What Is The Total Pressure Exerted By A Mixture Containing Two Gases If The Partial Pressure Of One Gas

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Understanding the behavior of gases in mixtures is fundamental in fields such as chemistry, physics, and engineering. When two gases coexist within a container, each exerts its own partial pressure, which collectively contribute to the total pressure within the system. If you know the partial pressure of one gas and the properties of both gases, you can determine the total pressure exerted by the mixture. This concept is rooted in Dalton's Law of Partial Pressures, a key principle in gas laws that describes how gas pressures combine in a mixture. This article explores what the total pressure is, how to calculate it, and the underlying principles governing gas mixtures.

Understanding Gas Pressure and Dalton's Law of Partial Pressures

What Is Gas Pressure?

Gas pressure is the force exerted by gas molecules as they collide with the walls of their container per unit area. It is a measure of the momentum transfer from molecules to the container walls and is influenced by factors such as temperature, volume, and the number of molecules.

Dalton’s Law of Partial Pressures

Dalton’s Law states that in a mixture of non-reacting gases, each gas exerts a partial pressure independently of the others. The total pressure of the mixture is the sum of these partial pressures:

$$P_{total} = P_1 + P_2 + P_3 + \dots$$

In a two-gas mixture, this simplifies to:

$$P_{total} = P_1 + P_2$$

Where:

- P_1 is the partial pressure of Gas 1
- P_2 is the partial pressure of Gas 2

This law assumes ideal gas behavior, meaning the gases do not interact chemically and obey the ideal gas law.

Calculating Total Pressure in a Two-Gas Mixture

Given Partial Pressure of One Gas

Suppose you are provided the partial pressure of Gas 1 (P_1) and either the partial pressure or the mole fraction of Gas 2. The goal is to find the total pressure of the mixture (P_{total}).

Key Variables Needed

To accurately determine the total pressure, the following information is typically needed:

- Partial pressure of one gas (P_1)
- Partial pressure of the other gas (P_2), or the mole fraction of each gas
- Total number of moles or the total pressure if partial pressures are not directly given
- Temperature and volume (if using the ideal gas law)

Using Dalton’s Law to Calculate Total Pressure

If the partial pressure of Gas 2 (P_2) is known, the total pressure is straightforward:

$$P_{total} = P_1 + P_2$$

Example:

Suppose:
- Partial pressure of oxygen (P_{O_2}) is 0.2 atm
- Partial pressure of nitrogen (P_{N_2}) is 0.8 atm

Then, the total pressure is:

$$P_{total} = 0.2\, \text{atm} + 0.8\, \text{atm} = 1.0\, \text{atm}$$

Relating Partial Pressures to Mole Fractions and the Ideal Gas Law

Mole Fraction and Partial Pressure

The partial pressure of a gas in a mixture can also be expressed in terms of mole fraction (X_i):

$$P_i = X_i \times P_{total}$$

Where:
- P_i is the partial pressure of gas i
- X_i is the mole fraction of gas i
- P_{total} is the total pressure

Rearranged, the total pressure can be derived if mole fractions and partial pressures are known:

$$P_{total} = \frac{P_i}{X_i}$$

Example:

If the mole fraction of Gas 1 (X_1) is 0.3, and its partial pressure P_1 is 0.6 atm, then:

$$P_{total} = \frac{0.6\, \text{atm}}{0.3} = 2.0\, \text{atm}$$

Calculating Total Pressure Using the Ideal Gas Law

Ideal Gas Law Overview

The ideal gas law relates pressure, volume, temperature, and moles:

$$PV = nRT$$

Where:
- P is the pressure
- V is the volume
- n is the number of moles
- R is the ideal gas constant ($8.314\, \text{J mol}^{-1} \text{K}^{-1}$)
- T is the temperature in Kelvin

