CHAPTER 11.3

MOLECULAR COMPOSITION OF GASES
INTRODUCTION

• The particles that make up different gases can vary greatly in size. The KMT assumes that the particles in a gas sample are so far apart that size has very little influence on the volume occupied by a gas.

• **For example:** 1000 relatively large krypton gas particles occupy the same volume as 1000 small helium gas particles at the same temperature and pressure.
It was Avogadro who first proposed this idea in 1811. He therefore stated that equal volumes of gases at the same temperature and pressure contain equal numbers of particles. This is known as Avogadro’s principle.

Recall that 1 mole of any substance contains $6.02 \times 10^{23}$ particles. Therefore according to Avogadro’s principle, 1 mole of any gas will occupy the same volume at the same temperature and pressure, despite mass differences.
The volume occupied by 1 mole of a gas at STP is known as the **standard molar volume of a gas**. The value has been found to be **22.4 L**. Therefore we can conclude that at STP 1 mole of any gas has a volume of 22.4 L. (1 mole = 22.4 L)

- What are the values of STP?

  \[ T = 0 \, ^\circ\text{C} = 273 \, \text{K} \]
  \[ P = 1 \, \text{atm} \]
EXAMPLES:

1. A chemical reaction produces 0.0680 mol of oxygen gas. What is the volume in liters occupied by this gas sample at STP?

\[
\frac{0.0680 \text{ mol } O_2}{1 \text{ mol } O_2} \times \frac{22.4 \text{ L } O_2}{1 \text{ mol } O_2} = 1.52 \text{ L}
\]

2. At STP, 3.0 L of chlorine is produced during a chemical reaction. What is the mass of this gas?

\[
\frac{3.0 \text{ L } Cl_2}{22.4 \text{ L } Cl_2} \times \frac{1 \text{ mol } Cl_2}{22.4 \text{ L } Cl_2} \times \frac{70.9 \text{ g } Cl_2}{1 \text{ mol } Cl_2} = 9.49 \text{ g } Cl_2 \quad \rightarrow \quad 9.5 \text{ g } Cl_2
\]
IDEAL GAS LAW

• Avogadro’s principle and the laws of Boyle’s, Charles, and Gay-Lussac can be combined into a single mathematical statement that describes the relationship among pressure, volume, and temperature and the number of moles of a gas.

• The *ideal gas law* is the mathematical relationship among pressure, volume, temperature, and the number of moles of a gas.

• Mathematical relationship: \( PV = nRT \)

  \[ P \text{ – Pressure} \quad V \text{ – volume (L)} \quad n \text{ – # of moles} \quad R \text{ – constant} \quad T \text{ – temperature (K)} \]
IDEAL GAS LAW CONTINUED

• R is known as the ideal gas constant. Its value depends on the units chosen for the pressure, volume, and temperature.

• If a gas is at STP what three values can be determined?
  1. Pressure
  2. Temperature
  3. Volume

• Substituting these values in the ideal gas law equation gives R the following values: (Note R has four units, the combined units for each of the four variables in the equation)

  \[
  R = \frac{0.0821 \text{ L atm}}{\text{mol K}} \quad \text{and} \quad R = \frac{8.314 \text{ L kPa}}{\text{mol K}}
  \]
EXAMPLES:

1. What is the pressure in atmospheres, exerted by a 0.500 mol sample of nitrogen gas in a 10.0 L container at 298 K?

   \[ PV = nRT \]

   \[
   P = \frac{V}{nRT} = \frac{10.0}{(0.500)(0.0821)(298)} = 1.22 \text{ atm}
   \]

2. What mass of chlorine gas, \( \text{Cl}_2 \), is contained in a 10.0 L tank at 27°C and 3.50 atm of pressure?

   \[ PV = nRT \]

   \[
   n = \frac{PV}{RT} = \frac{(3.50)(10.0)}{(0.0821)(300)} = 1.42 \text{ mol}
   \]

   \[
   \text{mass} = n \times \text{molar mass} = 1.42 \times 70.9 = 100.75 \text{ g Cl}_2
   \]

   \[ 1.0 \times 10^2 \text{ g Cl}_2 \]
MORE EQUATIONS

• Molecular Mass (Molar Mass)
  \[ M = \frac{mRT}{PV} \]
  - M – Molar Mass
  - m – mass of gas
  - P – Pressure
  - V – Volume
  - R – Constant
  - T – Temperature

  - The unit for molar mass is gram/mol

• Density
  \[ D = \frac{MP}{RT} \]
  - M – Molar mass
  - P – Pressure
  - R – Constant
  - T – Temperature
  - D – Density

  - The unit of density is in grams/liter
EXAMPLES:

1. At 28.0 °C and 0.974 atm, 1.00 L of gas has a mass of 5.16 g. What is the molar mass of this gas?

\[
M = \frac{mRT}{PV}
\]

\[
M = \frac{(5.16)(0.0821)(301)}{(0.974)(1.00)}
\]

\[
M = 130.918 \text{ g/mol}
\]

2. What is the density of argon gas, Ar, at a pressure of 551 torr and a temperature of 25 °C?

\[
D = \frac{MP}{RT}
\]

\[
D = \frac{(39.95)(0.725)}{(0.0821)(298)}
\]

\[
D = 1.18 \text{ g/L}
\]

3. The density of a gas was found to be 2.0 g/L at 151.95 kPa and 27 °C. What is the molar mass of the gas?

\[
D = \frac{MP}{RT}
\]

\[
2.0 = \frac{(M)(151.95)}{(8.314)(300)}
\]

\[
M = 33 \text{ g/mol}
\]