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The Average Molecular Speed In A Sample Of He Gas At A Certain Temperature Is 1.2610^3 m/s. The Average

Understanding the behavior of gases at a molecular level is fundamental in physics and chemistry. One key parameter that scientists analyze is the average molecular speed, which provides insights into the kinetic energy, temperature relationship, and molecular dynamics of gases. In this article, we delve into the concept of average molecular speed, specifically focusing on helium gas, its significance, calculation, and implications in various scientific contexts.

What Is The Average Molecular Speed?

The average molecular speed refers to the mean velocity of molecules within a gas sample. Since molecules are in constant, random motion, their speeds vary. The average speed provides a statistical measure that helps quantify the typical velocity of molecules under specific conditions, primarily temperature.

Key points about average molecular speed:

- It reflects the overall kinetic activity of molecules.
- It varies with temperature and molecular mass.
- It is different from root mean square speed and most probable speed, although related.

Significance of Molecular Speed in Gas Behavior

Understanding molecular speed is crucial for multiple reasons:

- Kinetic Theory of Gases: It forms the backbone of the kinetic theory, explaining gas laws and behaviors.
- Reaction Rates: Faster-moving molecules tend to collide more frequently and with higher energy, influencing reaction rates.
- Diffusion and Effusion: Molecular speed affects how gases diffuse and escape through small openings.
- Temperature Relationship: It provides a microscopic explanation for the macroscopic temperature of gases.

Calculating the Average Molecular Speed of Helium Gas

The average molecular speed of helium gas at a certain temperature can be calculated using the kinetic theory of gases. The key equation relates molecular speed to temperature and molecular mass:

Formula for Average Molecular Speed (v̄)

$$
\bar{v} = \sqrt{\frac{8RT}{\pi M}}
$$

Where:

- $\bar{v}$ = average molecular speed
- R = universal gas constant (8.314 J/mol·K)
- T = absolute temperature in Kelvin (K)
- M = molar mass of helium in kilograms per mole (kg/mol)

Note: When the molecular speed is given as 1.26×10^3 m/s, we can back-calculate the temperature or understand the conditions under which this average speed occurs.

Applying the Formula: Example Calculation

Suppose the average molecular speed of helium molecules is measured as 1261 m/s. Given the molar mass of helium (M_{He}) is approximately 4.00 g/mol, or 4.00×10^{-3} kg/mol, we can find the temperature:

Step 1: Rearranged formula to solve for T:

$$
T = \frac{\pi M \bar{v}^2}{8 R}
$$

Step 2: Plug in the known values:

- $M = 4.00 \times 10^{-3}$ kg/mol
- $\bar{v} = 1261$ m/s
- $R = 8.314$ J/mol·K

Step 3: Calculation:

$$
T = \frac{\pi \times 4.00 \times 10^{-3} \times (1261)^2}{8 \times 8.314}
$$

$$
T = \frac{3.1416 \times 4.00 \times 10^{-3} \times 1,589,321}{66.512}
$$

$$
T \approx \frac{3.1416 \times 4.00 \times 10^{-3} \times 1,589,321}{66.512}
$$

$$
T \approx \frac{3.1416 \times 6,357.284}{66.512}
$$

$$
T \approx \frac{19,944.42}{66.512} \approx 299.7\, \text{K}
$$

Result: The temperature of the helium gas at this average molecular speed is approximately 300 K.

Factors Affecting Molecular Speed

The average molecular speed of a gas molecule primarily depends on:

1. Temperature

- As temperature increases, molecular speed increases proportionally.
- The kinetic energy of molecules is directly related to temperature:

$$
KE_{avg} = \frac{3}{2} RT
$$

2. Molecular Mass

- Lighter molecules move faster at a given temperature.
- Helium, being a light noble gas, has higher average speeds compared to heavier gases like nitrogen or oxygen at the same temperature.

3. Gas Type and Composition

- Mixtures of gases exhibit average speeds based on their individual molecular masses and concentrations.

Comparison of Molecular Speeds in Different Gases

Understanding the differences in molecular speeds across various gases helps in applications like gas separation, diffusion processes, and the design of equipment.

Sample comparison:

Gas	Molar Mass (g/mol)	Typical Average Speed at 300 K (m/s)
Helium	4.00	~1,300
Nitrogen	28.02	~470
Oxygen	32.00	~430
Carbon Dioxide	44.01	~380

Note: Helium has the highest average molecular speed among these gases due to its low molar mass.

Implications of High Molecular Speeds in Helium

The high average molecular speed of helium has several practical implications:

- Efficient Heat Transfer: Helium's rapid molecular motion makes it an excellent conductor of heat, used in cooling systems like cryogenics.
- Low Density and Buoyancy: Helium's high speed contributes to its low density, making it ideal for lifting gases in balloons and airships.
- Fast Diffusion and Escape: Helium molecules diffuse quickly and can escape through tiny pores, important in nuclear safety and leak detection.

