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Understanding the behavior of gases under various conditions is fundamental in thermodynamics and physical chemistry. When a sample of an ideal gas undergoes a change—such as a contraction in volume—it's essential to analyze how its pressure, temperature, and other properties are affected. This article provides a comprehensive exploration of such a process, focusing on the case where an ideal gas initially at 300 K, 1.0 atm, and occupying 2.0 liters experiences a contraction in volume.

Introduction to Gas Laws and Ideal Gas Behavior

What Is an Ideal Gas?

An ideal gas is a hypothetical gas composed of point particles that do not interact with each other except through elastic collisions. Although no real gas perfectly fits this model, many gases behave ideally under certain conditions (low pressure and high temperature).

Fundamental Gas Laws

The behavior of ideal gases is described by several fundamental laws:

1. **Boyle's Law**: For a fixed amount of gas at constant temperature, the pressure and volume are inversely proportional (PV = const).

2. **Charles's Law**: At constant pressure, the volume is directly proportional to temperature (V/T = const).

3. **Gay-Lussac's Law**: At constant volume, the pressure is directly proportional to temperature (P/T = const).

4. **Combined Gas Law**: Combines Boyle's, Charles's, and Gay-Lussac's laws into one relation: $(P_1V_1/T_1) = (P_2V_2/T_2)$.

5. **Ideal Gas Law**: PV = nRT, where P is pressure, V is volume, n is the number of moles, R is the universal gas constant, and T is temperature in Kelvin.

Initial Conditions of the Gas Sample

Before analyzing the contraction, it’s crucial to understand the initial parameters:

- Temperature (T_1): 300 K
- Pressure (P_1): 1.0 atm
- Volume (V_1): 2.0 L

These initial conditions help determine the number of moles of gas and set the base for predicting the final state after volume change.

Analyzing the Volume Contraction

Possible Scenario for Volume Change

The problem states that the volume of the sample contracted, but it does not specify the final volume. Depending on the process, the final volume (V_2) could be:

- Less than 2.0 L (compression)
- More than 2.0 L (expansion, which contradicts the term "contracted")

For the purpose of this analysis, let’s assume the volume contracts to a new volume V_2 less than 2.0 L, say, 1.0 L, to illustrate the process fully.

Assumptions for the Process

- The process is carried out at constant temperature (isothermal process). This is common for volume changes where heat exchange occurs to maintain temperature.
- No chemical reactions occur; the gas remains ideal.
- The amount of gas (number of moles, n) remains constant.

Calculating the Number of Moles of Gas

Using the ideal gas law:
\[
PV = nRT
\]

Substituting initial conditions:

$$
n = \frac{P_1 V_1}{RT_1}
$$

Where:
- $P_1 = 1.0\, \text{atm}$
- $V_1 = 2.0\, \text{L}$
- $R = 0.0821\, \text{L·atm/(mol·K)}$
- $T_1 = 300\, \text{K}$

Calculations:

$$
n = \frac{1.0 \times 2.0}{0.0821 \times 300} = \frac{2.0}{24.63} \approx 0.0812\, \text{mol}
$$

This is the amount of gas in the sample, which remains unchanged during volume contraction.

Determining Final Conditions After Volume Contraction

Suppose the volume contracts from 2.0 L to 1.0 L under isothermal conditions:

$$
V_2 = 1.0\, \text{L}
$$

Using the ideal gas law again:

$$
P_2 = \frac{nRT}{V_2}
$$

Since the temperature and number of moles are constant:

$$
P_2 = \frac{nRT_1}{V_2}
$$

Calculating P_2:

$$
P_2 = \frac{0.0812 \times 0.0821 \times 300}{1.0} = \frac{2.0}{1.0} = 2.0\, \text{atm}
$$

Thus, the pressure doubles as the volume halves at constant temperature.

