500.0 Liters Of A Gas Are Prepared At 700 Mm Hg And 200 C. The Gas Is Placed Into A Tank Under High Pressure.

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This scenario involves understanding the fundamental principles of gas behavior, including how gases respond to changes in pressure, temperature, and volume. When a gas is prepared under specific conditions and then transferred into a different container under high pressure, it becomes essential to analyze these variables using gas laws such as Boyle's Law, Charles's Law, and the Ideal Gas Law. This article explores the scientific concepts involved, practical applications, and calculations relevant to such a process.

Understanding the Initial Conditions of the Gas

Before delving into the transfer process, it is crucial to understand the initial state of the gas, including its volume, pressure, and temperature.

Initial Volume

The gas volume is given as 500.0 liters, which is a substantial volume often encountered in industrial processes, laboratories, or storage tanks. This volume is a key parameter in calculating the amount of gas in moles and predicting how it will behave under different conditions.

Initial Pressure

The gas is prepared at a pressure of 700 mm Hg (millimeters of mercury). To work effectively with gas laws, this pressure should be converted into standard units such as atmospheres (atm):

$$ 1 \, \text{atm} = 760 \, \text{mm Hg} $$

So,

$$ P_{initial} = \frac{700 \, \text{mm Hg}}{760 \, \text{mm Hg/atm}} \approx 0.921 \, \text{atm} $$

Initial Temperature

The temperature is given as 200°C. Converting this to Kelvin (K), which is essential for gas law calculations:

$$ T_{initial} = 200 + 273.15 = 473.15 \, \text{K} $$

Applying the Ideal Gas Law

The ideal gas law provides a relationship between pressure (P), volume (V), temperature (T), and the number of moles (n):

$$ PV = nRT $$

Where:
- P = pressure in atm
- V = volume in liters
- n = number of moles
- R = universal gas constant, 0.0821 L·atm/(mol·K)
- T = temperature in Kelvin

Using the initial conditions, we can calculate the number of moles of gas prepared.

Calculating the Number of Moles

Given:
$$ P_{initial} = 0.921 \, \text{atm} $$
$$ V_{initial} = 500.0 \, \text{liters} $$
$$ T_{initial} = 473.15 \, \text{K} $$

Applying the ideal gas law:
$$ n = \frac{PV}{RT} $$
$$ n = \frac{0.921 \times 500.0}{0.0821 \times 473.15} $$

Calculating numerator:
$$ 0.921 \times 500.0 = 460.5 $$

Calculating denominator:
$$ 0.0821 \times 473.15 \approx 38.8 $$

Therefore,
$$ n \approx \frac{460.5}{38.8} \approx 11.87 \, \text{moles} $$

This is the amount of gas in moles initially present before transfer.

Transferring the Gas into a High-Pressure Tank

When the gas is moved into a tank under high pressure, the conditions change significantly. The volume, pressure, and temperature within the tank determine the new state of the gas.

Key Factors in the Transfer Process

During transfer, several factors influence the behavior of the gas:

- The pressure inside the tank, which is much higher than initial pressure.
- The temperature of the gas, which may change during compression.
- The volume of the tank, which may be different from the initial volume.

Assumptions for Simplification

In many practical cases, the transfer process can be approximated under certain assumptions:
- The process occurs quickly, so the amount of gas (moles) remains constant (no leaks).
- The gas behaves ideally, adhering to the ideal gas law.
- The temperature change during compression can be estimated or controlled.

Calculating the Final Conditions in the High-Pressure Tank

Suppose we place the gas into a tank of known volume V_{tank} and it reaches a high pressure P_{final} at a specified temperature T_{final}.

Determining Final Pressure at a Given Temperature and Volume

If the temperature remains constant (isothermal compression), then Boyle's Law applies:
$$P_1 V_1 = P_2 V_2$$

However, if temperature changes, the combined gas law (or ideal gas law) should be used:

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

Given that the number of moles and the initial conditions are known, you can solve for the unknown final pressure or temperature.

