What Quantity In Moles Of Chlorine Gas At 120.0 C And 33.3 Atm Would Occupy A Vessel Of 14.0 L?

Understanding the Problem: Calculating the Moles of Chlorine Gas in a Given Vessel

What Quantity In Moles Of Chlorine Gas At 120.0 C And 33.3 Atm Would Occupy A Vessel Of 14.0 L? This question probes the core principles of gas laws, specifically the Ideal Gas Law, to determine how many moles of chlorine gas (Cl_2) occupy a specific volume under defined temperature and pressure conditions. To solve this, we need to understand the relationship between pressure, volume, temperature, and moles of gas, which is succinctly described by the Ideal Gas Law:

\[PV = nRT \]

where:
- \(P \) = pressure
- \(V \) = volume
- \(n \) = number of moles
- \(R \) = ideal gas constant
- \(T \) = temperature in Kelvin

This article will guide you through the process of calculating the number of moles of chlorine gas in the specified conditions, including converting units, understanding the relevant formulas, and performing step-by-step calculations.

Fundamentals of the Ideal Gas Law

What is the Ideal Gas Law?

The Ideal Gas Law is an equation of state for gases that combines Boyle's Law, Charles's Law, and Avogadro's Law. It relates the four variables—pressure, volume, temperature, and moles—allowing us to predict the behavior of gases under different conditions.

The law is expressed as:

\[PV = nRT \]

- P (pressure): The force exerted by gas particles per unit area, typically measured in atmospheres (atm), pascals (Pa), or other units.
- V (volume): The space occupied by the gas, generally in liters (L) for laboratory contexts.

- n (moles): The amount of gas in moles.
- R (ideal gas constant): The proportionality constant, with a common value $R = 0.0821\, \mathrm{L\,atm\,mol^{-1}\,K^{-1}}$.
- T (temperature): The absolute temperature in Kelvin (K).

Why Use the Ideal Gas Law?

The law provides a practical way to relate measurable quantities like pressure, volume, and temperature to the amount of gas present, which is often the unknown we want to find, as in this case.

Step-by-Step Calculation of Moles of Chlorine Gas

Let's proceed with the calculation using the given data:

- Temperature, $T = 120.0\,^\circ C$
- Pressure, $P = 33.3\, \mathrm{atm}$
- Volume, $V = 14.0\, \mathrm{L}$
- Gas constant, $R = 0.0821\, \mathrm{L\,atm\,mol^{-1}\,K^{-1}}$

Step 1: Convert Temperature to Kelvin

Since the ideal gas law requires temperature in Kelvin:

$$T(K) = T(^\circ C) + 273.15$$

$$T = 120.0 + 273.15 = 393.15\, \mathrm{K}$$

Step 2: Apply the Ideal Gas Law to Find Moles n

Rearranged to solve for n:

$$n = \frac{PV}{RT}$$

Now, substitute the known values:

$$n = \frac{(33.3\, \mathrm{atm}) \times (14.0\, \mathrm{L})}{(0.0821\, \mathrm{L\,atm\,mol^{-1}\,K^{-1}}) \times 393.15\, \mathrm{K}}$$

Calculate numerator:

$$33.3 \times 14.0 = 466.2$$

Calculate denominator:

$$ 0.0821 \times 393.15 \approx 32.28 $$

Finally,

$$ n = \frac{466.2}{32.28} \approx 14.45\, \text{moles} $$

Thus, approximately 14.45 moles of chlorine gas occupy the vessel under the given conditions.

Understanding the Significance of the Calculation

Implications of the Result

Knowing the quantity of chlorine gas in moles is essential in various chemical processes, including:

- Determining reactant or product amounts in chemical reactions.
- Planning for storage and safety considerations when handling gases.
- Calculating partial pressures in mixture scenarios.

Real-World Applications

This kind of calculation is routinely used in:

- Industrial manufacturing of chlorine-based compounds.
- Environmental science for modeling gas emissions.
- Laboratory experiments involving gas reactions.

Factors Affecting Gas Calculations

Ideal vs. Real Gases

While the ideal gas law is a good approximation under many conditions, real gases may deviate at high pressures or low temperatures due to intermolecular forces. Chlorine gas, being diatomic and polarizable, generally behaves close to an ideal gas at moderate conditions, making the ideal gas law applicable here.