Applying the Ideal Gas Law to Gas Mixtures

For a mixture containing gases 1 and 2:

$$ P_{total} V = (n_1 + n_2) RT $$

If the partial pressures of individual gases are known, they relate to moles via:

$$ P_i V = n_i RT $$

Thus, the partial pressure of each gas can be found if the moles and conditions are known:

$$ P_i = \frac{n_i RT}{V} $$

The total pressure then is the sum of these partial pressures:

$$ P_{total} = \frac{(n_1 + n_2) RT}{V} $$

Practical Examples of Calculating Total Pressure

Example 1: Known Partial Pressure of One Gas and Total Moles

Suppose:
- Partial pressure of Gas 1 (P_1) = 0.5 atm
- Total moles of gases n_{total} = 2 mol
- Mole fraction of Gas 1 (X_1) = 0.4
- Volume (V) = 10 L
- Temperature (T) = 300 K

Calculate the total pressure:

1. Find moles of Gas 1:

$$ n_1 = X_1 \times n_{total} = 0.4 \times 2 = 0.8\, \text{mol} $$

2. Use the ideal gas law to find total pressure:

$$ P_{total} = \frac{(n_1 + n_2) RT}{V} $$

But since $n_2 = n_{total} - n_1 = 1.2\, \text{mol}$, total pressure is:

$$ P_{total} = \frac{n_{total} RT}{V} = \frac{2 \times 8.314 \times 300}{10} $$

$$ P_{total} = \frac{2 \times 8.314 \times 300}{10} = \frac{4988.4}{10} = 498.84\, \text{kPa} $$

Convert to atm:

$$ 1\, \text{atm} = 101.325\, \text{kPa} $$

$$ P_{total} = \frac{498.84}{101.325} \approx 4.93\, \text{atm} $$

3. Verify partial pressure of Gas 1:

$$ P_1 = X_1 \times P_{total} = 0.4 \times 4.93 \approx 1.97\, \text{atm} $$

This example demonstrates how partial pressures relate to total pressure and mole fractions.

Factors Affecting Total Pressure in Gas Mixtures

Temperature

Increasing temperature generally increases the kinetic energy of molecules, leading to higher partial pressures if volume and moles are constant.

Volume

Expanding the volume of the container reduces pressure, following Boyle’s Law, but the partial pressure of each gas depends on their mole fractions and temperature.

Mole Ratios

The relative amounts (moles) of each gas influence their partial pressures and, consequently, the total pressure.

Interactions Between Gases

While Dalton’s Law assumes ideal behavior, real gases may deviate due to interactions, particularly at high pressures or low temperatures, affecting the total pressure calculations.

Applications of Total Pressure Calculations in Real-World Scenarios

- Industrial Gas Mixtures: Ensuring proper pressure conditions during gas storage and transport.
- Respiratory Physiology: Understanding partial pressures of oxygen and carbon dioxide in blood.
- Chemical Reactions: Calculating pressures in reactions involving multiple gases.
- Aerospace Engineering: Managing gas pressures in spacecraft cabins.

Summary and Key Takeaways

- The total pressure exerted by a mixture of two gases is the sum of their partial pressures, as per Dalton’s Law.
- If the partial pressure of one gas and the mole fraction or partial pressure of the other are known, the total pressure can be calculated directly.
- The ideal gas law provides a framework to

Frequently Asked Questions

What is the total pressure exerted by a gas mixture if the partial pressure of one gas is known?

The total pressure is the sum of the partial pressures of all gases in the mixture, so you add the known partial pressure to the partial pressure of the other gas(ses). For example, if the partial pressure of one gas is P_1 and the other is P_2, then total pressure $P_t = P_1 + P_2$.

How do Dalton's Law of Partial Pressures and the partial pressure of one gas relate to the total pressure?

Dalton's Law states that the total pressure of a gas mixture is equal to the sum of the partial pressures of individual gases. If the partial pressure of one gas is known, and the partial pressure of the other is determined or measured, their sum gives the total pressure exerted by the mixture.

Can the total pressure be calculated if only the partial pressure of one gas and the mole fractions are known?

Yes. If the mole fraction of each gas and the total pressure are known, you can find the partial pressure of each gas. Conversely, if the partial pressure of one gas and the mole fractions are known, you can determine the total pressure using the relation P_total = P_partial / mole_fraction of that gas.

