A Gas Weighs 16 N/m^3 At 25 C And At An Absolute Pressure Of 0.25 N/mm^2. Determine The Gas Constant

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Understanding the properties of gases and calculating the gas constant are fundamental topics in thermodynamics and physical chemistry. Accurate determination of the gas constant, often denoted as R, enables scientists and engineers to analyze gas behavior under various conditions, design chemical processes, and understand atmospheric phenomena. In this comprehensive article, we will explore the process of determining the gas constant given specific parameters: a gas weighing 16 N/m^3 at 25°C and an absolute pressure of 0.25 N/mm^2. We will delve into the relevant concepts, formulas, and calculations involved, providing a clear and detailed explanation suitable for students, educators, and professionals alike.

Understanding the Basic Principles: Gas Density, Pressure, and the Gas Constant

Before diving into calculations, it's essential to understand the foundational concepts related to gases, including density, pressure, temperature, and the ideal gas law.

What is Gas Density?

- Gas density (ρ) is the mass of gas per unit volume, typically expressed as kg/m^3 or g/L.
- It indicates how much mass is contained within a specific volume of gas.

Pressure of a Gas

- Pressure (P) measures the force exerted by gas molecules colliding with container walls, expressed in units like N/m^2 (pascals) or N/mm^2.
- It is a key parameter in describing the state of a gas.

Temperature and Its Effect

- Temperature (T) influences the kinetic energy of gas particles.
- It is measured in Kelvin (K) in thermodynamic calculations.

The Gas Constant (R)

- The gas constant links the macroscopic properties of gases in the ideal gas law.

- Its value varies based on units but is approximately 8.314 J/(mol·K) in SI units.

Given Data and Objective

Let’s review the provided data points and clarify what we need to find:

- Gas density (ρ): 16 N/m^3
- Temperature (T): 25°C
- Absolute pressure (P): 0.25 N/mm^2
- Goal: Determine the gas constant (R)

Converting Units for Consistency

Handling different units requires converting all measurements into compatible SI units.

Converting Temperature to Kelvin

- Temperature in Celsius: 25°C
- Conversion: T(K) = 25 + 273.15 = 298.15 K

Converting Pressure to Pascals (N/m^2)

- Pressure in N/mm^2: 0.25 N/mm^2
- 1 N/mm^2 = 1,000,000 N/m^2 (since 1 $mm^2 = 1\times10^{-6}$ m^2)
- Therefore: P = 0.25 × 1,000,000 = 250,000 N/m^2 = 2.5×10^5 Pa

Understanding Gas Density in SI Units

- Density is given as 16 N/m^3
- Since weight (force) = mass × gravity, and N (newtons) = $kg\cdot m/s^2$
- To find mass density (kg/m^3), divide the force density by acceleration due to gravity ($g \approx 9.81$ m/s^2):

$$
\text{Mass density} = \frac{\text{Force density}}{\text{g}} = \frac{16\, \text{N/m}^3}{9.81\, \text{m/s}^2} \approx 1.629\, \text{kg/m}^3
$$

This is the mass per unit volume of the gas.

Applying the Ideal Gas Law to Find the Gas Constant (R)

The ideal gas law relates pressure (P), volume (V), number of moles (n), the gas constant (R), and temperature (T):

$$
PV = nRT
$$

Alternatively, in terms of density:

$$
\rho = \frac{m}{V}
$$

and the number of moles:

$$
n = \frac{m}{M}
$$

where M is molar mass (kg/mol).

Rearranged, the ideal gas law becomes:

$$
P = \frac{\rho R T}{M}
$$

From this, the gas constant R can be expressed as:

$$
R = \frac{P M}{\rho T}
$$

Since the molar mass M is unknown, but the gas density and pressure are known, and the gas constant is to be determined, we need to find M or use the relation involving molar quantities.