Real-World Applications of Molecular Speed Knowledge

Understanding and calculating molecular speeds are critical in various scientific and industrial applications:

- Designing Gas-Based Systems: Rockets, HVAC systems, and cooling devices depend on gas properties including molecular speed.
- Atmospheric Science: Molecular speeds influence atmospheric diffusion and the escape of gases into space.

- Material Science: Gas permeation in materials is affected by molecular velocities.
- Medical Technologies: Helium’s properties are utilized in MRI cooling systems and respiratory therapies.

Summary and Conclusion

The average molecular speed of helium gas at a certain temperature, measured as 1.26×10^3 m/s, exemplifies the dynamic microscopic world of gases. Calculated using the kinetic theory of gases, this parameter provides a bridge between microscopic molecular behavior and macroscopic thermodynamic properties. The high speed of helium molecules at room temperature underscores its unique physical characteristics, including high thermal conductivity and low density.

By understanding the factors influencing molecular speed—primarily temperature and molecular mass—scientists and engineers can optimize systems ranging from cryogenics to aerospace. Recognizing the significance of molecular velocity not only deepens our understanding of gas behavior but also enhances our ability to innovate and improve technological applications.

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Frequently Asked Questions

What does the average molecular speed of 1.26 x 10^3 m/s indicate about helium gas at a given temperature?

It indicates the average velocity of helium atoms in the sample, reflecting how fast the molecules are moving at that specific temperature based on kinetic theory.

How is the average molecular speed of helium related to its temperature?

The average molecular speed increases with temperature, following the relation $v_{avg} = \sqrt{8RT/\pi M}$, meaning higher temperatures lead to higher average speeds.

What formula can be used to determine the temperature of helium gas given its average molecular speed?

The temperature can be found using T = (πM v_avg^2) / (8R), where M is molar mass, R is the gas constant, and v_avg is the average molecular speed.

Why is the average molecular speed of helium important in understanding its physical behavior?

It helps explain properties like diffusion rates, pressure, and thermal conductivity of helium gas, as these depend on molecular velocities.

If the average molecular speed of helium increases, what can be inferred about the temperature of the gas?

An increase in average molecular speed implies that the temperature of the helium gas has risen, as molecular speed is directly related to temperature through kinetic energy.

Additional Resources

The Average Molecular Speed in a Sample of He Gas at a Certain Temperature Is 1.2610^{3} m/s. The Average molecular speed is a fundamental concept in kinetic molecular theory and thermodynamics, offering critical insights into the microscopic behavior of gases. Understanding how molecules move, how their speeds relate to temperature, and what factors influence these dynamics helps scientists and engineers interpret phenomena ranging from gas diffusion to reaction kinetics. In this article, we delve into the significance of the average molecular speed, particularly in a helium (He) gas sample, and explore the underlying principles, calculations, and implications.

Understanding Molecular Speed in Gases

Before diving into specific calculations or conclusions, it's essential to grasp what we mean by average molecular speed. Unlike macroscopic speed measurements, molecular speeds are statistically distributed because individual molecules continually collide and change directions and velocities. Several types of average speeds are used:

- Average (Mean) Speed: The arithmetic mean of all molecular speeds.
- Root Mean Square (RMS) Speed: The square root of the average of the squares of molecular speeds; often used because it relates directly to kinetic energy.
- Most Probable Speed: The speed at which the maximum number of molecules are moving.

Each of these speeds provides different insights, but in many analyses, the average (mean) speed is a primary focus, especially when evaluating molecular motion in relation to temperature.

The Significance of the Average Molecular Speed

In a sample of helium gas, knowing the average molecular speed allows us to:

- Estimate diffusion rates: Faster-moving molecules tend to diffuse more quickly.
- Understand energy distribution: Molecular speed relates directly to the kinetic energy of particles.
- Predict reaction rates: Many reactions depend on molecules reaching certain energies or collision velocities.
- Apply in real-world contexts: Such as designing more efficient gas separation processes or understanding atmospheric phenomena.

Given that the average molecular speed in helium at a certain temperature is 1.26×10^3 m/s, we can analyze what this tells us about the thermal state of the gas.

Fundamental Principles and Equations

Kinetic Molecular Theory

The kinetic theory models gases as collections of molecules in constant, random motion. The average molecular speed relates directly to temperature, molecular mass, and the statistical distribution of molecular velocities.

Maxwell-Boltzmann Distribution

The distribution of molecular speeds in gases follows the Maxwell-Boltzmann distribution, which describes the probability of molecules moving at various speeds at a given temperature.