What additional information is needed to find the total pressure if only the partial pressure of one gas is given?

You need either the partial pressure of the other gas(ses) in the mixture or the mole fractions of the gases involved. Without this, you cannot determine the total pressure solely from one partial pressure.

Why is understanding the total pressure important in gas mixture calculations?

Understanding the total pressure helps in predicting how gases will behave under different conditions, calculating gas densities, and applying gas laws accurately to real-world scenarios such as chemical reactions, respiratory systems, and industrial processes.

Additional Resources

What Is The Total Pressure Exerted By A Mixture Containing Two Gases If The Partial Pressure Of One Gas

Understanding the behavior of gases when they coexist in a mixture is fundamental in fields ranging from chemistry and physics to engineering and environmental science. Among the core principles governing these interactions is Dalton's Law of Partial Pressures, which provides a straightforward way to determine the total pressure exerted by a gaseous mixture based on the partial pressures of its constituents. In particular, knowing the partial pressure of one component enables scientists and engineers to infer the total pressure in complex systems, facilitating analysis and design across various applications.

This article aims to delve deep into the concept of total pressure in gas mixtures, especially focusing on situations where the partial pressure of one gas is known. Through detailed explanations, theoretical foundations, and practical considerations, we will explore how to accurately determine total pressure, the underlying assumptions of Dalton's Law, and the broader implications in real-world scenarios.

Understanding Gas Mixtures and Partial Pressures

Fundamental Concepts of Gas Mixtures

Gases are characterized by their particles' rapid, random motion, and their behavior is well-described by the kinetic molecular theory. When multiple gases are combined in a container, they do not chemically react (assuming ideal behavior) but instead coexist, exerting pressure on the container walls. The resulting system is called a gas mixture.

In such mixtures, each gas component contributes to the total pressure independently, an idea central to Dalton's Law. This independence stems from the assumption that gas particles do not interact significantly with each other beyond elastic collisions, which is valid under ideal conditions.

Definition of Partial Pressure

The partial pressure of a gas component within a mixture is the hypothetical pressure the gas would exert if it alone occupied the entire volume at the same temperature. It quantifies the individual contribution of each gas to the total pressure.

Mathematically, for a gas component i in a mixture:

$$
P_i = y_i P_{total}
$$

where:
- P_i is the partial pressure of gas i,
- y_i is the mole fraction of gas i in the mixture,
- P_{total} is the total pressure of the mixture.

The mole fraction y_i is given by:

$$
y_i = \frac{n_i}{n_{total}}
$$

with n_i being the number of moles of gas i, and n_{total} the total number of moles in the mixture.

Dalton's Law of Partial Pressures: Theoretical Framework

Statement of Dalton's Law

Dalton's Law states that in a mixture of non-reacting gases, the total pressure exerted is equal to the sum of the partial pressures of individual gases:

$$
P_{total} = P_1 + P_2 + P_3 + \dots
$$

For a two-gas system, this simplifies to:

$$
P_{total} = P_A + P_B
$$

where:
- P_A and P_B are the partial pressures of gases A and B, respectively.

This law assumes gases behave ideally, the mixture is at equilibrium, and there are no interactions between different gas molecules besides elastic collisions.

Implications of Dalton's Law

- Additivity of Pressures: The total pressure is directly additive based on individual contributions.
- Independence of Gases: Each gas acts independently, unaffected by the presence of others, under ideal conditions.
- Application in Calculations: Given the mole fractions and total pressure, partial pressures can be directly calculated, or vice versa.

Calculating Total Pressure When Partial Pressure of One Gas Is Known

Scenario Setup

Suppose in a mixture of two gases, Gas A and Gas B, the partial pressure of Gas A (P_A) is known, along with the mole fraction of Gas A (y_A), and the partial pressure of Gas B (P_B) is either known or can be deduced.

The question is: How do we determine the total pressure P_{total} given P_A?