Example Calculation: Final Pressure at Constant Temperature

Assuming the gas is compressed into a smaller volume V_{tank} with the temperature held constant at 200°C (473.15 K):

Suppose the tank volume is 50 liters (much smaller than the initial volume).
The initial state:
$$P_1 = 0.921 \, \text{atm}$$
$$V_1 = 500 \, \text{L}$$
Final state:

$$ V_2 = 50 \, \text{L} $$
$$ T_2 = T_1 = 473.15 \, \text{K} $$

Applying Boyle’s Law:
$$ P_2 = \frac{P_1 V_1}{V_2} = \frac{0.921 \times 500}{50} = 0.921 \times 10 = 9.21 \, \text{atm} $$

Converting back to pressure units:
$$ P_{final} \approx 9.21 \, \text{atm} $$

In mm Hg:
$$ P_{final} = 9.21 \times 760 \approx 7000 \, \text{mm Hg} $$

This illustrates that compressing the gas into a smaller volume under constant temperature results in a significant increase in pressure.

Practical Applications and Safety Considerations

The process of preparing gas at certain conditions and then placing it into high-pressure tanks has numerous industrial and scientific applications.

Industrial Gas Storage

Industries often store gases such as oxygen, nitrogen, or specialty gases under high pressure to maximize storage efficiency. Understanding the gas laws helps in designing tanks that can withstand the required pressures safely.

Chemical Manufacturing

Many chemical reactions depend on precise gas conditions. Controlling pressure and temperature during reactions ensures safety and optimal yields.

Safety Measures in Handling High-Pressure Gases

Handling gases at high pressure involves risks such as explosions or leaks. Safety protocols include:
- Using tanks with appropriate pressure ratings.
- Regular inspection for leaks or damages.
- Employing pressure relief valves.
- Monitoring temperature and pressure during operations.

Conclusion

The preparation and transfer of 500.0 liters of gas at 700 mm Hg and 200°C into a high-pressure tank exemplify fundamental principles of gas behavior. By applying the ideal gas law and understanding how pressure, volume, and temperature relate, engineers and scientists can design processes that optimize storage, safety, and efficiency. Whether in industrial settings or laboratory environments, mastering these concepts is essential for effective gas management and ensuring safe handling of high-pressure systems.

Frequently Asked Questions

What is the initial pressure of the gas in atm?

The initial pressure is approximately 0.921 atm, calculated by converting 700 mm Hg to atm (700 mm Hg / 760 mm Hg = 0.921 atm).

What is the initial temperature of the gas in Kelvin?

The initial temperature is 473 K, calculated by adding 273 to 200°C (200 + 273).

How do you determine the volume of the gas after it is placed into a high-pressure tank?

By applying the combined gas law: (P1 V1) / T1 = (P2 V2) / T2, where P, V, and T are initial and final conditions.

If the gas is compressed into a tank at higher pressure and possibly different temperature, how does the volume change?

The volume changes according to the combined gas law, decreasing as pressure increases, assuming temperature remains constant or changes in known ways.

What is the significance of the gas's initial conditions in calculating its final volume?

Initial conditions (pressure, volume, temperature) serve as the baseline for applying gas laws to determine how the volume changes under new conditions.

How does increasing pressure affect the volume of

the gas at constant temperature?

At constant temperature, increasing pressure decreases the volume proportionally, following Boyle's law.

What assumptions are made when applying the ideal gas law to this scenario?

It is assumed that the gas behaves ideally, meaning interactions between molecules are negligible and the gas particles occupy no volume.

How would an increase in temperature influence the volume of the gas when placed into a high-pressure tank?

An increase in temperature would tend to increase the volume if pressure is kept constant, according to Charles's law, or affect the pressure if volume is fixed.

Why is it important to convert units properly when solving gas law problems?

Proper unit conversion ensures calculations are accurate, as gas law equations require consistent units (e.g., atm for pressure, Kelvin for temperature).