Impact of Volume Contraction on Gas Properties

Pressure Increase

- According to Boyle's Law, when volume decreases at constant temperature, pressure increases proportionally.
- In our example, halving the volume from 2.0 L to 1.0 L doubles the pressure from 1.0 atm to 2.0 atm.

Temperature Stability

- Since the process is assumed isothermal, the temperature remains at 300 K.
- No heat exchange is necessary if the process is perfectly isothermal, achieved via thermal contact with surroundings.

Final Moles and Composition

- The moles of gas remain unchanged at approximately 0.0812 mol.
- The gas composition remains the same; only the physical state (pressure and volume) changes.

Alternative Process Scenarios

While the above analysis assumes an isothermal process, real-world processes could involve other paths, such as adiabatic or isobaric changes.

Adiabatic Compression

- No heat exchange with surroundings.
- Both temperature and pressure increase during contraction.
- The relation between initial and final states follows:

$$
PV^\gamma = \text{constant}
$$

where $\gamma = C_p / C_v$ (for ideal gases).

Isobaric Compression or Expansion

- Pressure remains constant.
- Volume and temperature change proportionally:

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

- Heat exchange occurs to change the temperature during the process.

Practical Applications and Real-World Implications

Understanding gas behavior during volume change is critical in various fields:

1. **Engineering:** Designing engines and turbines where gases undergo compression and expansion cycles.

2. **Chemical Processes:** Reactor design where gases are compressed or expanded during reactions.

3. **Environmental Science:** Modeling atmospheric processes involving pressure and volume changes.

4. **Medical Field:** Understanding respiration and lung function involving gas volume changes.

Conclusion

This comprehensive analysis of a sample of an ideal gas undergoing volume contraction highlights the fundamental principles governing gas behavior. By applying the ideal gas law and understanding the relationships between pressure, volume, and temperature, we can predict the final state of the gas accurately. Whether the process is isothermal, adiabatic, or occurs under other thermodynamic conditions, the core concepts remain essential for both academic understanding and practical applications.

In the scenario where a gas initially at 300 K, 1.0 atm, and 2.0 L contracts to a smaller volume (say, 1.0 L), the pressure doubles to 2.0 atm, temperature remains unchanged, and the number of moles stays constant. This knowledge is vital for scientists and engineers working with gases in various technological and scientific contexts.

Keywords: ideal gas, gas law, volume contraction, isothermal process, pressure, temperature, ideal gas law calculations, thermodynamics, gas behavior, Boyle’s Law, physics, chemistry

Frequently Asked Questions

What is the initial state of the ideal gas in the problem?

The initial state of the ideal gas is at a temperature of 300 K, a pressure of 1.0 atm, and a volume of 2.0 L.

What does it mean when the volume of an ideal gas 'contracts'?

It means the volume decreases from its initial value during a process, which can involve compression or other processes affecting the gas.

Which thermodynamic law relates initial and final states of an ideal gas during volume contraction?

The ideal gas law, $PV = nRT$, relates initial and final states, allowing calculations of changes in pressure, volume, or temperature during the process.

If only the volume changes during contraction and temperature remains constant, what is this process called?

This process is called an isothermal process.

How can we calculate the final volume of the gas after contraction?

If the process is known (e.g., isothermal, adiabatic), we can use the ideal gas law and relevant formulas to determine the final volume based on initial conditions and process specifics.

What additional information is needed to determine the final state of the gas?

The type of process (isothermal, adiabatic, etc.) and whether temperature or pressure remains constant are needed to fully determine the final state.

How does contraction of volume affect the pressure of the ideal gas if temperature remains constant?

According to Boyle's law, if temperature is constant, pressure and volume are inversely proportional, so as volume decreases, pressure increases.

Can the temperature change during the volume contraction? How would that affect calculations?

Yes, if the process is not isothermal, temperature can change, affecting the final state. Calculations would then need to include the change in temperature, possibly using adiabatic equations.

What is the significance of knowing the initial state parameters in solving this problem?

