

Describe A Scenario Using The Combined Gas Law In Which Changes Occur In The Pressure And Temperature

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Understanding the behavior of gases under varying conditions is fundamental in chemistry and physics. The combined gas law provides a mathematical relationship that explains how pressure, volume, and temperature of a gas are interconnected when multiple variables change simultaneously. In this article, we will explore a detailed scenario demonstrating how the combined gas law operates in real-life situations where both pressure and temperature undergo alterations, illustrating the principles with clarity and depth.

Introduction to the Combined Gas Law

The combined gas law is derived from Boyle's law, Charles's law, and Gay-Lussac's law, which describe the relationships between pressure, volume, and temperature of gases under specific conditions. The combined gas law consolidates these into a single formula:

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

Where:

- P_1 and P_2 are the initial and final pressures,
- V_1 and V_2 are the initial and final volumes,
- T_1 and T_2 are the initial and final temperatures (measured in Kelvin).

This law is particularly useful when a gas's pressure and temperature change simultaneously, and the volume remains constant or is known to vary accordingly.

Setting the Scene: A Real-World Scenario

Imagine a sealed, rigid container—a metal cylinder—that contains a specific amount of gas, such as oxygen. This cylinder is initially at room temperature and atmospheric pressure. Now, suppose this container is subjected to a series of changes: it is heated externally while being transported to a higher altitude, causing both the temperature and pressure inside the container to change.

Let's define the initial conditions:

- Initial pressure, (P_1) : 1 atm (atmospheric pressure)
- Initial temperature, (T_1) : 25°C (which converts to 298 K)
- Initial volume, (V_1) : fixed (since the container is rigid)

The key points of this scenario are:

- The container is heated externally, raising the temperature to a higher value.
- The container is taken to a higher altitude, where atmospheric pressure decreases.
- The container remains sealed, so the amount of gas and volume stay constant unless specified otherwise.

Step-by-Step Application of the Combined Gas Law

Step 1: Establish Initial Conditions

- $(P_1 = 1 \text{ atm})$
- $(T_1 = 25^\circ\text{C} = 298 \text{ K})$
- $(V_1 = \text{constant})$

Step 2: External Heating and Altitude Change

Suppose the container is heated to 100°C (373 K). Simultaneously, it is transported to an altitude where atmospheric pressure drops to 0.5 atm due to thinner air.

- Final temperature, $(T_2 = 100^\circ\text{C} = 373 \text{ K})$
- Final pressure, $(P_2 = 0.5 \text{ atm})$

Since the container is rigid, the volume remains constant:

- $(V_2 = V_1)$

We can now use the combined gas law to analyze what happens to the pressure inside the container during this process.

Analyzing the Scenario Using the Combined Gas Law

Given the initial and final conditions, the combined gas law simplifies because volume remains constant:

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

Rearranged, the final pressure:

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

Plugging in the known values:

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

Interpretation: Even though the external atmospheric pressure drops to 0.5 atm at higher altitude, the internal pressure of the gas inside the sealed container increases to approximately 1.25 atm due to heating. This is because the temperature increase causes the gas particles to move more rapidly, increasing pressure within the sealed environment according to Gay-Lussac's law, a part of the combined gas law.

Implications and Real-World Applications

This scenario exemplifies several important concepts:

- **Pressure-Temperature Relationship:** When a gas is confined in a rigid container, heating causes an increase in pressure, even if external pressure decreases.
- **Effect of External Conditions on Internal Gas Behavior:** External temperature and pressure changes influence the internal state of gases, which is critical in engineering and safety considerations.
- **Designing Pressure-Resistant Containers:** Understanding these relationships helps in designing tanks and cylinders that can withstand internal pressure fluctuations due to temperature changes.

Extended Scenario: Volume Change in a Flexible Container

To deepen understanding, consider a variation where the container is flexible (like a balloon), allowing volume to change as well.

Suppose:

- Initial conditions: $(P_1 = 1 \text{ atm}), (V_1 = 2 \text{ L}), (T_1 = 298 \text{ K})$
- Heating to $(T_2 = 373 \text{ K})$
- External pressure at high altitude: $(P_2 = 0.5 \text{ atm})$

Applying the combined gas law:

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

Solving for (V_2) :

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

Plugging in the values:

$$V_2 = 2 \text{ L} \times \frac{1 \text{ atm}}{0.5 \text{ atm}} \times \frac{373 \text{ K}}{298 \text{ K}} \approx 2 \text{ L} \times 2 \times 1.25 = 5 \text{ L}$$

Interpretation: The flexible container expands from 2 L to approximately 5 L due to the combined effects of increased temperature and decreased external pressure, demonstrating how volume adjusts in response to these variables.

