight into the behavior of ideal gases under energy transfer.
- Serves as a basis for more complex thermodynamic cycle analysis.

Pros and Cons of Constant-volume Heating Processes

Pros:
- Simplifies analysis due to no work interaction.
- Provides clear understanding of heat transfer effects.
- Useful in experimental setups requiring volume control.
- Facilitates precise temperature control and measurement.

Cons:
- Limited practical applications where volume is constrained.
- Cannot account for real gas deviations in non-ideal conditions.
- Does not consider effects of pressure changes explicitly unless combined with other processes.
- In real systems, volume changes often accompany heat transfer, making this idealization a simplification.

Broader Implications and Applications

Relevance in Thermodynamic Cycles

Constant-volume heating is a fundamental step in various thermodynamic cycles, such as the Otto cycle in internal combustion engines, where gases are compressed, heated, and expanded in a controlled manner. Understanding the heat transfer and energy changes in such processes is vital for optimizing efficiency.

Engineering and Practical Applications

- Calibration of equipment: Using rigid containers for precise heat addition.
- Laboratory experiments: Studying ideal gas behavior and verifying thermodynamic laws.
- Design of thermodynamic systems: Where volume constraints are unavoidable.

Limitations and Considerations

While the analysis provides fundamental insights, real-world systems often involve complexities such as:
- Non-ideal gas behavior at high pressures or low temperatures.
- Heat losses to surroundings.
- Material constraints of the container.
- Pressure variations that may induce work interactions in more complex

processes.

Accounting for these factors requires more advanced models beyond the ideal assumptions.

Conclusion

The scenario of In A Constant-volume Process, 210 J Of Energy Is Transferred By Heat To 1.01 Mol Of An Ideal Monatomic offers a quintessential example of basic thermodynamic principles in action. It exemplifies how heat transfer directly influences internal energy and temperature in an idealized setting, serving as a foundational concept in thermal physics education. The process's simplicity allows students and engineers to grasp core ideas such as the relationship between heat and internal energy, the significance of process constraints, and the utility of thermodynamic equations in practical applications.

Understanding such idealized processes provides a stepping stone to grasping more complex phenomena encountered in real-world systems, where additional factors like work interactions, non-ideal behavior, and irreversibilities come into play. As a teaching and analytical tool, constant-volume heat transfer processes remain invaluable, enriching our comprehension of energy dynamics in thermodynamic systems.

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