Knowing the initial temperature, pressure, and volume allows us to apply the ideal gas law and relevant process equations to determine the final state after contraction.

How would the final pressure be calculated if the volume contracts to a new volume and temperature remains constant?

Using Boyle's law: P1V1 = P2V2, rearranged to P2 = P1V1 / V2, where V2 is the final volume, to find the final pressure.

Additional Resources

A Sample Of An Ideal Gas Is Initially At 300 K, 1.0 Atm, And Occupies 2.0 L. If The Final Volume Contracted — this scenario presents an excellent opportunity to explore the fundamental principles of gas behavior, thermodynamics, and the ideal gas law. Understanding how gases respond to changes in conditions is essential in fields ranging from chemistry and physics to engineering and environmental science. In this comprehensive guide, we will dissect the problem step by step, providing a detailed analysis of the processes involved, key concepts, and the calculations needed to determine the final state of the gas after volume contraction.

Introduction: Understanding the Scenario

Imagine a sample of an ideal gas contained in a sealed vessel. Initially, the gas has the following properties:

- Temperature (T_1) = 300 K
- Pressure (P_1) = 1.0 atm
- Volume (V_1) = 2.0 L

Now, suppose the volume of the container is reduced — "contracted" — to a smaller size. The question is: what will be the new pressure, temperature, or other relevant parameters after this change, assuming the gas behaves ideally?

This scenario is a classic example of a thermodynamic process involving the ideal gas law, which relates pressure, volume, and temperature in a straightforward manner. To analyze it thoroughly, we need to understand the underlying principles and the assumptions made during the process.

Fundamental Concepts: The Ideal Gas Law and Thermodynamic Processes

The Ideal Gas Law

The ideal gas law provides the foundation for analyzing any process involving gases:

\[PV = nRT \]

Where:
- P = Pressure

- V = Volume
- n = Number of moles of gas
- R = Universal gas constant (8.314 J/mol·K)
- T = Temperature in Kelvin

In problems where the amount of gas remains constant, the law simplifies to a relation between the three variables, which can be manipulated depending on the process:

- Isothermal process: T is constant
- Isobaric process: P is constant
- Isochoric process: V is constant
- Adiabatic process: No heat exchange with surroundings

Assumptions for an Ideal Gas

- Gas particles have negligible volume compared to the container.
- There are no intermolecular forces.
- Collisions are perfectly elastic.

These assumptions mean the behavior of the gas can be accurately predicted by the ideal gas law under most conditions of moderate pressure and temperature.

Step 1: Establishing Initial Conditions and Known Data

Let's summarize what we know:

Parameter	Initial State (1)	Final State (2)
Temperature	300 K	?
Pressure	1.0 atm	?
Volume	2.0 L	?

Since the problem states "If the Final Volume Contracted", but does not specify the final volume, we will analyze the process generally, assuming the volume decreases. For a complete analysis, we can consider different possible scenarios, such as:

- The final volume V_2 is less than V_1 (say, 1.0 L, 0.5 L, etc.)
- The process type (is it isothermal, adiabatic, or another process?)

Step 2: Analyzing Different Types of Volume Contraction

The behavior of the gas depends on whether the process occurs at constant temperature, pressure, or involves heat exchange.

2.1 Isothermal Contraction (Temperature constant)

In this case, T remains at 300 K during the volume change. According to the ideal gas law:

$$P_1 V_1 = P_2 V_2$$

Since T is constant, the number of moles n and R are constants and thus:

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

Implication: When the volume decreases, the pressure increases proportionally.

Example: If the volume contracts from 2.0 L to 1.0 L,

$$P_2 = \frac{(1.0\, \text{atm}) \times 2.0\, \text{L}}{1.0\, \text{L}} = 2.0\, \text{atm}$$

Temperature stays at 300 K.