Critical Insights and Takeaways

This scenario underscores vital principles of gas behavior:

- Interdependence of Pressure, Volume, and Temperature: Changes in any two variables affect the third, as captured by the combined gas law.
- Real-Life Relevance: Engineers, chemists, and safety professionals use these principles to predict gas behavior in pipelines, submarines, spacecraft, and industrial processes.
- Predictive Power: The combined gas law provides a reliable method to forecast how gases respond to environmental changes, aiding in the design of equipment and safety protocols.

Conclusion

Using the combined gas law to analyze a scenario where both pressure and temperature change reveals the intricate balance gases maintain under varying conditions. Whether in sealed rigid containers or flexible balloons, the law provides a quantitative framework to predict and understand gas behavior. Recognizing these relationships is essential across scientific and engineering disciplines, ensuring safety, efficiency, and innovation in

applications involving gases.

In summary, the scenario of heating a sealed container at high altitude beautifully illustrates how temperature increases can raise internal pressure despite external pressure decreasing, thanks to the principles encapsulated in the combined gas law. This understanding enables professionals to anticipate outcomes and design systems that account for the dynamic nature of gases in our environment.

Frequently Asked Questions

How does the combined gas law explain the change in pressure and temperature when a gas in a sealed container is heated?

The combined gas law states that $(P_1 \times V_1)/T_1 = (P_2 \times V_2)/T_2$. If the volume remains constant and the temperature increases, the pressure must also increase proportionally, illustrating how heating a gas in a sealed container raises its pressure.

What scenario demonstrates the combined gas law when a gas expands and cools simultaneously?

Imagine a gas in a piston that expands freely while being cooled. As the gas expands (increasing volume) and temperature drops, the combined gas law shows how pressure decreases if the volume increases and temperature decreases, maintaining the relationship between these variables.

In what way does the combined gas law apply when releasing compressed gas into a lower-pressure environment with temperature changes?

When releasing compressed gas, if the temperature decreases due to cooling and the pressure drops, the combined gas law helps predict the new pressure and temperature based on initial conditions, assuming volume remains constant or known.

How can the combined gas law be used to determine the final pressure and temperature of a gas after heating and compression?

By knowing the initial pressure, temperature, and volume, and the changes in volume or temperature, the combined gas law allows calculation of the final pressure and temperature, considering the relationships between these variables during heating and compression.

What real-life example illustrates the application of the combined gas law involving changes in pressure

and temperature?

A common example is a bicycle pump: when you pump air into the tire, increasing pressure and temperature, the combined gas law explains how these variables are related, especially when the volume of the tire remains constant but both pressure and temperature change.

Additional Resources

Combined Gas Law

Introduction: The Significance of the Combined Gas Law in Real-World Scenarios

Imagine a bustling industrial facility where gases are transported, stored, and utilized under varying conditions. Whether it's an industrial furnace, scuba diving tanks, or even weather systems, understanding how gases behave when pressure, temperature, and volume change is crucial for safety, efficiency, and innovation. The Combined Gas Law elegantly encapsulates these relationships, providing a comprehensive framework to predict how a gas's pressure, volume, and temperature interact under different conditions.

In this article, we explore a detailed scenario illustrating the practical application of the combined gas law, emphasizing how changes in pressure and temperature influence a gas's behavior. By examining this scenario step-by-step, we aim to shed light on the law's significance in engineering, scientific research, and everyday life.

Understanding the Combined Gas Law: A Primer

Before diving into the scenario, it is essential to comprehend the core principle behind the combined gas law. It synthesizes three fundamental gas laws:

- Boyle's Law: $(P_1V_1 = P_2V_2)$ (at constant temperature)
- Charles's Law: $(\frac{V_1}{T_1} = \frac{V_2}{T_2})$ (at constant pressure)
- Gay-Lussac's Law: $(\frac{P_1}{T_1} = \frac{P_2}{T_2})$ (at constant volume)

The combined gas law integrates these into a single equation:

$$\left[\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \right]$$

where:

- P is the pressure,
- V is the volume,
- T is the temperature in Kelvin,
- Subscripts 1 and 2 denote initial and final states, respectively.

This law is particularly valuable when more than one of the variables—pressure, volume, temperature—change simultaneously, and it allows scientists and engineers to predict the outcome of such changes precisely.