Additional Resources

500.0 Liters of a Gas Are Prepared at 700 mm Hg and 200°C. The Gas Is Placed Into a Tank Under High Pressure.

Understanding the behavior of gases under varying conditions is essential in fields ranging from chemical engineering to environmental science. The scenario of preparing a specific volume of gas at given temperature and pressure, then subsequently compressing it into a high-pressure tank, encapsulates fundamental principles of gas laws and thermodynamics. This article provides a comprehensive analysis of this process, exploring the underlying physics, calculations involved, practical applications, and safety considerations.

Introduction to Gas Behavior and the Context of

the Scenario

Gases are characterized by their ability to expand to fill containers and their behavior governed primarily by the ideal gas law, PV = nRT. In this context, a known volume of gas—500.0 liters—is prepared at a specific pressure and temperature before being compressed into a high-pressure tank.

This process is commonplace in industries such as aerospace, chemical manufacturing, and gas storage and transportation. Understanding the transformations the gas undergoes during compression and the associated thermodynamic principles is vital for efficiency, safety, and compliance with regulations.

Fundamental Principles Governing Gas Behavior

Ideal Gas Law and Its Applicability

The ideal gas law, PV = nRT, relates pressure (P), volume (V), temperature (T), and amount of substance (n). While it simplifies real gas behavior, it provides a solid approximation under many conditions.

- Variables:
- P = pressure
- V = volume
- n = number of moles
- R = universal gas constant (8.314 J/(mol·K))
- T = temperature in Kelvin

- Assumptions:
- Gas particles have negligible volume.
- Intermolecular forces are insignificant.
- Collisions are perfectly elastic.

In real-world applications, deviations can occur, especially at high pressures or low temperatures, necessitating correction factors or the use of real gas equations of state like Van der Waals.

Conversion of Units and Initial Conditions

- Pressure:
- Given as 700 mm Hg (millimeters of mercury).
- Conversion to atmospheres: 1 atm = 760 mm Hg.

- $P = 700$ mm Hg × (1 atm / 760 mm Hg) ≈ 0.921 atm.

- Temperature:
- Given as 200°C.
- Conversion to Kelvin: $T(K) = T(°C) + 273.15 = 200 + 273.15 \approx 473.15$ K.

- Volume:
- $V = 500.0$ liters (or 0.5 m^3).

Calculating the Number of Moles of Gas Prepared

Using the ideal gas law, the initial amount of gas in moles can be calculated:

$$n = (PV) / (RT)$$

Plugging in the known values:

$$n = (0.921 \text{ atm} \times 0.5 \text{ m}^3 \times 101.325 \text{ Pa/atm}) / (8.314 \text{ J/(mol·K)} \times 473.15 \text{ K})$$

Note: To match units, convert volume from liters to cubic meters and pressure to Pascals:

- Volume: 500 liters = 0.5 m^3 (since 1 liter = 0.001 m^3),
- Pressure: 0.921 atm × 101.325 Pa/atm ≈ 93.33 kPa = 93,330 Pa.

Calculating:

$$n = (93{,}330 \text{ Pa} \times 0.5 \text{ m}^3) / (8.314 \text{ J/(mol·K)} \times 473.15 \text{ K})$$

$$n \approx (46{,}665 \text{ J}) / (3929.8 \text{ J/mol})$$

$$n \approx 11.87 \text{ mol}$$

This calculation indicates approximately 11.87 moles of gas are present initially.

Implications of High-Pressure Compression

Reasons for Compression

Compressing gases into high-pressure tanks serves multiple purposes:

- Storage Efficiency: Reduces the volume occupied by the gas, enabling economical storage and transportation.
- Industrial Use: Many processes require gases at specific high pressures, such as in manufacturing or propulsion systems.
- Safety and Handling: Properly compressed gases are easier to contain and control.

Pressure-Volume Relationships During Compression

The process of compressing the gas involves reducing its volume while maintaining or adjusting temperature. Depending on the process specifics, compression can be:

- Isothermal (constant temperature): The temperature remains constant, and pressure increases proportionally as volume decreases.
- Adiabatic (no heat exchange): Temperature increases as gas compresses, following the adiabatic relation PV^γ = constant, where γ is the heat capacity ratio.

