

In One Or Two Sentences, Describe A Scenario Using The Combined Gas Law In Which Changes Occur In The

In One Or Two Sentences, Describe A Scenario Using The Combined Gas Law In Which Changes Occur In The a sealed container during a temperature increase, illustrating how pressure, volume, and temperature are interrelated according to the combined gas law, which is fundamental in understanding real-world gas behavior in various scientific and industrial applications.

Understanding the Combined Gas Law

The combined gas law is a fundamental principle in chemistry that describes the relationship between pressure (P), volume (V), and temperature (T) of a fixed amount of gas when these variables change. It combines Boyle's Law, Charles's Law, and Gay-Lussac's Law into a single equation:

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

where:

- (P_1) , (V_1) , (T_1) are the initial pressure, volume, and temperature,
- (P_2) , (V_2) , (T_2) are the final pressure, volume, and temperature.

This law assumes the amount of gas remains constant and temperature must be in Kelvin to ensure proper calculations.

Real-World Scenario: Heating a Gas in a Sealed Container

Imagine a scenario where a scientist heats a sealed, rigid container of gas. Initially, the gas is at a certain pressure, volume, and temperature. When heated, the gas particles gain kinetic energy, leading to increased pressure if the volume is fixed, or increased volume if the pressure is held constant, or a combination of both if both variables are free to change.

The Setup:

- The gas is enclosed in a rigid, sealed container with a fixed volume.
- Initially, the gas is at room temperature (around 25°C or 298 K) with a pressure of 1 atm.
- The scientist heats the container to a higher temperature, say 100°C (373 K).

What Happens During Heating?

Since the container is rigid and sealed:

- Volume remains constant because the walls of the container do not allow expansion.
- Temperature increases from 298 K to 373 K.
- Pressure increases due to the increase in kinetic energy of gas particles.

Applying the combined gas law:

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

Given that $(V_1 = V_2)$ (fixed volume), the equation simplifies to:

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

which rearranges to:

$$P_2 = P_1 \times \frac{T_2}{T_1}$$

Substituting the known values:

$$P_2 = 1 \text{ atm} \times \frac{373 \text{ K}}{298 \text{ K}} \approx 1.25 \text{ atm}$$

This indicates that by heating the gas from 25°C to 100°C in a sealed, rigid container, the pressure increases from 1 atm to approximately 1.25 atm.

Implications of the Combined Gas Law in Industrial and Scientific Contexts

Understanding how gases behave under different conditions is crucial in various industries, including:

- Aerospace Engineering: Designing pressurized cabins that withstand temperature fluctuations during flights.
- Chemical Manufacturing: Controlling pressure and temperature during

reactions to ensure safety and efficiency.

- Medical Applications: Ensuring proper functioning of gas-based devices like ventilators that operate under varying conditions.

Key Takeaways:

- In a rigid container, increasing temperature results in increased pressure.
- In a flexible container, the volume adjusts with temperature changes if pressure is kept constant.
- The combined gas law allows for precise calculations of how one variable changes when others are altered.

Additional Scenarios Using the Combined Gas Law

While the previous example focused on heating a fixed-volume container, the combined gas law applies to many other situations:

1. Expansion of a Gas in a Balloon:

- As temperature rises, the balloon expands if the pressure is constant.
- Calculations can determine the new volume after heating.

2. Compression of Gases:

- If a gas is compressed in a cylinder, the temperature change can be predicted.
- Useful in refrigeration cycles and internal combustion engines.

3. Altitude and Atmospheric Pressure:

- As altitude increases, pressure decreases, affecting gas volume and temperature.
- The combined gas law helps model these changes.

Practical Exercise:

Suppose a gas in a flexible container has an initial volume of 2 liters at 300 K and 1 atm. If the temperature increases to 350 K and the pressure is maintained constant, what is the new volume?

Using Charles's Law (a special case of the combined gas law):

$$\left[\frac{V_1}{T_1} = \frac{V_2}{T_2} \right]$$

Rearranged to:

$$\left[V_2 = V_1 \times \frac{T_2}{T_1} \right]$$

Substitute the known values:

$V_2 = 2 \text{ L} \times \frac{350 \text{ K}}{300 \text{ K}} \approx 2.33 \text{ L}$

The gas volume expands to approximately 2.33 liters when heated from 300 K to 350 K at constant pressure.