Temperature and Pressure Variations

Any change in temperature or pressure affects the volume and the number of moles, highlighting the importance of accurate measurements.

Additional Considerations for Gas Calculations

Unit Consistency

Always ensure units are consistent; for example, pressure in atm, volume in liters, and temperature in Kelvin.

Using Other Gas Constants

If pressure is given in different units (like Pa), use the appropriate value of R:

- $R = 8.314\, \mathrm{J\,mol^{-1}\,K^{-1}}$
- Convert units accordingly.

Summary of the Calculation Process

1. Convert temperature to Kelvin.
2. Use the ideal gas law $n = \frac{PV}{RT}$.
3. Plug in the known values.
4. Perform the calculation step-by-step.
5. Interpret the result in the context of the problem.

Conclusion

By applying the ideal gas law and carefully converting units, we determined that approximately 14.45 moles of chlorine gas occupy a 14.0 L vessel at 120.0°C and 33.3 atm pressure. This calculation exemplifies fundamental gas laws used extensively in chemistry and engineering to predict and analyze the behavior of gases under various conditions.

Whether you're a student preparing for exams, a chemical engineer designing processes, or a safety officer assessing gas storage, mastering these calculations is essential for accurate and safe handling of gases.

Frequently Asked Questions

How do I calculate the number of moles of chlorine gas at a given temperature and pressure in a specific volume?

You can use the Ideal Gas Law: n = (PV) / (RT), where P is pressure, V is volume, R is the gas constant, and T is temperature in Kelvin.

What is the value of the gas constant R in appropriate units for this calculation?

For calculations using atmospheres and liters, R = 0.0821 L·atm/(mol·K).

How do I convert the temperature from Celsius to Kelvin?

Add 273.15 to the Celsius temperature: T(K) = 120.0 + 273.15 = 393.15 K.

What is the pressure in atmospheres for this problem?

The pressure is given as 33.3 atm, so no conversion is needed.

How do I calculate the number of moles of chlorine gas in this vessel?

Use the ideal gas law: n = (P × V) / (R × T). Plug in P = 33.3 atm, V = 14.0 L, R = 0.0821 L·atm/(mol·K), and T = 393.15 K.

What is the calculation process for finding the moles of chlorine gas?

Calculate n = (33.3 atm × 14.0 L) / (0.0821 L·atm/(mol·K) × 393.15 K).

What is the approximate number of moles of chlorine gas in this vessel?

n ≈ (466.2) / (32.27) ≈ 14.45 moles of chlorine gas.

How does temperature affect the amount of gas in moles at constant pressure and volume?

According to the ideal gas law, increasing temperature increases the number of moles or volume, assuming pressure is constant. In this case, temperature directly influences the calculation of moles.

Can I determine the mass of chlorine gas in the vessel from the moles calculated?

Yes, multiply the moles by the molar mass of chlorine gas (70.90 g/mol) to find the mass: approximately 14.45 mol × 70.90 g/mol ≈ 1025.7 grams.

Additional Resources

Quantity in Moles of Chlorine Gas at 120.0°C and 33.3 atm in a 14.0 L Vessel is a fundamental problem in chemistry, particularly in the study of gases and their behaviors under different conditions. Determining the amount of a gas in moles when given temperature, pressure, and volume is a classic application of the Ideal Gas Law, which serves as a cornerstone in understanding gaseous systems. This type of calculation is essential for chemists working in laboratories and industries, including manufacturing, environmental science, and chemical engineering, where precise control and measurement of gases are crucial.

Understanding the Fundamental Concepts

Before delving into the calculations, it is essential to grasp the key principles involved. The ideal gas law, expressed as PV = nRT, links the pressure (P), volume (V), amount in moles (n), the ideal gas constant (R), and temperature (T). Each factor plays a critical role:

- Pressure (P): The force exerted by gas particles per unit area, measured in atmospheres (atm).
- Volume (V): The space occupied by the gas, measured in liters (L).
- Number of Moles (n): The quantity of gas molecules, measured in moles.
- Temperature (T): The kinetic energy of the molecules, measured in Kelvin (K).
- Gas Constant (R): A proportionality constant, R = 0.0821 L·atm/(mol·K).

