The Temperature Of A Sample Of Gas Is Changed, Causing The Volume To Go From 3500 Cm' To 4700 Cm3. If

The Temperature Of A Sample Of Gas Is Changed, Causing The Volume To Go From 3500 Cm' To 4700 Cm3. If you are exploring the fascinating relationship between temperature and volume in gases, understanding how these variables interact is essential in fields ranging from chemistry and physics to engineering and meteorology. When the temperature of a gas sample changes, it directly influences its volume, especially under constant pressure conditions, due to the fundamental principles described by the ideal gas law. This article delves into the science behind this phenomenon, explaining key concepts, calculations, and real-world applications to provide a comprehensive understanding of how temperature variations affect gas volume.

Understanding the Relationship Between Temperature and Volume in Gases

Charles's Law: The Foundation of Gas Behavior

Charles's Law states that, for a fixed amount of gas at constant pressure, the volume is directly proportional to its temperature expressed in Kelvin. Mathematically, it is represented as:

- $V \propto T$
- or $V_1 / T_1 = V_2 / T_2$

where:

- V_1 and V_2 are the initial and final volumes,
- T_1 and T_2 are the initial and final temperatures in Kelvin.

This law explains why heating a gas causes it to expand and cooling causes contraction, assuming the pressure remains unchanged.

Applying the Ideal Gas Law

The ideal gas law combines multiple variables and provides a comprehensive framework:

- $PV = nRT$

where:

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

In scenarios where pressure and the amount of gas are constant, the law simplifies to Charles's Law, connecting temperature and volume.

Calculating the Change in Volume Due to Temperature Change

Given data:

- Initial volume, V_1 = 3500 cm³
- Final volume, V_2 = 4700 cm³
- Initial temperature, T_1 (unknown)
- Final temperature, T_2 (unknown)

Assuming the pressure and the amount of gas remain constant, we can use Charles's Law to find the relationship between the initial and final temperatures.

Converting Volumes to Consistent Units

Since the volumes are already in cubic centimeters, and Charles's Law uses ratios, units are consistent, and no conversion is necessary for volume.

Expressing Temperatures in Kelvin

To accurately apply the law, temperatures must be in Kelvin:

- $T(K) = T(°C) + 273.15$

Suppose we are given the initial temperature in Celsius, or we want to find it, we can proceed accordingly.

Calculating Final Temperature

Using Charles's Law:

$$V_1 / T_1 = V_2 / T_2$$

Rearranged to find T_2:

$T_2 = (V_2 \times T_1) / V_1$

If the initial temperature T_1 is known, T_2 can be calculated directly. Alternatively, if T_1 is unknown, additional information is necessary.

Practical Example: Determining Temperature Change

Suppose:
- The initial temperature T_1 is 25°C (which is 298.15 K),
- The volume expands from 3500 cm^3 to 4700 cm^3.

Calculate the final temperature T_2 in Celsius.

- V_1 = 3500 cm^3
- V_2 = 4700 cm^3
- T_1 = 25°C = 298.15 K

Applying the formula:

$T_2 = (V_2 \times T_1) / V_1$

$T_2 = (4700\ cm^3 \times 298.15\ K) / 3500\ cm^3$

$T_2 \approx (1{,}402{,}050) / 3500$

$T_2 \approx 400.58$ K

Converting back to Celsius:

$T_2(°C) = T_2(K) - 273.15 \approx 400.58 - 273.15 \approx 127.43°C$

Thus, increasing the volume from 3500 cm^3 to 4700 cm^3 at constant pressure and amount of gas, the temperature must have increased from 25°C to approximately 127.43°C.

Implications and Applications of Gas Volume and Temperature Changes

Industrial Applications

Understanding how gases expand or contract with temperature changes is crucial in various industries:

- **Engine Design:** Ensuring cylinders can withstand expansion due to heat.
- **Gas Storage:** Designing containers that accommodate volume changes with temperature fluctuations.
- **HVAC Systems:** Managing air flow and pressure in heating and cooling systems.

Scientific and Laboratory Use

Accurate measurements of gas behavior under different temperatures enable scientists to:

- Determine molecular weights.
- Study gas laws and validate theoretical models.
- Calibrate instruments sensitive to volume and temperature changes.

Environmental and Meteorological Contexts

Temperature-driven volume changes influence weather patterns, altitude calculations, and atmospheric studies.

Factors Affecting Gas Volume Beyond Temperature

While temperature plays a significant role, other factors also influence gas volume:

Pressure Variations

Changes in pressure can cause gases to compress or expand, often working synergistically with temperature effects.

Amount of Gas (Number of Moles)

Adding or removing gas molecules alters the volume, especially at constant temperature and pressure.

Real Gas Behavior

At high pressures or low temperatures, gases deviate from ideal behavior, requiring more complex models like Van der Waals equation for accurate predictions.