Conclusion: The Significance of the Combined Gas Law

The combined gas law provides a comprehensive framework for understanding and predicting how gases respond to simultaneous changes in pressure, volume, and temperature. Whether in laboratory experiments, industrial processes, or environmental science, this law is essential for ensuring safety, efficiency, and accuracy in manipulating gaseous systems.

By mastering the principles of the combined gas law, scientists and engineers can anticipate the behavior of gases in diverse scenarios, making it an indispensable tool in both theoretical and practical applications.

Frequently Asked Questions

How does the combined gas law explain the behavior of a balloon shrinking when cooled at constant pressure?

It shows that as temperature decreases, the volume decreases proportionally, demonstrating the inverse relationship between temperature and volume when pressure is constant.

In a scuba tank, how does increasing the temperature affect the pressure and volume of the gas inside according to the combined gas law?

Increasing temperature causes the pressure and volume of the gas to increase proportionally if the other variables are held constant.

Describe a scenario where a car tire's pressure changes with temperature, using the combined gas

law.

As the tire heats up from driving, the gas's temperature rises, and the pressure increases, illustrating the relationship between temperature and pressure at constant volume.

How does the combined gas law explain the expansion of a hot air balloon as it heats up?

Heating the air inside increases its temperature and volume, causing the balloon to expand, consistent with the combined gas law's relationship among pressure, volume, and temperature.

In what way does the combined gas law relate to the compression of a gas in a piston when cooled?

Cooling the gas reduces its temperature, leading to a decrease in volume if pressure remains constant, as described by the combined gas law.

How can the combined gas law be used to predict changes in a gas sample when both pressure and temperature vary?

It allows calculating the new volume or pressure based on initial conditions when temperature and pressure change simultaneously, keeping the amount of gas constant.

Explain how the combined gas law applies when a container of gas is cooled from 300K to 150K at constant pressure.

The volume of the gas decreases by half, as volume is directly proportional to temperature at constant pressure according to the combined gas law.

What scenario illustrates the combined gas law where both temperature and volume change while pressure remains constant?

Cooling a heated gas in a flexible container causes the volume to decrease proportionally to the temperature decrease, following the combined gas law.

How does the combined gas law help explain the behavior of a pressure cooker when heated?

Heating increases the temperature and pressure of the gas inside, which

expands the volume if the container allows, consistent with the law's relationships.

In a laboratory experiment, how would increasing the temperature of a gas in a rigid container affect its pressure according to the combined gas law?

Since volume is constant, increasing temperature raises the pressure proportionally, as described by the combined gas law.

Additional Resources

In one or two sentences, describe a scenario using the combined gas law in which changes occur in the temperature, pressure, and volume of a gas, illustrating how these variables interact under different conditions.

Introduction

The combined gas law is a fundamental principle in chemistry and physics that describes how the pressure, volume, and temperature of a fixed amount of gas are interrelated. It synthesizes Boyle's Law, Charles's Law, and Gay-Lussac's Law into a single equation, providing a comprehensive understanding of gas behavior under varying conditions. This law is essential in numerous real-world applications, from industrial processes to weather phenomena, where the state of gases changes dynamically. To appreciate the practical implications of the combined gas law, consider a scenario involving a sealed cylinder containing gas subjected to temperature changes, which consequently affects its pressure and volume.

Understanding the Combined Gas Law

Definition and Mathematical Expression

The combined gas law states that for a fixed amount of gas, the ratio of the pressure multiplied by volume to temperature remains constant, expressed mathematically as:

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

where:

- (P_1, V_1, T_1) are the initial pressure, volume, and temperature.
- (P_2, V_2, T_2) are the final pressure, volume, and temperature.

This equation allows us to predict how one variable will change when the other two are altered, assuming the amount of gas remains unchanged.

Physical Significance

- Pressure (P): The force exerted by gas molecules colliding with container walls.
- Volume (V): The space occupied by the gas.
- Temperature (T): A measure of the average kinetic energy of gas molecules.

The law explains that if temperature increases, the gas tends to expand (increase in volume) or exert more pressure if confined, while cooling causes contraction or pressure reduction.