Scenario Description: The Heating of a Compressed Gas Cylinder

Let's consider a real-world scenario involving a pressurized gas cylinder used in industrial welding operations. The cylinder contains oxygen gas at a high pressure and ambient temperature. Suppose the cylinder is initially at:

- Initial pressure, P_1 : 200 atm
- Initial temperature, T_1 : 300 K (approximately 27°C)
- Initial volume, V_1 : 10 liters

The process involves heating the cylinder while keeping the volume constant (since the cylinder's volume is fixed). During this heating, the pressure and temperature change, and we want to determine the new pressure after the temperature increases to 600 K.

This scenario is common in industrial settings, where gases are often heated to facilitate reactions or processes, and understanding the resulting pressure changes is critical for safety and equipment integrity.

Applying the Combined Gas Law Step-by-Step

Step 1: Identify known and unknown variables

Variable	Initial State (1)	Final State (2)
Pressure (P)	200 atm	?
Temperature (T)	300 K	600 K
Volume (V)	10 L	10 L

Since the volume remains constant ($V_1 = V_2$), the combined gas law simplifies when solving for pressure:

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

Step 2: Rearrange the formula to solve for the unknown pressure

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

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

Step 3: Plug in the known values

$$P_2 = 200 \text{ atm} \times \frac{600 \text{ K}}{300 \text{ K}} = 200 \text{ atm} \times 2 = 400 \text{ atm}$$

Step 4: Interpret the results

The pressure in the cylinder doubles to 400 atm when the temperature increases from 300 K to 600 K, assuming the volume remains fixed and the gas behaves ideally.

Implications and Safety Considerations

This example underscores a crucial principle: pressure and temperature are directly proportional when volume is held constant. In practical terms, heating a pressurized cylinder significantly increases the internal pressure, which can pose safety risks if the cylinder is not designed to withstand such high pressures.

Safety protocols in industrial settings often include:

- Pressure relief valves to prevent over-pressurization.
- Temperature monitoring to avoid exceeding safe operating limits.
- Regular maintenance to ensure structural integrity under changing conditions.

Failure to account for these changes could lead to catastrophic failures, including explosion or leaks, emphasizing the importance of understanding the combined gas law.

Alternative Scenario: Allowing Volume Expansion

To further explore the flexibility of the combined gas law, consider a different scenario where the gas is allowed to expand during heating, such as in a flexible container or a piston system.

Suppose the same initial conditions apply:

- $P_1 = 200 \text{ atm}$
- $T_1 = 300 \text{ K}$
- $V_1 = 10 \text{ L}$

And the gas is heated to:

- $T_2 = 600 \text{ K}$

Now, if the container can expand freely, what is the final volume (V_2) ?

Using the combined gas law:

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

Assuming the pressure remains constant at 200 atm (e.g., a pressure regulator maintains pressure), the equation simplifies to Charles's Law:

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

Rearranged:

$$V_2 = V_1 \times \frac{T_2}{T_1} = 10\text{ L} \times 2 = 20\text{ L}$$

This doubling of volume during heating demonstrates how gases expand when heated at constant pressure, aligning with everyday observations like a balloon expanding in the sun.

Real-World Applications and Broader Impacts

The combined gas law isn't confined to academic exercises; it underpins many technological and scientific advancements:

- Aerospace Engineering: Designing pressurized cabins and fuel tanks requires precise calculations of gas behavior at varying altitudes and temperatures.
- Medical Devices: Oxygen tanks and anesthesia machines rely on predictable gas behavior under changing conditions.
- Environmental Science: Modeling atmospheric pressure and temperature variations helps in weather prediction and climate studies.
- Industrial Processes: In chemical manufacturing, controlling temperature and pressure ensures safety and optimal yields.

Understanding how pressure and temperature influence gases through the combined gas law allows engineers and scientists to predict outcomes accurately, optimize designs, and prevent accidents.

Conclusion: Mastering Gas Behavior for Safety and Innovation

The scenario of heating a pressurized gas cylinder vividly demonstrates the practical importance of the combined gas law. It reveals that increasing temperature at constant volume results in proportional increases in pressure—a principle that must be carefully managed in industrial

applications. Conversely, allowing volume to change during heating illustrates the gas's capacity to expand, emphasizing the law's versatility.

In essence, the combined gas law provides a fundamental tool for predicting and controlling gas behavior across countless domains. Whether safeguarding personnel in a manufacturing plant or designing advanced aerospace systems, mastery of this principle is indispensable. As technology advances and safety standards become more stringent, a thorough understanding of how pressure and temperature interplay in gases remains vital – a testament to the enduring relevance of the combined gas law in science and industry.

Note: Always remember to convert temperatures to Kelvin when applying the combined gas law, as it uses absolute temperature for calculations.

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