Conclusion

The relationship between temperature and volume in gases is a fundamental concept rooted in the principles of thermodynamics and kinetic theory. When the temperature of a gas sample is increased, its volume tends to expand proportionally, provided pressure and the amount of gas remain constant, as described by Charles's Law. Conversely, cooling the gas causes contraction. Understanding this relationship allows scientists and engineers to predict how gases will behave under different thermal conditions, ensuring safety, efficiency, and accuracy in various applications.

By mastering the calculations involved, such as determining the new temperature after a volume change, professionals can design better systems, conduct precise experiments, and interpret atmospheric data effectively. Whether in designing engines, storing gases safely, or studying natural phenomena, the interplay between temperature and volume remains a cornerstone of gas behavior analysis.

Key Takeaways:
- Gas volume and temperature are directly proportional at constant pressure.
- Charles's Law provides the mathematical framework for calculating temperature or volume changes.
- Practical applications span industry, science, and environmental studies.

- Always convert temperatures to Kelvin for accurate calculations.

Understanding how the temperature of a sample of gas influences its volume is essential in science and engineering, helping us harness and predict the behavior of gases in countless real-world scenarios.

Frequently Asked Questions

What is the relationship between temperature and volume of a gas at constant pressure?

At constant pressure, the volume of a gas is directly proportional to its temperature in Kelvin, as described by Charles's Law.

How do you calculate the change in temperature when the volume of a gas changes?

Using Charles's Law: $(V1 / T1) = (V2 / T2)$, where you can solve for $T2 = (V2 \times T1) / V1$.

Given a gas volume changing from 3500 cm^3 to 4700 cm^3, how can you find the new temperature if the initial temperature is known?

Apply Charles's Law: $T2 = (V2 \times T1) / V1$. Plug in the known values to find T2.

What assumptions are made when using Charles's Law for this problem?

The assumptions include constant pressure, ideal gas behavior, and that the amount of gas remains unchanged.

If the initial temperature of the gas is 300 K, what is the new temperature after the volume change?

Using $T_2 = (V_2 \times T_1) / V_1$, $T_2 = (4700 \text{ cm}^3 \times 300 \text{ K}) / 3500 \text{ cm}^3$ □ 402.86 K.

Why does the volume of a gas increase when its temperature increases?

Because increasing temperature provides more kinetic energy to gas particles, causing them to occupy more space, thus increasing volume.

Can the relationship between temperature and volume be used for real gases?

It can approximate behavior for real gases at low pressures and high temperatures, but deviations occur at high pressures or low temperatures.

What is the significance of converting temperatures to Kelvin in these calculations?

Kelvin scale starts at absolute zero, ensuring proportional relationships like Charles's Law are valid; Celsius cannot be used directly for these calculations.

How does pressure affect the relationship between temperature and volume in this context?

If pressure is not constant, the simple proportionality between temperature and volume no longer holds, and Boyle’s or combined gas laws must be applied.

Additional Resources

The temperature of a sample of gas is changed, causing the volume to go from 3500 cm³ to 4700 cm³. If this statement indicates a fundamental principle of gas behavior governed by well-established physical laws. Understanding the relationship between temperature and volume in gases is pivotal not only in theoretical physics but also in practical applications ranging from engineering systems to atmospheric science. This article delves into the underlying principles, detailed explanations of the laws involved, and their implications, providing a comprehensive analysis of what happens when the temperature of a gas sample is altered, and how it influences the volumetric properties.

Understanding Gas Behavior: The Foundations of Gas Laws

The relationship between the temperature, volume, pressure, and amount of gas is described by the ideal gas law, which forms the core of classical thermodynamics and kinetic molecular theory.

The Ideal Gas Law

The ideal gas law is expressed mathematically as:

\[PV = nRT \]

where:

- P = pressure of the gas (in atmospheres, Pa, etc.)
- V = volume of the gas (in liters, m^3, or cm^3)
- n = number of moles of gas
- R = universal gas constant (8.314 J/mol·K)

- T = temperature (in Kelvin)

This law assumes that gas particles are point masses with no intermolecular forces and that collisions are perfectly elastic. Although real gases deviate from this behavior at high pressures or low temperatures, the ideal gas law provides a very accurate approximation under many conditions.

Key Relationships

From the ideal gas law, the following relationships are critical:

- At constant n and P, $V \propto T$ (Volume is directly proportional to temperature)
- At constant n and V, $P \propto T$
- At constant T and n, $P \propto 1/V$

In the context of our problem, where the volume changes with temperature, the proportionality between V and T becomes especially relevant.