Real-World Scenario: A Heated Gas Cylinder

Setting the Scene

Imagine a sealed, rigid cylinder containing compressed gas, such as oxygen, used in industrial welding. Initially, the gas is at a pressure of 2 atm, a volume of 10 liters, and a temperature of 300 K (Kelvin). The operator heats the cylinder, raising its temperature to 450 K. During this process, the cylinder is flexible enough to allow volume change, or pressure is monitored so adjustments can be made.

Applying the Combined Gas Law

In this scenario, both temperature and pressure are changing, and the volume may also vary if the cylinder is flexible. The key question is: How will the pressure and volume change when the temperature increases?

Using the combined gas law:

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

If the cylinder's volume is allowed to change (e.g., a flexible container), the operator can calculate the new pressure and volume after heating:

- Initial conditions:
 - $P_1 = 2$, atm
 - $V_1 = 10$, L
 - $T_1 = 300$, K
- Final temperature:
 - $T_2 = 450$, K

Assuming the volume is flexible, the operator might want to know the new

pressure (P_2) and volume (V_2).

Detailed Analytical Breakdown

1. When Volume is Allowed to Change

Suppose the operator wants to maintain a constant pressure, or observe how pressure and volume change with temperature. For simplicity, let's analyze how the pressure adjusts if the volume remains constant:

$$V_1 = V_2$$

Thus,

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

$$P_2 = P_1 \times \frac{T_2}{T_1}$$

$$P_2 = 2 \text{ atm} \times \frac{450 \text{ K}}{300 \text{ K}} = 3 \text{ atm}$$

Result: The pressure increases from 2 atm to 3 atm when the temperature rises from 300 K to 450 K, assuming volume remains constant.

2. When Pressure is Maintained Constant

If the pressure is kept constant (e.g., the cylinder is flexible or connected to a pressure regulator), then:

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

$$V_2 = V_1 \times \frac{T_2}{T_1} = 10 \text{ L} \times \frac{450 \text{ K}}{300 \text{ K}} = 15 \text{ L}$$

Result: The volume expands from 10 liters to 15 liters as the temperature increases, assuming the pressure remains constant.

3. Combined Changes: Both Pressure and Volume Vary

In a more complex scenario, both pressure and volume could change

simultaneously, such as in an adaptable container with a pressure release mechanism. Suppose the operator observes that the pressure increases to 3 atm after heating; then, using the law:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$
$$V_2 = V_1 \times \frac{P_1 T_2}{P_2 T_1}$$
$$V_2 = 10\text{ L} \times \frac{2\text{ atm} \times 450\text{ K}}{3\text{ atm} \times 300\text{ K}} = 10\text{ L} \times \frac{900}{900} = 10\text{ L}$$

Result: Interestingly, the volume remains the same when pressure increases proportionally with temperature, indicating a direct relationship.

Practical Implications and Safety Considerations

Industrial Applications

Understanding how gases respond to temperature changes is critical in industrial settings for safety and efficiency. For example:

- Welding and Cutting: Gas cylinders are heated or pressurized; knowing how pressure and volume change helps prevent accidents.
- Chemical Manufacturing: Reactions involving gases often require precise control of temperature and pressure for optimal yields.
- Aviation: Cabin pressurization relies on predictable gas behavior with altitude-induced temperature changes.

Safety Precautions

- Monitoring Variables: Operators must regularly monitor pressure and temperature to prevent over-pressurization.
- Vessel Design: Equipment should accommodate volume changes due to heating.
- Emergency Protocols: Systems should release pressure safely if gases expand beyond safe limits.

Broader Scientific Significance

Atmospheric Science

The combined gas law helps explain weather patterns, such as how warm air rises (expanding and decreasing in pressure), leading to cloud formation and

storms.

Engineering and Design

Engineers use the law to design engines, pressurized containers, and HVAC systems, ensuring they operate safely under temperature fluctuations.

Limitations

While powerful, the combined gas law assumes ideal gas behavior, which may not hold under extremely high pressures or low temperatures where gases deviate from ideality.

Conclusion

The combined gas law offers a versatile framework to predict and analyze how gases respond to simultaneous changes in pressure, volume, and temperature. The scenario of heating a gas within a cylinder demonstrates the interconnectedness of these variables, emphasizing the importance of understanding these relationships in practical applications. Whether in industrial safety, atmospheric science, or engineering, mastering the principles of the combined gas law enables professionals to design safer systems, optimize processes, and deepen scientific comprehension of gas behavior under varying conditions.

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