Step-by-Step Calculation of the Gas Constant (R)

Given:
- $\rho = 1.629\, \text{kg/m}^3$
- $P = 2.5 \times 10^5\, \text{Pa}$
- $T = 298.15\, \text{K}$

We need to find R, but since R is per mol, we require the molar mass (M). To proceed, we can assume the gas behaves ideally and relate the specific gas constant $R_{specific}$ to the universal gas constant R:

\[

$$
R_{specific} = \frac{R}{M}
$$

The specific gas constant $R_{specific}$ relates to density via:

$$
\rho = \frac{P M}{R T}
$$

Rearranged to solve for R:

$$
R = \frac{P M}{\rho T}
$$

However, because M is unknown, we can approach this by considering the specific gas constant:

$$
R_{specific} = \frac{R}{M}
$$

and relate it to the density:

$$
\rho = \frac{P}{R_{specific} T}
$$

which simplifies to:

$$
R_{specific} = \frac{P}{\rho T}
$$

Substituting the known values:

$$
R_{specific} = \frac{2.5 \times 10^5\, \text{Pa}}{1.629\, \text{kg/m}^3 \times 298.15\, \text{K}} \approx \frac{2.5 \times 10^5}{485.20} \approx 515.00\, \text{J/(kg·K)}
$$

Now, the universal gas constant R relates to the specific gas constant via:

$$
R = R_{specific} \times M
$$

Assuming the gas is air (common assumption unless specified), with molar mass $M \approx 0.02897\, \text{kg/mol}$.

Thus,

$$
R = 515.00\, \text{J/(kg·K)} \times 0.02897\, \text{kg/mol} \approx 14.92\, \text{J/(mol·K)}
$$

Final value:

$$
\boxed{
R \approx 14.92\, \text{J/(mol·K)}
}
$$

This is very close to the standard gas constant value (8.314 J/(mol·K)), but the discrepancy suggests a different gas or measurement considerations. If the gas is air, the expected R value is approximately 8.314 J/(mol·K). The difference indicates the need for precise molar mass assumptions or more data.

Summary and Key Takeaways

- The process of determining the gas constant involves converting all given data into SI units.
- Using the ideal gas law, and knowledge of the gas's density and pressure, allows calculation of the specific gas constant.
- For common gases like air, the molar mass is well-known (≈0.02897 kg/mol), facilitating the calculation of R.
- The calculated R value (~14.92 J/(mol·K)) suggests the gas might differ from air or measurement parameters.

Additional Considerations in Gas Law Calculations

- Assumption of Ideal Gas Behavior: Real gases deviate from ideal behavior at high pressures or low temperatures.
- Molar Mass Variations: Different gases have different molar masses, affecting the calculation of R.
- Measurement Accuracy: Precise measurements of pressure, temperature, and density are critical for accurate calculations.

Conclusion

Determining the gas constant from given physical parameters involves understanding the relationships between pressure, density, temperature, and molar mass within the framework of the ideal gas law. By carefully converting units and applying fundamental thermodynamic principles, scientists and engineers can accurately compute R, enabling deeper insights into gas behavior. This process underscores the importance of unit consistency, assumptions about ideality, and the relevance of molar mass in thermodynamic calculations. Whether analyzing atmospheric gases, designing chemical reactors, or studying thermodynamic cycles, mastering these calculations is essential for scientific and engineering success.

Keywords: Gas constant calculation, ideal gas law, gas density, pressure conversion, thermodynamics, molar mass, SI units, gas behavior, physical chemistry

Frequently Asked Questions

What is the given density of the gas in the problem?

The density of the gas is 16 N/m^3 at 25°C and an absolute pressure of 0.25 N/mm^2.

How do you convert the pressure from N/mm^2 to N/m^2 in the problem?

Since 1 N/mm^2 equals 1,000,000 N/m^2, convert the pressure by multiplying 0.25 N/mm^2 by 1,000,000 to get 250,000 N/m^2.

What is the significance of using absolute pressure in the calculation?

Absolute pressure includes atmospheric pressure, ensuring the calculation correctly reflects the total pressure exerted on the gas for accurate gas constant determination.

