Skills Tested by This Quiz

- Identify the theory applicable to each problem, and calculate the desirable quantity from a given set of conditions.

Properties of Gases

This quiz tests your comprehension and ability to apply the following topics to solve problems:

- Gases - the gaseous state of matter
- Gas laws - the ABCD gas laws
- Ideal gas law - a summary of gas laws
- Gas kinetics - motion of gas molecules
- Gas & stoichiometry - stoichiometry problems involving gases

A brief review is given again here, but it is your responsibility to identify the theory applicable to each problem, and calculate the desirable quantity from a given set of conditions. There is always more than one way to solve a problem, and a logical approach is a useful skill in itself. It is the process of problem solving, not the result, that is useful to you.

Common Gas Properties

Gas is a state of matter. In this state, all substances behave alike. The properties of the gaseous state are:

- Amount of gas in moles, \( n \), number of molecules, mass, and volume.
- The pressure, \( P \), exerted to the walls of the container by gas molecules or by the wall to contain the gas to a fixed volume \( V \).
- The temperature, \( T \), which is a measure of the kinetic energy of the molecules.
- The volume, \( V \), occupied by a gas at temperature \( T \), under the pressure \( P \).
- The average kinetic energy of a gas, and the root mean square speed of gas molecules.

These properties are often expressed in various units, and ability to convert units from one to another is always required.

Gas Laws - Some Key Equations

You are expected to have mastered the ABCD laws of gases.

You should use the proper units for pressure, \( P \), volume \( V \), and temperature \( T \). Letters \( i \) and \( f \) following these quantities refer to the initial and final states respectively. A summary of key equations is given below, but you should be able to derive one from each other, and understand the system from which these formulas apply.

Boyle's Law

\[(P_i V_i = k) \quad (k \text{ is a constant})\]
\(P_i V_i = P_f V_f\)

**Charles Law**

\(T = 273.15 + t^\text{C}\)

\(\frac{V_i}{T_i} = \frac{V_f}{T_f} = k\)

\(\frac{P_i}{T_i} = \frac{P_f}{T_f} = k\)

**The Ideal Gas Law**

\((P V = n R T)\)

where

\[
\begin{align*}
R &= \frac{1 \text{ atm} \cdot 22.4 \text{ L}}{1 \text{ mol} \cdot 273.15 \text{ K}} \\
&= 0.082058 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \\
&= 8.3145 \frac{\text{J}}{\text{mol} \cdot \text{K}}
\end{align*}
\]

**Avogadro's Law and Gas Density**

\((n = \frac{P V}{R T})\)

\((P M = \frac{n M}{V} R T)\) -- where \(M\) is the molecular weight of the gas

\((P V = n R T)\) -- Ideal gas equation

\((P = \frac{d R T}{M})\) -- where \(d\) is the density of the gas

\((d = \frac{P M}{R T})\) -- density of gas is given by this equation

\((M = \frac{d R T}{P})\) -- hence, the Molecular Weight of a gas is given by this.

**Dalton's Law of Partial Pressures**

If \(P_{total}\) is the total pressure of a gas mixture, and \(P_a, P_b, P_c, \ldots\) are partial pressures of gas A, B, C, ..., then

\[P_{(total)} = P_a + P_b + P_c + \ldots\]

If \(n_{total}\) is the total number of moles, and \(n_a, n_b, n_c, \ldots\) are number of moles of gas A, B, C, ..., then

\[n_{(total)} = n_a + n_b + n_c + \ldots\]

\[
\begin{align*}
n_{t} R T &= PV \backslash \\
&= (n_a + n_b + n_c + \ldots) R T \backslash \\
&= P_a + P_b + P_c + \ldots \backslash \\
\end{align*}
\]
Mole Fraction

The mole fraction of a gas A, \(x_a\), in a system containing \(n_{total}\) mole of gas is

\[
x_a = \frac{n_a}{n_{total}}
\]

Non-Ideal Behavior of Gas

The ideal gas law has a limited precision for predicting the properties of gases. The imprecision is known as the non-ideal behavior of gas, and the \textit{van der Waals equation}

\[
(P + \frac{n^2a}{V^2})(V - n b) = n R T
\]

has been introduced to deal with non-ideal behavior of gases in ideal gas law. For practical application in chemical manufacturing processes and in chemical reactions, the non-ideality has to be taken into account. For these applications, other methods of correction to the ideal gas law are also used.