The Equation for Average Molecular Speed

For a gas, the average (mean) molecular speed $\bar{v}$ is given by:

$$
\bar{v} = \sqrt{\frac{8 RT}{\pi M}}
$$

Where:
- R = Universal gas constant ($8.314\, \mathrm{J/(mol\,K)}$)
- T = Absolute temperature in Kelvin (K)
- M = Molar mass of the gas in kilograms per mole (kg/mol)

Alternatively, when considering individual molecules, the average molecular speed can be derived from the kinetic energy expression:

$$
\frac{1}{2} m \bar{v}^2 = \frac{3}{2} k_B T
$$

Where:
- m = mass of a single molecule
- k_B = Boltzmann's constant ($1.380649 \times 10^{-23}\, \mathrm{J/K}$)
- T = Temperature in Kelvin (K)

Calculating the Temperature of Helium Gas

Given the average molecular speed $\bar{v} = 1.26 \times 10^3\, \mathrm{m/s}$ for helium, we can determine the temperature of the sample.

Step 1: Find the molar mass of helium

$$
M_{He} = 4.00\, \mathrm{g/mol} = 4.00 \times 10^{-3}\, \mathrm{kg/mol}
$$

Step 2: Find the mass of a single helium molecule

$$
m = \frac{M_{He}}{N_A}
$$

Where $N_A = 6.022 \times 10^{23}$ mol^{-1}

$$
m = \frac{4.00 \times 10^{-3}}{6.022 \times 10^{23}} \approx 6.64 \times 10^{-27}\, \mathrm{kg}
$$

Step 3: Rearrange the kinetic energy equation

$$
\frac{1}{2} m \bar{v}^2 = \frac{3}{2} k_B T
$$

Solve for T:

$$
T = \frac{m \bar{v}^2}{3 k_B}
$$

Step 4: Plug in the values

$$
T = \frac{6.64 \times 10^{-27} \times (1.26 \times 10^{3})^2}{3 \times 1.380649 \times 10^{-23}}
$$

Calculations:

$$
\bar{v}^2 = (1.26 \times 10^3)^2 = 1.59 \times 10^6
$$

$$
T = \frac{6.64 \times 10^{-27} \times 1.59 \times 10^6}{4.141947 \times 10^{-23}}
$$

$$
T = \frac{1.055 \times 10^{-20}}{4.141947 \times 10^{-23}} \approx 255\, \mathrm{K}
$$

Therefore, the temperature of the helium gas sample is approximately 255 Kelvin.

Interpreting the Results

The calculated temperature (~255 K) is just above the freezing point of helium (~4.2 K) and well below room temperature (~300 K). This indicates that the sample is relatively cool, which aligns with the high molecular speed for helium molecules—lighter gases tend to have higher average speeds at a given temperature.

Key takeaways:

- Light gases like helium have high average molecular speeds at moderate temperatures.
- Temperature directly influences molecular speed: higher temperatures mean higher molecule velocities.
- The relationship is inverse for mass: heavier molecules move slower at the same temperature.

Practical Applications and Implications

Understanding the average molecular speed in helium gas at a specific temperature has several practical implications:

1. Gas Diffusion and Effusion

Helium's high average speed contributes to its rapid diffusion and effusion rates, which are important in applications like gas chromatography, leak detection, and atmospheric studies.

2. Heat Transfer Efficiency

Faster-moving molecules transfer heat more effectively, making helium useful in cooling systems, such as in cryogenics and superconducting magnets.

3. Designing Gas Separation Processes

Knowing molecular speeds helps optimize processes like gas separation and purification, especially when exploiting differences in molecular velocities.

4. Modeling Atmospheric Phenomena

Helium’s behavior at various temperatures influences its dispersal in the atmosphere and helps in understanding planetary atmospheres.

Summary and Final Remarks

- The average molecular speed in a helium gas sample at a certain temperature offers deep insights into the microscopic kinetic behavior of the gas.
- Using fundamental physics equations, we estimated the temperature of the helium sample to be approximately 255 K based on the provided molecular speed.
- This analysis underscores the importance of molecular mass and temperature in determining molecular velocities, with lighter gases like helium moving faster on average at a given temperature.
- Such understanding guides practical applications across scientific and engineering disciplines, emphasizing the significance of thermal and molecular dynamics.

Additional Resources

- Kinetic Molecular Theory: Explore textbooks or online courses for a detailed understanding.
- Maxwell-Boltzmann Distribution: Delve into statistical mechanics for a comprehensive view.
- Gas Laws and Thermodynamics: Review fundamental principles to connect microscopic behavior with macroscopic observations.

By grasping the relationship between molecular speed and temperature, scientists and engineers can better predict and manipulate the behavior of gases like helium in various environments and applications.

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