How do you convert the temperature from Celsius to Kelvin?

Add 273.15 to the Celsius temperature: 25°C + 273.15 = 298.15 K.

What is the ideal gas law formula used to determine the gas constant R?

The ideal gas law is $PV = nRT$, where R can be calculated as $R = (PV) / (nT)$.

How do you find the number of moles (n) of the gas using its density?

Using the relation n = (mass) / (molar mass), and since density (ρ) = mass / volume, you can relate density to molar mass and pressure to find n.

What is the formula to calculate the gas constant R in this context?

$R = (P \times V) / (n \times T)$, where P is pressure, V is volume, n is number of moles, and T is temperature in Kelvin.

What is the final step to determine the gas constant R from the given data?

Express the density as mass per unit volume, find the molar mass using the ideal gas law, and then compute R using the relation $R = (P \times V) / (n \times T)$.

What is the approximate value of the gas constant R calculated from the given data?

Using the provided data, the approximate value of R is about 8.31 J/(mol·K).

Additional Resources

A Gas Weighs 16 N/m^3 At 25°C And At An Absolute Pressure Of 0.25 N/mm^2. Determine The Gas Constant

Understanding the properties of gases is fundamental in thermodynamics and fluid mechanics, with applications ranging from industrial processes to atmospheric science. This article delves into a specific problem involving a gaseous substance characterized by its weight density, pressure, and temperature, aiming to determine the universal gas constant (R). Through a systematic analysis, we explore the physical principles, calculations, and implications of the problem, providing a comprehensive understanding of the concepts involved.

Introduction to Gas Properties and Their Significance

Gases are characterized by several measurable properties, including pressure (P), temperature (T), volume (V), and density (ρ). The relationships among these parameters are governed by fundamental laws like the Ideal Gas Law, which links the gas constant (R) to the specific properties of the gas. The precise determination of R allows for deeper insights into the molecular nature of the gas and enables predictions about its behavior under various conditions.

In the problem at hand, we are given:
- Weight density (γ) = 16 N/m^3
- Temperature (T) = 25°C
- Absolute pressure (P) = 0.25 N/mm^2

These parameters offer a pathway to deduce the molecular weight or specific gas constant, provided we interpret the data correctly and apply the relevant equations.

Understanding the Given Data

Weight Density (γ)

Weight density, γ, is defined as the weight per unit volume of the gas:

$$
\gamma = \frac{W}{V}
$$

where W is the weight, and V is the volume. In SI units, γ is expressed in N/m^3. Given $\gamma = 16\ N/m^3$, this implies that each cubic meter of the gas weighs 16 Newtons.

This parameter is crucial because it directly relates to the mass density (ρ) via the acceleration due to gravity (g):

$$
\gamma = \rho g
$$

where ρ is the mass density in kg/m^3 and $g \approx 9.81\ m/s^2$.

Pressure (P)

The pressure is given as $0.25\ N/mm^2$. To work consistently in SI units, it is necessary to convert this into Pascals (Pa):

$$
1\, \text{N/mm}^2 = 10^6\, \text{N/m}^2 = 1\, \text{MPa}
$$

Thus,

$$
P = 0.25\, \text{N/mm}^2 = 0.25 \times 10^6\, \text{Pa} = 250,000\, \text{Pa}
$$

Temperature (T)

The temperature provided is 25°C. Converting to Kelvin:

$$
T = 25 + 273.15 = 298.15\, \text{K}
$$

Temperature in Kelvin is essential for thermodynamic calculations involving the ideal gas law.

Fundamental Relationships and Equations

The core equation connecting pressure, volume, temperature, and the amount of gas is the Ideal Gas Law:

$$
PV = nRT
$$

where:
- P = pressure
- V = volume
- n = number of moles
- R = universal gas constant
- T = absolute temperature

Alternatively, in terms of mass (m) and specific gas constant (R_specific), the law can be written as:
\[
PV = m R_{specific} T
\]
or
\[
P = ρ R_{specific} T
\]
since \(ρ = \frac{m}{V} \).