To accurately find the number of moles, one must convert all given quantities into the appropriate units, particularly temperature to Kelvin, and ensure pressure and volume are expressed in atm and liters, respectively.

Step-by-Step Calculation Approach

1. Convert Temperature to Kelvin

Given temperature: 120.0°C

Kelvin temperature (T) = °C + 273.15 = 120.0 + 273.15 = 393.15 K

2. Use the Ideal Gas Law Formula

The ideal gas law:

$$ PV = nRT $$

Rearranged to solve for n (moles):

$$ n = \frac{PV}{RT} $$

3. Plug in the Known Values

- $P = 33.3$ atm
- $V = 14.0$ L
- $R = 0.0821$ L·atm/(mol·K)
- $T = 393.15$ K

Calculating:

$$ n = \frac{(33.3\, \text{atm})(14.0\, \text{L})}{(0.0821\, \text{L·atm/(mol·K)})(393.15\, \text{K})} $$

Performing the Calculation

Calculating numerator:

$$ 33.3 \times 14.0 = 466.2 $$

Calculating denominator:

$$ 0.0821 \times 393.15 \approx 32.262 $$

Now, dividing:

$$ n = \frac{466.2}{32.262} \approx 14.45 \text{ mol} $$

Result: Approximately 14.45 moles of chlorine gas occupy a 14.0 L vessel at 120.0°C and 33.3 atm.

Analysis and Implications

This calculation reveals that under the specified conditions, a substantial amount of chlorine gas—about 14.45 mol—is present in the vessel. Several important insights and considerations stem from this result:

- High Pressure and Temperature: The pressure of 33.3 atm and temperature of 120°C (which is above room temperature) significantly influence the gas's behavior, making the ideal gas law an approximation that assumes gases behave ideally under these conditions.
- Real-World Deviations: While ideal gas law provides a good estimate, real gases like chlorine may deviate slightly, especially at high pressures or low temperatures where intermolecular forces become significant.
- Safety Considerations: Chlorine gas is toxic and corrosive; handling such quantities requires strict safety protocols, especially at elevated temperatures and pressures.

Features and Limitations of the Ideal Gas Law in This Context

Features:

- Simplicity: Provides a straightforward way to estimate the amount of gas with easily measurable parameters.
- Universality: Applies broadly to gases under many conditions, especially at relatively low pressures and high temperatures.
- Educational Value: Serves as a foundational principle in gas chemistry and physics.

Limitations:

- Non-ideal behavior: Deviations increase at high pressures or low temperatures, where intermolecular forces and molecular volume become non-negligible.
- Assumption of point particles: The model assumes gases have no volume, which isn't true for real molecules like chlorine.
- Needs correction factors: In precise industrial applications, Van der Waals equation or other real-gas models may be necessary.

Practical Applications of This Calculation

Understanding the quantity of chlorine gas in a vessel under specific conditions has multiple real-world applications:

- Industrial Synthesis: Chlorine is used in manufacturing of plastics (PVC), disinfectants, and other chemicals. Precise quantification ensures safety and efficiency.
- Environmental Monitoring: Estimating gas quantities in containment systems to prevent leaks or over-pressurization.
- Laboratory Experiments: Calculating reagent amounts for controlled reactions involving chlorine.

Additional Considerations and Variations

While the calculation provided is straightforward, several factors could alter the outcome or necessitate more advanced calculation methods:

- Non-ideal gas corrections: Use of Van der Waals or Redlich-Kwong equations for more precise results.

- Change in conditions: If temperature or pressure varies, recalculations are necessary.
- Gas purity: Impurities or mixtures could influence the actual gas behavior.
- Leakages and container flexibility: Real containers may expand or contract, affecting the volume and pressure relationships.

Conclusion

Determining the quantity in moles of chlorine gas at 120.0°C and 33.3 atm occupying a 14.0 L vessel demonstrates the practical utility of the ideal gas law in chemical calculations. With approximately 14.45 mol of chlorine present under these conditions, chemists and engineers can plan processes, ensure safety, and optimize reactions. Despite its limitations, the ideal gas law remains an invaluable tool, especially when combined with awareness of real-gas deviations and safety considerations associated with hazardous gases like chlorine. Mastery of such calculations empowers professionals across scientific and industrial fields to manipulate gases accurately and responsibly.

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