This is a common situation in experimental setups where, for example, the partial pressure of oxygen in a mixture is known, and the goal is to find the total pressure exerted by the entire mixture.

Mathematical Derivation and Steps

1. Identify Known Variables:
- Partial pressure of one gas, P_A
- Mole fraction of Gas A, y_A
- Partial pressure of the other gas, P_B, or the mole fraction y_B

2. Express the Partial Pressures in Terms of Total Pressure:

Using Dalton's Law:

$$
P_A = y_A P_{total}
$$

$$
P_B = y_B P_{total}
$$

Since the mole fractions sum to 1:

$$
y_A + y_B = 1
$$

3. Determine the Mole Fractions:

If the partial pressure of Gas A and its mole fraction are known, then:

$$
y_A = \frac{P_A}{P_{total}}
$$

From this, the mole fraction of Gas B is:

$$
y_B = 1 - y_A
$$

4. Calculate Total Pressure:

If the mole fraction y_A is known:

$$
P_{total} = \frac{P_A}{y_A}
$$

Alternatively, if the partial pressure of Gas B is known:

$$
P_B = y_B P_{total}
$$

then:

$$
P_{total} = P_A + P_B
$$

assuming ideal behavior and that partial pressures are directly additive.

5. Handling Unknowns:

If only P_A is known, but the mole fraction y_A or the partial pressure of the other gas is unknown, additional information such as the number of moles or the total amount of gas and temperature conditions are needed for precise calculation.

Practical Examples and Applications

Example 1: Atmospheric Composition Analysis

Suppose atmospheric air contains approximately 21% oxygen by mole, and the total atmospheric pressure at a certain altitude is 750 mm Hg. The partial pressure of oxygen (P_{O_2}) can be calculated as:

$$
P_{O_2} = y_{O_2} P_{total} = 0.21 \times 750\, \text{mm Hg} = 157.5\, \text{mm Hg}
$$

If a scientist measures P_{O_2} to be 160 mm Hg, they can estimate the total pressure:

$$
P_{total} = \frac{P_{O_2}}{y_{O_2}} = \frac{160\, \text{mm Hg}}{0.21} \approx 761.9\, \text{mm Hg}
$$

This illustrates how partial pressure measurements can inform us about total system pressure.

Example 2: Gas Mixture in Industrial Processes

In chemical reactors, gases often interact under controlled conditions. For instance, if an engineer knows the partial pressure of hydrogen in a mixture and the mole fraction, they can determine the total pressure to ensure safety and efficiency.

Suppose:
- Partial pressure of H_2 is 2 atm.
- Mole fraction of H_2 is 0.4.

Then,

$$
P_{total} = \frac{P_{H_2}}{y_{H_2}} = \frac{2\, \text{atm}}{0.4} = 5\, \text{atm}
$$

This total pressure helps determine safe operating limits and design considerations.

Limitations and Assumptions of Dalton's Law

While Dalton's Law provides a practical and straightforward approach to calculating total pressure, it rests on several assumptions and has limitations:

- Ideal Gas Behavior: The law assumes gases behave ideally, meaning there are no intermolecular forces and particles occupy negligible volume. Real gases deviate from ideality at high pressures and low temperatures.
- No Chemical Reactions: The gases must be non-reactive; otherwise, chemical interactions alter partial pressures.
- Uniform Temperature and Volume: The temperature and volume of the mixture are uniform, and the system is at equilibrium.

In real-world applications, deviations from ideality may require correction factors or advanced equations of state such as the Van der Waals equation.

Conclusion and Broader Implications

Understanding the relationship between partial pressures and total pressure in gas mixtures is fundamental to both theoretical and applied sciences. When the partial pressure of one gas is known, and the mixture behaves ideally, the total pressure can be accurately determined using Dalton's Law. This principle underpins diverse applications, from atmospheric science and respiratory physiology to industrial gas production and chemical engineering.

Moreover, the insights derived from this understanding contribute to safety protocols, environmental monitoring, and the design of equipment and processes involving gases. While the simplicity of Dalton's Law makes it invaluable, practitioners must remain mindful of its

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