A Sample Of Gas At Occupies 10m3 At A Pressure Of 120 KPa. If The Volume Of The Sample Is Changed To

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Understanding how gases behave under different conditions is fundamental in chemistry and physics. When a sample of gas undergoes a change in volume, its pressure and temperature also tend to change, depending on the process involved. In this article, we will explore the principles governing such changes, focusing on a specific scenario: a gas occupying 10 cubic meters at a pressure of 120 kPa, and examining what happens when its volume is altered. We will delve into the underlying gas laws, particularly Boyle's Law, and provide detailed calculations and real-world applications to help you grasp these concepts thoroughly.

Understanding the Initial Gas Conditions

Before we analyze what happens when the volume of the gas changes, it's essential to understand the initial state of the gas sample.

Initial Parameters of the Gas Sample

- Volume (V_1): 10 m^3
- Pressure (P_1): 120 kPa
- Temperature (T_1): Assumed constant unless specified

Note: In many classical gas law problems, unless temperature is specified to change, it is often assumed to be held constant (isothermal process).

Fundamental Gas Laws Relevant to Volume Changes

When analyzing how a gas responds to volume changes, several physical laws come into play. The primary laws relevant here are:

Boyle's Law

Boyle's Law states that, for a given amount of gas at constant temperature, the pressure of the gas is inversely proportional to its volume. Mathematically, it is expressed as:

$$P_1V_1 = P_2V_2$$

where:

- P_1, V_1 = initial pressure and volume
- P_2, V_2 = final pressure and volume

Other Gas Laws (Brief Overview)

- **Charles's Law:** relates volume and temperature at constant pressure.
- **Gay-Lussac's Law:** relates pressure and temperature at constant volume.
- **Ideal Gas Law:** combines all three variables (pressure, volume, temperature) with the amount of gas (n), expressed as $PV = nRT$.

In our case, if temperature remains constant, Boyle's Law suffices to analyze volume-pressure relationships.

Calculating the New Pressure After Volume Change

Suppose the volume of the gas sample is changed from 10 m^3 to a new volume V_2. We aim to determine the new pressure P_2, assuming temperature and the amount of gas remain constant.

Scenario 1: Volume Doubles to 20m^3

- $V_2 = 20\ m^3$

Applying Boyle's Law:

$$P_1V_1 = P_2V_2$$

Rearranged to solve for P_2:

$$P_2 = (P_1V_1) / V_2$$

Plugging in the values:

$$P_2 = (120\ KPa \times 10\ m^3) / 20\ m^3 = 1200 / 20 = 60\ KPa$$

Result: When the volume doubles, the pressure halves, indicating an inverse relationship.

Scenario 2: Volume Reduces to 5m^3

- $V_2 = 5\ m^3$

Applying Boyle's Law:

$$P_2 = (120\ KPa \times 10\ m^3) / 5\ m^3 = 1200 / 5 = 240\ KPa$$

Result: Reducing the volume to half doubles the pressure.

Implications of Volume Changes on Gas Behavior

Understanding the relationship between volume and pressure helps in various practical scenarios:

Applications in Engineering and Industry

- Designing pressurized systems like scuba tanks, where volume and pressure must be carefully managed.
- Calculating gas pressures in HVAC systems and pneumatic tools.
- Understanding how engine cylinders compress gases during operation.

Real-World Examples of Volume-Pressure Relationships

- In a bicycle pump, compressing the pump increases pressure proportionally to decreasing volume.
- In deep-sea diving, increasing water pressure compresses air in tanks, affecting volume and pressure relationships.

Effect of Temperature on Gas Volume and Pressure

While Boyle's Law assumes constant temperature, real-world scenarios often involve temperature changes which influence the behavior of gases.

Charles's Law: Volume and Temperature

At constant pressure, the volume of a gas is directly proportional to its temperature:

$$V_1 / T_1 = V_2 / T_2$$

Gay-Lussac's Law: Pressure and Temperature

At constant volume, the pressure is directly proportional to temperature:

$$P_1 / T_1 = P_2 / T_2$$

Note: To accurately predict gas behavior when temperature varies, the ideal gas law $PV = nRT$ is used, where R is the universal gas constant and n is the amount of substance.

Calculating Final Conditions When Temperature Changes

Suppose the temperature of the gas also changes when the volume is altered. For example, if the initial temperature T_1 is 300 K, and the final temperature T_2 is 350 K, with the volume changing from 10 m^3 to 15 m^3, what will be the final pressure?