Given that, the specific gas constant \(R_{specific} \) relates to the universal gas constant R and the molecular weight (M) of the gas:
\[
R_{specific} = \frac{R}{M}
\]
where R ≈ 8.314 J/(mol·K).

Understanding these relationships allows us to determine R once the molecular weight M or the specific gas constant is known.

Calculating the Gas Density from Weight Density

From the weight density:
\[
γ = ρg
\]
we can solve for the mass density (ρ):
\[
ρ = \frac{γ}{g} = \frac{16\, \text{N/m}^3}{9.81\, \text{m/s}^2} \approx 1.629\, \text{kg/m}^3
\]

This value indicates that each cubic meter of the gas weighs approximately 1.629 kilograms.

Implication: The mass density is crucial because it allows us to connect the macroscopic properties (pressure and temperature) with microscopic parameters (molecular weight and the gas constant).

Applying the Ideal Gas Law to Find the Gas Constant

Using the relation:
\[
P = ρ R_{specific} T
\]
we can isolate \(R_{specific} \):
\[
R_{specific} = \frac{P}{ρ T}
\]

Substituting the known values:
\[

$$
R_{specific} = \frac{250,000\, \text{Pa}}{1.629\, \text{kg/m}^3 \times 298.15\, \text{K}}
$$

Calculating the denominator:
$$
1.629 \times 298.15 \approx 485.36
$$

Thus:
$$
R_{specific} \approx \frac{250,000}{485.36} \approx 515.18\, \text{J/(kg·K)}
$$

This is the specific gas constant for the gas under the given conditions.

Determining the Molecular Weight and the Universal Gas Constant

The relationship between the specific gas constant $R_{specific}$, universal gas constant R, and molecular weight M is:
$$
R_{specific} = \frac{R}{M}
$$
Rearranging:
$$
M = \frac{R}{R_{specific}}
$$

Using $R \approx 8.314$ J/(mol·K):
$$
M = \frac{8.314}{515.18} \approx 0.01614\, \text{kg/mol} = 16.14\, \text{g/mol}
$$

This value indicates the molecular weight of the gas is approximately 16.14 grams per mole, which is close to that of methane (CH_4), suggesting the gas could be methane or a similar light hydrocarbon.

Finally, to find the universal gas constant R, the earlier calculation of $R_{specific}$ confirms the consistency with the known value:
$$
R = M \times R_{specific} = 0.01614\, \text{kg/mol} \times 515.18\, \text{J/(kg·K)} \approx 8.314\, \text{J/(mol·K)}
$$

This aligns well with the standard value of the universal gas constant, validating the calculations.

Discussion and Implications

The analysis illustrates how macroscopic measurements like weight density, pressure, and temperature can be employed to deduce fundamental gaseous properties. The derived molecular weight (~16.14 g/mol) aligns with the characteristics of methane, which is a common constituent of natural gas.

Understanding the molecular weight is essential for designing chemical processes, calculating reaction rates, and modeling atmospheric phenomena. Moreover, calculating the specific gas constant provides insights into the thermodynamic behavior of the gas, influencing how it responds to changes in temperature and pressure.

The approach also demonstrates the importance of unit conversions and the careful interpretation of given data, as errors in units can lead to significant inaccuracies. For example, converting pressure from N/mm^2 to Pa was crucial in ensuring consistency across calculations.

Conclusion

This comprehensive analysis has elucidated the process of determining the universal gas constant from given physical properties of a gas. Starting from basic principles and leveraging the ideal gas law, we calculated the gas's specific gas constant and molecular weight, arriving at a value consistent with methane. Such calculations are fundamental in thermodynamics, enabling engineers and scientists to predict gas behavior accurately and design efficient systems.

By understanding these relationships, professionals can better interpret experimental data, optimize industrial processes, and deepen their grasp of molecular physics. The problem underscores the interconnectedness of macroscopic measurements and microscopic properties, illustrating the elegance and utility of thermodynamic principles in real-world applications.

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