2.2 Isobaric Contraction (Constant pressure)

If the pressure remains constant during contraction, then:

$$V_2 = \frac{nRT}{P}$$

Since P and T are constant, V_2 is directly proportional to T. If volume contracts, then temperature must decrease:

$$T_2 = \frac{P V_2}{n R}$$

In practice, unless heat is added or removed, temperature will not stay constant during a volume change unless the process happens at constant temperature (isothermal). This is more typical in controlled experiments.

2.3 Adiabatic Contraction (No heat exchange)

An adiabatic process involves rapid contraction where no heat is exchanged. The relation between pressure, volume, and temperature is given by:

$$PV^{\gamma} = \text{constant}$$
$$TV^{\gamma - 1} = \text{constant}$$

Where γ is the heat capacity ratio (Cp/Cv). For a monatomic ideal gas, $\gamma \approx 5/3$; for diatomic gases, $\gamma \approx 7/5$.

In such a process, the final temperature T_2 can be determined from the initial conditions and the ratio of volumes:

$$T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{\gamma - 1}$$

And the final pressure:

$$ P_2 = P_1 \left(\frac{V_1}{V_2} \right)^{\gamma} $$

Step 3: Calculations for a Specific Case (Assuming Isothermal Process)

Let's walk through an example assuming the process is isothermal and the volume contracts from 2.0 L to 1.0 L.

Step 3.1: Find the new pressure

Using the ideal gas law relation:

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

$$ P_2 = \frac{1.0\, \text{atm} \times 2.0\, \text{L}}{1.0\, \text{L}} = 2.0\, \text{atm} $$

Step 3.2: Confirm temperature remains at 300 K

Since the process is isothermal, $T_2 = T_1 = 300$ K.

Step 3.3: Calculate the number of moles

Using initial conditions:

$$ n = \frac{P_1 V_1}{RT_1} $$

Convert units:

- $P_1 = 1.0$ atm
- $V_1 = 2.0$ L
- R = 0.0821 L·atm/(mol·K)
- $T_1 = 300$ K

$$ n = \frac{1.0 \times 2.0}{0.0821 \times 300} \approx \frac{2.0}{24.63} \approx 0.0812\, \text{mol} $$

This amount of gas remains constant.

Step 4: Summary of Results for the Isothermal Contracting Gas

Parameter	Initial	Final ($V_2 = 1.0$ L)
Temperature	300 K	300 K (assumed)
Pressure	1.0 atm	2.0 atm
Volume	2.0 L	1.0 L
Moles	0.0812 mol	0.0812 mol

This example illustrates how volume contraction at constant temperature increases pressure proportionally, consistent with Boyle's law.

Step 5: Exploring Other Scenarios

The above example simplifies the problem to an isothermal process. However, real-world volume contraction may involve different thermodynamic paths:

- Adiabatic contraction: Temperature would decrease during compression.
- Isobaric process: Temperature may increase as volume decreases if external heat is supplied.
- Polytropic processes: Combination of heat exchange and work done, characterized by a specific polytropic index.

Each scenario requires tailored calculations based on the relevant thermodynamic relations.

Practical Applications and Significance

Understanding how gases behave during volume contraction is vital in numerous applications:

- Internal combustion engines: Compression of gases increases pressure and temperature.
- Chemical reactors: Volume changes influence reaction equilibrium and kinetics.
- Atmospheric science: Understanding compression and expansion of air masses.
- Vacuum systems: Contracting gases to create low-pressure environments.

Final Thoughts

The problem of a gas contracting in volume is a classic illustration of thermodynamic principles and the power of the ideal gas law. Whether the process is isothermal, adiabatic, or another type, the core concepts — pressure, volume, temperature, and the amount of gas — are interconnected. Grasping these relationships enables scientists and engineers to predict and manipulate gas behaviors in a vast array of practical scenarios.

In summary, a sample of an ideal gas initially at 300 K, 1.0 atm, and occupying 2.0 L, when contracted:

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