Analyzing the Volume Change: From 3500 cm^3 to 4700 cm^3

The initial and final volumes are given as:

- Initial volume, $V_1 = 3500\, \text{cm}^3$
- Final volume, $V_2 = 4700\, \text{cm}^3$

Assuming the gas is confined in a rigid container that can expand or contract, and that the pressure remains constant, the change in volume is directly related to the change in temperature based on the ideal gas law.

Assumptions for Simplification

To analyze the problem:

- Constant pressure (P): The pressure of the gas remains unchanged during the process.
- Constant amount of gas (n): No gas is added or removed.
- Ideal behavior: The gas behaves ideally during the process.

Under these assumptions, the relation simplifies to:

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

or equivalently,

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

where:

- T_1 = initial temperature in Kelvin
- T_2 = final temperature in Kelvin

Rearranging to find the unknown temperature change:

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

Calculating the Temperature Change

Suppose the initial temperature T_1 is known, or a typical starting temperature is assumed (say room temperature, approximately 25°C or 298 K). The change in volume provides a way to calculate the new temperature.

Example Calculation

Assuming:

- Initial temperature $T_1 = 298\, \text{K}$ (25°C)
- Initial volume $V_1 = 3500\, \text{cm}^3$
- Final volume $V_2 = 4700\, \text{cm}^3$

Using the proportionality:

$$T_2 = T_1 \times \frac{V_2}{V_1} = 298 \times \frac{4700}{3500}$$

$$T_2 \approx 298 \times 1.3429$$

$$T_2 \approx 400.2\, \text{K}$$

This corresponds to approximately 127°C (since $T_{°C} = T_{K} - 273$), indicating a significant temperature increase.

Implications of the Calculation

The calculation demonstrates that a substantial increase in temperature (about 102°C) causes the volume to expand from 3500 cm^3 to 4700 cm^3 at constant pressure. This aligns with the fundamental gas law, confirming the direct proportionality between temperature and volume under the specified conditions.

Real-World Applications and Significance

Understanding how gases respond to temperature changes is essential across various scientific and industrial fields.

Engineering and Design

- Engine functioning: Combustion engines rely on the expansion of gases with temperature to generate power.
- Pressure vessels: Knowledge of volume and temperature relationships ensures safety and efficiency in designing pressurized tanks.
- HVAC systems: Heating, ventilation, and air conditioning systems depend on accurate predictions of air and refrigerant behavior.

Atmospheric and Environmental Science

- Climate modeling: Variations in temperature influence atmospheric volume and pressure, affecting weather and climate patterns.
- Pollution dispersion: Temperature-driven expansion or contraction of gases affects how pollutants spread in the atmosphere.

Scientific Research

- Laboratory experiments: Precise control of temperature and volume is crucial for experimental accuracy.
- Materials science: Gases involved in processes like chemical vapor deposition are sensitive to temperature variations.

Beyond the Ideal Gas Law: Real Gas Behavior and Deviations

While the ideal gas law offers a simplified model, real gases exhibit deviations, especially at high pressures and low temperatures.

Van der Waals Equation

The Van der Waals equation introduces correction factors for intermolecular forces and finite molecular size:

$$\left(P + a \left(\frac{n}{V}\right)^2 \right) (V - nb) = nRT$$

where:

- a accounts for attractive forces between molecules
- b accounts for the finite size of molecules

These corrections are significant when gases are compressed or cooled to conditions where ideal behavior no longer holds.

Impacts on the Volume-Temperature Relationship

Deviations mean that:

- The proportionality between volume and temperature becomes less linear.

- At low temperatures or high pressures, gases may liquefy or solidify.
- Accurate modeling requires considering real gas equations and experimental data.

Practical Considerations and Limitations

While calculations based on the ideal gas law are instructive, real-world scenarios often involve complexities:

- Pressure changes: If the pressure is not held constant, the relationship between temperature and volume becomes more complex.
- Heat transfer: In actual processes, heat exchange with surroundings influences temperature changes.
- Container constraints: Physical limitations of containers may restrict volume expansion or contraction.
- Gas purity: Impurities can alter thermodynamic behavior.

Concluding Insights and Future Outlook

The exploration of how temperature influences the volume of a gas sample reveals fundamental thermodynamic principles that underpin countless technological and scientific processes. From the straightforward calculations assuming ideal behavior to the nuanced complexities of real gases, understanding these relationships allows engineers, scientists, and policymakers to make informed decisions in designing systems, predicting environmental changes, and conducting experiments.

Future advancements in materials, measurement techniques, and computational modeling will continue to refine our understanding of gas behavior under various conditions. As we deepen this knowledge, new applications will emerge – from more efficient engines and better climate models to innovations in space exploration and nanotechnology.

In essence, the simple act of changing the temperature of a gas sample and observing its volume change encapsulates the elegance and utility of thermodynamics, bridging theoretical physics with tangible, real-world impact.

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