Using the combined gas law:

$$(P_1V_1) / T_1 = (P_2V_2) / T_2$$

Rearranged to find P_2:

$$P_2 = (P_1 V_1 T_2) / (V_2 T_1)$$

Plugging in the values:

$$P_2 = (120 \text{ KPa} \times 10 \text{ m}^3 \times 350 \text{ K}) / (15 \text{ m}^3 \times 300 \text{ K}) = (120 \times 10 \times 350) / (15 \times 300) = (420{,}000) / (4{,}500) \approx 93.33 \text{ KPa}$$

This example illustrates how increasing temperature can influence pressure and volume simultaneously.

Summary and Key Takeaways

- The behavior of gases under changing volume conditions can be effectively described using Boyle's Law, which states that pressure and volume are inversely proportional at constant temperature.
- When the volume of a gas increases, the pressure decreases proportionally, and vice versa.
- Calculations are straightforward: $P_2 = (P_1V_1) / V_2$, assuming temperature remains constant.
- In real-world applications, temperature changes often accompany volume changes, requiring the use of combined gas laws or the ideal gas law for accurate predictions.
- Understanding these principles is critical in fields like engineering, meteorology, medicine, and chemical manufacturing.

Final Thoughts

Manipulating the volume of a gas provides a simple yet powerful way to control its pressure, essential in a wide array of scientific and industrial processes. Whether designing pressurized systems, understanding natural phenomena, or conducting laboratory experiments, grasping the relationship between volume and pressure, rooted in Boyle's Law, is fundamental. Remember, always consider temperature variations and the amount of gas for comprehensive analyses, especially in complex situations.

By mastering these concepts, you can predict and control gas behavior more accurately, ensuring safety, efficiency, and innovation in your applications involving gases.

Frequently Asked Questions

What is the initial volume and pressure of the gas sample?

The initial volume is 10 m^3 and the pressure is 120 KPa.

How does changing the volume of a gas sample affect its pressure if temperature remains constant?

According to Boyle's Law, if temperature and amount of gas are constant, increasing the volume decreases the pressure, and decreasing the volume increases the pressure.

What is Boyle's Law and how is it applied in this scenario?

Boyle's Law states that for a fixed amount of gas at constant temperature, pressure and volume are inversely proportional ($P_1V_1 = P_2V_2$). It can be used to determine the new pressure or volume after a change.

If the volume of the gas is changed to 20 m³, what will be the new pressure?

Using Boyle's Law: $P_1V_1 = P_2V_2$. So, $P_2 = (P_1V_1) / V_2 = (120 \text{ kPa} \times 10 \text{ m}^3) / 20 \text{ m}^3 = 60$ kPa.

What assumptions are made when applying Boyle's Law in this problem?

It is assumed that the temperature and the amount of gas remain constant during the volume change, and the gas behaves ideally.

Additional Resources

Understanding Gas Behavior: Analyzing Volume Changes at Constant Conditions

In the realm of thermodynamics and fluid mechanics, gases exhibit fascinating behaviors governed by well-established physical laws. One fundamental principle involves understanding how the volume, pressure, and temperature of a gas relate to each other, especially when subjected to changes. This article delves into a specific scenario: a gas sample initially occupying 10 cubic meters (m^3) at a pressure of 120 kilopascals (kPa), and explores how its volume responds when subjected to various conditions. Through detailed explanations and analytical insights, we aim to elucidate the underlying principles governing such transformations, providing a comprehensive understanding for students, engineers, and science enthusiasts alike.

Initial Conditions and Basic Assumptions

Understanding the Given Data

The problem begins with a gas sample characterized by the following initial conditions:

- Initial volume (V_1): 10 m^3
- Initial pressure (P_1): 120 kPa
- Initial temperature (T_1): Not explicitly provided, which introduces the necessity for assumptions or additional data to proceed.

In analyzing gas behavior, the relationship among pressure, volume, and temperature is encapsulated by the Ideal Gas Law:

\[PV = nRT \]

where:

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

For the purpose of this analysis, unless otherwise specified, we assume that the gas behaves ideally and that the process occurs at constant temperature (isothermal conditions). This is a common assumption in many practical problems because gases tend to behave ideally under moderate pressures and temperatures.

Key assumption: The temperature remains constant during the volume change, which simplifies the analysis to

Boyle's Law, a subset of the ideal gas law.

Boyle's Law and Its Implications

Boyle's Law states that, for a fixed amount of gas at constant temperature, the pressure and volume are inversely proportional:

$$P_1 V_1 = P_2 V_2$$

where:

- P_1, V_1 = initial pressure and volume
- P_2, V_2 = final pressure and volume after change

This relationship forms the backbone for analyzing how the volume of the gas adjusts when pressure changes, assuming temperature remains unchanged.

