5.9 Stoichiometry of Reacting Gases

- The volume ratios of gases in reactions are the same as their mole ratios (follows from Avogadro's principle)

$3H_2(g) + N_2(g) \rightarrow 2NH_3(g)$

$\Rightarrow$3 mol H_2 react with 1 mol N_2

$\Rightarrow$3 L H_2 react with 1 L N_2

Example: How many liters of N_2 are needed to react completely with 5.0 L H_2?

5.0 L H_2×[1 L N_2/3 L H_2] = 1.7 L N_2

- The molar volume is used as a conversion factor between mols and volumes of gases (V_m = RT/P)

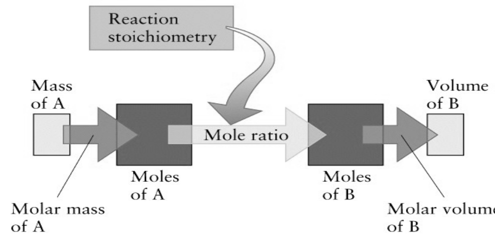

Fig. 5.17

- **Example:** Calculate the volume of CO_2 produced by the decomposition of 2.0 g $CaCO_3$ at 25ºC and 1.0 atm.

$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

$$V_m = \frac{RT}{P} = \frac{0.08206\,\frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}} \times 298\text{ K}}{1.0\text{ atm}} = 24.45\ \frac{\text{L}}{\text{mol}}$$

$$2.0\text{ g CaCO}_3 \times \left(\frac{1\text{ mol CaCO}_3}{100.1\text{ g CaCO}_3}\right) \times \left(\frac{1\text{ mol CO}_2}{1\text{ mol CaCO}_3}\right) \times \left(\frac{24.45\text{ L}}{1\text{ mol CO}_2}\right) = 0.49\text{ L}$$

- **Example:** Calculate the mass of NaN_3 needed to produce 10 L of N_2 in an air bag at 25ºC and 1.0 atm by the reaction:

$6NaN_3(s) + 2Fe_2O_3(s) \rightarrow 3Na_2O_2(s) + 4Fe(s) + 9N_2(g)$

V_m = 24.45 L/mol at 25ºC and 1.0 atm

$$10\text{ L} \times \left(\frac{1\text{ mol N}_2}{24.45\text{ L}}\right) \times \left(\frac{6\text{ mol NaN}_3}{9\text{ mol N}_2}\right) \times \left(\frac{65.02\text{ g NaN}_3}{1\text{ mol NaN}_3}\right) = 18\text{ g NaN}_3$$

5.10 Gas Density

$$\text{density} = \frac{\text{mass}}{\text{volume}} \rightarrow d = \frac{m}{V}$$

$$\text{molar mass} = \frac{\text{mass}}{\text{moles}} \rightarrow M = \frac{m}{n} \rightarrow m = nM$$

$$PV = nRT \rightarrow n = \frac{PV}{RT}$$

$$d = \frac{m}{V} = \frac{nM}{V} = \frac{PVM}{RTV} \rightarrow d = \frac{MP}{RT} \rightarrow M = \frac{dRT}{P}$$

- The density of a gas is proportional to its molar mass and pressure and inversely proportional to its temperature

Example: Calculate the density of O_2 at STP.

***M* = 32.00 g/mol**

***P* = 1.000 atm** **_T_ = 0ºC = 273.15 K** **(STP)**

$$d = \frac{MP}{RT} = \frac{32.00\,\frac{\text{g}}{\text{mol}} \times 1.000\text{ atm}}{0.08206\,\frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}} \times 273.15\text{ K}} = 1.428\,\frac{\text{g}}{\text{L}}$$

- **Example:** Calculate the molar mass of a gas if 2.50 L of it have mass of 0.955 g at 200ºC and 45.0 Torr.

***d* = *m*/*V* = 0.955 g/2.50 L = 0.382 g/L**

***T* = 200ºC = 473 K**

***P* = 45.0 Torr×[1 atm/760 Torr] = 0.0592 atm**

$$M = \frac{dRT}{P} = \frac{0.382\,\frac{\text{g}}{\text{L}} \times 0.08206\,\frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}} \times 473\,\text{K}}{0.0592\,\text{atm}} = 250\,\frac{\text{g}}{\text{mol}}$$

5.11 Mixtures of Gasses

- Mixtures are treated just like pure gases – same gas laws apply
- **Partial pressure** of a gas in a mixture – the pressure the gas would exert if it occupied the container alone
- Dalton's **law of partial pressures** - the total pressure (***P***) of a gaseous mixture is the sum of the partial pressures ($\boldsymbol{P_i}$) of its components

$$\boldsymbol{P = P_A + P_B + \ldots} \quad \text{or} \quad \boldsymbol{P = \Sigma P_i}$$

- **Mole fraction** (χ_i) of a gas in a mixture – a fraction of the total number of moles that belongs to that gas

$$\chi_i = \frac{n_i}{\sum n_i} = \frac{n_i}{n} \qquad \sum n_i = n \qquad \sum \chi_i = 1$$

- The sum of all mol fractions is equal to one
- The ideal gas law can be written for each gas in a mixture in terms of partial pressures

$$\boldsymbol{P_i V = n_i RT} \qquad \boldsymbol{PV = nRT}$$

$$\frac{P_i V}{PV} = \frac{n_i RT}{nRT} \qquad \frac{P_i}{P} = \frac{n_i}{n} = \chi_i$$

$$P_i = \chi_i P$$

⇒The partial pressure of a gas is proportional to its mol fraction

- **Example:** Calculate the total pressure and the partial pressures of He and Ne in a **2.0 L** mixture containing **1.0 g He** and **2.0 g Ne** at **20ºC**.

moles of He and Ne → mole fractions of He and Ne → total pressure → partial pressures

$$1.0\ \text{g He} \times \left(\frac{1\ \text{mol He}}{4.00\ \text{g He}}\right) = 0.25\ \text{mol He}$$

$$2.0\ \text{g Ne} \times \left(\frac{1\ \text{mol Ne}}{20.18\ \text{g Ne}}\right) = 0.099\ \text{mol Ne}$$

$$\chi_{He} = \frac{n_{He}}{n_{He} + n_{Ne}} = \frac{0.25}{0.25 + 0.099} = 0.72$$

$$\chi_{Ne} = \frac{n_{Ne}}{n_{He} + n_{Ne}} = \frac{0.099}{0.25 + 0.099} = 0.28$$

$$n = 0.25 + 0.099 = 0.35\ \text{mol}$$

$$PV = nRT \quad \rightarrow \quad P = \frac{nRT}{V}$$

$$P = \frac{nRT}{V} =$$

$$= \frac{0.35\ \text{mol} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 293\ \text{K}}{2.0\ \text{L}} =$$

$$= 4.2\ \text{atm}$$

$$P_{He} = c_{He} P = 0.72 \times 4.2\ \text{atm} = 3.0\ \text{atm}$$

$$P_{Ne} = c_{Ne} P = 0.28 \times 4.2\ \text{atm} = 1.2\ \text{atm}$$