Practice Questions

1. What does the variable \(P\) stand for in the ideal gas law, \((P V = n R T)\)?

   Hint: pressure

   **Skill:**
   Describe the ideal gas law.

2. If 0.40 and 0.10 mol of \(\ce{N2}\) and \(\ce{O2}\) are enclosed in a 2-liter container at a temperature of 311 K, what is the pressure?

   Hint: 6.4 atm

   **Skill:**
   Apply the ideal gas law to solve a problem.

3. If 0.40 and 0.10 mol of \(\ce{N2}\) and \(\ce{O2}\) are enclosed in a 2-liter container at a temperature of 311 K, what is the partial pressure of \(\ce{N2}\)?

   Hint: 5.1 atm

   **Skill:**
   Apply Dalton's partial pressure law to solve a problem.

4. A gas collected over water contains water vapor. At 23 °C, the vapor pressure of water is 2.8 kPa. Calculate the amount of water (molar mass 18) in mg contained in 3.0 L of a saturated air sample.
Discussion
0.061 g of water = \(37000000000000000000000\) molecules.

5. In the van der Waals equation,

\[
(P + \frac{n^2a}{V^2})(V - n b) = n R T
\]

what unit should \(n b\) have if units for \(V\) is L?

Hint: L

Discussion:
Addition and subtraction can be carried out only on quantities having the same units.

6. At room temperature, \(\text{CO}_2\) deviates from ideal gas behavior due to its high molecular mass and high boiling point. At 300 K, choose the gas that behaves most like an ideal gas from: \(\text{CO}\), \(\text{CO}_2\), \(\text{HF}\), \(\text{NH}_3\), \(\text{H}_2\text{S}\), \(\text{SO}_3\), \(\text{NO}_2\), \(\text{CH}_4\), \(\text{H}_2\).

Hint: Hydrogen gas

Discussion:
Molecules of \(\text{NH}_3\), \(\text{H}_2\text{S}\) and \(\text{HF}\) are polar, and their molecules interact strongly. These gases are less ideal at room temperature compared to \(\text{H}_2\), \(\text{N}_2\) and \(\text{O}_2\).

7. A weather balloon filled with \(\text{He}\) gas at 300.0 K has a volume of 2.0 m\(^3\) at ground level where the pressure is 1.0 atm. After the balloon rises to a height where the atmospheric pressure is 0.40 atm, its volume increases to 4.0 m\(^3\). Calculate the temperature in K of the \(\text{He}\) gas. \(R = 0.08205\ \text{L atm} / (\text{mol K})\)

Hint: 240 K

Skill:
Easily solved by the application of the formula

\[
\frac{P_i V_i}{T_i} = \frac{P_f V_f}{T_f}
\]

8. The van der Waals constants for \(\text{CO}_2\) are: \(a = 3.592\ \text{L}^2\ \text{atm mol}^{-2}\), \(b = 0.04267\ \text{L/mol}\). Use the van der Waals equation to estimate the pressure exerted by 0.500 mol of \(\text{CO}_2\) in a 1.00 L tank at 298 K.

Hint: 11.6 atm

Skill:
Rearrange the van der Waals formula as

\[
(P = \frac{n R T}{V - n b} - \frac{n^2 a}{V^2})
\]
9. A 1.0-L sample vapor of an unknown substance has a mass of 2.548 g at 101.3 kPa and 100 °C. Estimate the molar mass.

Hint: 78

Skill:
Apply the formula: \( M = \frac{d R T}{P} \) to solve the problem.

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