Important considerations:

- The law applies strictly when temperature and the amount of gas are constant.
- Deviations occur if temperature varies or if the gas behaves non-ideally at high pressures or low temperatures.

Scenario 1: Changing the Pressure and Finding the New Volume

Suppose the problem states, "If the volume of the sample is changed to a new value, what is the corresponding pressure?" or vice versa. Without explicit parameters, we explore typical cases.

Case A: Increasing Pressure at Constant Temperature

If the gas is compressed, increasing the pressure from 120 kPa to a higher value, the new volume can be calculated using Boyle's Law.

Example:

- Final pressure, P_2 = 240 kPa (doubling the initial pressure)

Applying Boyle's Law:

$$P_1 V_1 = P_2 V_2$$

$$120\, \text{kPa} \times 10\, \text{m}^3 = 240\, \text{kPa} \times V_2$$

$$V_2 = \frac{120 \times 10}{240} = 5\, \text{m}^3$$

Interpretation:

- Doubling the pressure halves the volume, consistent with the inverse relationship.

Case B: Reducing Pressure

If the pressure decreases, the volume increases proportionally.

- For example, $P_2 = 60$ kPa:

$$ V_2 = \frac{120 \times 10}{60} = 20\, \text{m}^3 $$

This illustrates the inverse relationship vividly: halving the pressure doubles the volume.

Scenario 2: Changing Volume and Determining the Pressure

Suppose the volume is increased or decreased, and the task is to find the resulting pressure.

Example:

- Final volume, $V_2 = 15$ m^3

Using Boyle's Law:

$$ P_2 = \frac{P_1 V_1}{V_2} = \frac{120 \times 10}{15} = 80\, \text{kPa} $$

Implication:

- Increasing the volume from 10 m^3 to 15 m^3 decreases the pressure from 120 kPa to 80 kPa.

Considerations When Temperature Is Not Constant

While Boyle's Law provides a straightforward approach under isothermal conditions, real-world scenarios often involve temperature variations. If temperature changes, the Combined Gas Law applies:

$$ \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} $$

This equation accounts for both pressure and temperature changes, making it essential in more complex situations.

Example:

Suppose the temperature increases from T_1 to T_2, then the relationship becomes:

$$ P_1 V_1 / T_1 = P_2 V_2 / T_2 $$

If T_2 is known, the new pressure or volume can be calculated accordingly.

Real-World Applications and Practical Implications

Understanding how gases respond to volume and pressure changes is crucial across various industries and scientific fields:

1. Chemical Engineering

Designing reactors and storage tanks requires precise knowledge of gas behavior under different conditions, ensuring safety and efficiency.

2. Aerospace Engineering

Rocket propulsion relies on the expansion of gases; understanding the relationship between pressure and volume guides the design of engines and fuel systems.

3. Environmental Science

Monitoring atmospheric gases and pollutants involves analyzing changes in gas volumes under varying pressure and temperature conditions.

4. Medical Devices

Instruments such as ventilators depend on accurate control of gas volumes and pressures to ensure patient safety.

Limitations and Deviations from Ideal Behavior

While the ideal gas law provides a solid foundation, real gases exhibit deviations, especially under high pressures or low temperatures. Key factors include:

- Intermolecular Forces: Attractive or repulsive forces between molecules affect pressure and volume.
- Finite Molecular Size: Molecules occupy space, influencing volume calculations.
- Critical Points: Near phase transition points, gases may liquefy, invalidating ideal assumptions.

Real gases are better modeled using equations like the Van der Waals equation, which introduces correction factors for these deviations.

Conclusion: Integrating Principles for Accurate Predictions

The analysis of a gas sample initially occupying 10 m^3 at 120 kPa underscores fundamental thermodynamic principles, notably Boyle's Law, in predicting how gases respond to volume or pressure changes under constant temperature. Recognizing the assumptions and limitations of these laws is vital for accurate modeling and practical application.

In real-world scenarios, engineers and scientists often combine these principles with advanced equations and empirical data to account for non-ideal behaviors. Whether designing a spacecraft's fuel system, managing industrial gas storage, or conducting laboratory experiments, understanding the detailed relationships among pressure, volume, and temperature remains essential.

By mastering these concepts, professionals can ensure safety, optimize performance, and deepen their comprehension of the dynamic behaviors that gases exhibit across countless applications. As research advances and technology evolves, the foundational laws explored here continue to serve as the bedrock of thermodynamic understanding and innovation.

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