Chapter 11 - Molecular Composition of Gases

11-1 Volume-Mass Relationships of Gases

I. Measuring and Comparing the Volumes of Reacting Gases
   A. Observations of Gay-Lussac
      1. 2 liters H_2 + 1 liter O_2 → 2 liters H_2O vapor
      2. 2 volumes H_2 + 1 volume O_2 → 2 volumes H_2O vapor
      3. 1 volume H_2 + 1 volume Cl_2 → 2 volumes HCl
      4. 1 volume HCl + 1 volume NH_3 → NH_4Cl (s)
   B. Gay -Lussacs Law of Combining Volumes
      1. Under the same conditions of temperature and pressure, the volumes of reacting gases and their gaseous products are expressed in ratios of small whole numbers

II. Avogadro's Law
   A. An Explanation of Gay-Lussacs Observations
      1. Equal volumes of all gases under the same conditions of temperature and pressure, contain the same number of molecules
      2. The number of molecules of all gases, as reactants and products, must be in the same ratio as their respective gas volumes

$$V = kn$$

   B. Diatomic Molecules
      1. The ratio at which certain gases combine supports the existence of diatomic molecules
         a. Molecules of active gaseous elements are diatomic
            (1) H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2
         b. Molecules of noble gases are monatomic

III. Molar Volume of a Gas
   A. Standard Molar Volume
      1. The volume occupied by one mole of any gas at STP
      2. 1 mole of any gas at STP occupies 22.4 liters of volume
   B. Determining Densities
      1. Density = m/v
      2. density at STP = mass of one mole / 22.4 liters

11-2 The Ideal Gas Law

   A. Ideal Gas Law
      1. The mathematical relationship of pressure, volume, temperature, and the number of moles of a gas.
      2. Mathematically:

$$PV = nRT$$

         a. P = Pressure in atmospheres
         b. V = Volume in liters
         c. n = # of moles
         d. T = Temperature in Kelvins
      3. The ideal gas law reduces to Boyle's, Charles's, or Gay-Lussac's Law if the necessary variable is held constant

B. The Ideal Gas Constant
   1. Units for R depend on units of measurement used for *P, V,* and *T*
   2. For units of atmospheres, liters, and Kelvins:

$$R = 0.0821 \frac{L \cdot atm}{mol \cdot K}$$

C. Finding *P, V, T* or *n*
   1. Three of the four variables must be known in order to use the ideal gas law

D. Finding Molar Mass Using the Ideal Gas Law
   1. $n = \frac{mass}{molar\ mass}$ so… $PV = \frac{mRT}{M}$ $\therefore$ $M = \frac{mRT}{PV}$

E. Finding Density Using the Ideal Gas Law
   1. $D = \frac{m}{V}$ and $M = \frac{mRT}{PV}$ Substituting *D* for $\frac{m}{V}$, you get $M = \frac{DRT}{P}$
   2. Rearranging to solve for *D*:

$$D = \frac{MP}{RT}$$

11-3 Stoichiometry of Gases

I. <u>Volume-Volume Calculations</u>
   A. Assumptions
      1. All products and reactants are at the same temp and pressure
      2. Unless otherwise stated, assume STP
   B. Solve by normal stoichiometric processes
      1. Volume ratios are the same as mole ratios

II. <u>Volume-Mass and Mass-Volume Calculations</u>
   A. Order of Calculations
      1. You are given a gas volume and asked to find a mass
         gas volume A → moles A → moles B → mass B
      2. You are given a mass and asked to find a gas volume
         mass A → moles A → moles B → gas volume B

11-4 Effusion and Diffusion

I. <u>Graham's Law of Effusion</u>

A. Kinetic Energy

1. For two different gases, A and B, at the same temperature

$$\frac{1}{2}M_A v_A{}^2 = \frac{1}{2}M_B v_B{}^2 \quad \text{so} \quad M_A v_A{}^2 = M_B v_B{}^2$$

by rearranging, we get:

$$\frac{v_A{}^2}{v_B{}^2} = \frac{M_B}{M_A} \quad \text{and then} \quad \frac{v_A}{v_B} = \frac{\sqrt{M_B}}{\sqrt{M_A}} \quad \text{concluding that} \quad \boxed{\frac{rate \;\; of \;\; effusion \;\; of \;\; A}{rate \;\; of \;\; effusion \;\; of \;\; B} = \frac{\sqrt{M_B}}{\sqrt{M_A}}}$$

B. Graham's Law of Effusion

1. The rates of effusion of gases at the same temperature and pressure are inversely proportional to the square roots of their molar masses

$$\frac{rate \;\; of \;\; effusion \;\; of \;\; A}{rate \;\; of \;\; effusion \;\; of \;\; B} = \frac{\sqrt{M_B}}{\sqrt{M_A}}$$

C. Applications of Graham's Law

1. Density can replace molar mass since density is directly proportional to molar mass

$$\frac{rate \;\; of \;\; effusion \;\; of \;\; A}{rate \;\; of \;\; effusion \;\; of \;\; B} = \frac{\sqrt{density_B}}{\sqrt{density_A}}$$

2. Isotopes of elements can be separated by vaporizing the element, and allowing it to effuse. The heavier isotope effuses more slowly than the lighter isotope