Key considerations:

- In practical settings, the compression process often isn't perfectly isothermal or adiabatic but a combination, influenced by heat exchange with surroundings.
- Understanding the thermodynamics helps in designing compression systems that optimize energy efficiency and safety.

Calculating Final Conditions in the High-Pressure Tank

Suppose the gas is compressed into a tank with a known volume (say, V_{final}). The goal is to determine the final pressure and temperature of the gas after compression, assuming ideal behavior.

Scenario assumptions:

- The amount of gas (n) remains constant.
- Compression occurs quickly, perhaps approximating adiabatic conditions.
- Initial temperature remains the same during the process (if isothermal), or

temperature increases (if adiabatic).

Case 1: Isothermal Compression

- The temperature remains at 200°C (473.15 K).
- Initial volume: 0.5 m^3.
- Final volume: V_{final} (unknown).

Using PV = nRT:

- Initial pressure: 93,330 Pa.
- Final pressure: P_{final}.

Because T is constant:

$$P_{final} \times V_{final} = P_{initial} \times V_{initial}$$

If the final volume V_{final} is known, the final pressure can be calculated directly.

Case 2: Adiabatic Compression

- Final pressure and temperature are related by:

$$P_{final} / P_{initial} = (V_{initial} / V_{final}) ^ \gamma$$

- Final temperature T_{final} can be calculated using:

$$T_{final} = T_{initial} \times (V_{initial} / V_{final}) ^ {(\gamma - 1)}$$

Where γ depends on the gas type (e.g., for diatomic gases like oxygen or nitrogen, γ ≈ 1.4).

Practical Applications and Industry Significance

Understanding and controlling the process of preparing, compressing, and storing gases is fundamental in various industries.

Chemical Manufacturing:

- Gases like hydrogen, oxygen, and nitrogen are stored under high pressure for use in synthesis, welding, or as reactants.

Aerospace:

- Propellants and life-support systems depend on high-pressure gas storage, requiring precise calculations to ensure safety and performance.

Environmental Science:

- Storage of gases such as carbon dioxide for sequestration or transport involves similar principles.

Healthcare:

- Medical gases like oxygen are compressed for distribution, emphasizing the need for rigorous safety measures and precise calculations.

Safety Considerations in High-Pressure Gas Storage

Handling high-pressure gases involves significant safety risks, including:

- Risk of Explosion or Rupture: Improperly designed tanks can fail under high pressure.
- Material Compatibility: Tank materials must withstand corrosive gases and prevent leaks.
- Temperature Control: Rapid compression can lead to temperature spikes, increasing risk.
- Regulatory Compliance: Adherence to standards like ASME Boiler and Pressure Vessel Code is mandatory.

Proper safety protocols include regular inspection, pressure relief devices, and controlled compression rates to prevent accidents.

Environmental and Economic Impacts

Compressing and storing gases efficiently can have broader environmental and economic implications:

- Energy Consumption: Compression requires energy; optimizing processes reduces costs and emissions.
- Leakage Prevention: Safe storage minimizes gas leaks, reducing environmental impact.
- Cost Efficiency: Proper calculations prevent over-engineering or under-utilization of storage tanks.

Advances in materials and compression technology continue to improve safety, efficiency, and sustainability in gas handling.

Conclusion: Integrating Theory and Practice

The process of preparing 500.0 liters of gas at specified conditions and then placing it into a high-pressure tank is a classic application of gas laws and thermodynamics principles. Through careful calculations and understanding of the relationships between pressure, volume, and temperature, engineers and scientists can design systems that maximize efficiency, safety, and functionality.

This scenario underscores the importance of precise measurement, rigorous adherence to safety standards, and ongoing innovation in gas compression and storage technologies. As industries evolve and new gases are utilized, mastery of these fundamental principles remains essential for advancing scientific and technological frontiers.

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Author’s Note: This analysis provides a detailed understanding of the physical principles, calculations, and practical considerations involved in gas preparation and compression.

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