Molecular Motion of Gases

5.12 Diffusion and Effusion

- **Diffusion** - gradual dispersal of one substance through another
  - gases diffuse from places with high to places with low concentration
- **Effusion** - escape of a substance through a small hole into vacuum
  - effusion through porous materials, pin holes, cracks, etc.

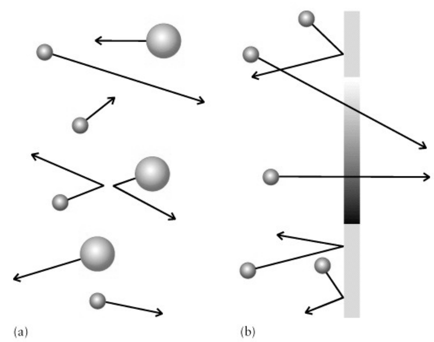

Fig. 5.24

- **Graham's Law** - the effusion rate (***ER***) of a gas is inversely proportional to the square root of its molar mass

$$ER \propto \sqrt{\frac{1}{M}}$$

- The time of effusion (t_{eff}) is inversely proportional to ***ER***

$$t_{eff} \propto \frac{1}{ER} \quad \Rightarrow \quad t_{eff} \propto \sqrt{M}$$

- Same relations are valid in general for the diffusion rate

For two gases, A and B:

$$\frac{ER(A)}{ER(B)} = \sqrt{\frac{M_B}{M_A}} \qquad \frac{t_{eff}(A)}{t_{eff}(B)} = \sqrt{\frac{M_A}{M_B}}$$

Example: If it takes a certain amount of H_2 **15 s** to effuse through a small hole, how long does it take for the same amount of O_2?

$$\frac{t_{eff}(O_2)}{t_{eff}(H_2)} = \sqrt{\frac{M_{O_2}}{M_{H_2}}} \qquad t_{eff}(O_2) = \sqrt{\frac{M_{O_2}}{M_{H_2}}} \times t_{eff}(H_2)$$

$$t_{eff}(O_2) = \sqrt{\frac{32.00\ \text{g/mol}}{2.02\ \text{g/mol}}} \times 15\ \text{s} = 60\ \text{s}$$

5.13 The Kinetic Model of Gases

- Kinetic Molecular Theory
  - Gas particles are in constant, random motion
  - Gas particles are negligibly small
  - Gas particles move in straight lines and do not interact except during collisions
  - The average kinetic energy of gas particles, $\bar{E}_k$, is proportional to the absolute temperature, ***T***
- The model is consistent with the properties of ideal gases and provides explanations of the observed deviations from ideal behavior

$$\bar{E}_k \propto T \qquad \bar{E}_k = \frac{1}{2} m \overline{v^2}$$

$$\Rightarrow \quad \overline{v^2} \propto T \qquad \sqrt{\overline{v^2}} \propto \sqrt{T}$$

m **- mass of particles**
`*v*² - average square speed

- Root mean square speed of gas particles (v_{rms})

$$v_{rms} = \sqrt{\overline{v^2}} \qquad v_{rms} \propto \sqrt{T}$$

$$v_{rms} = \sqrt{\frac{3RT}{M}}$$

Example: Calculate the root mean square speed of N_2 at 25ºC.

***T* = 25ºC = 298 K**

***M* = 28.02 g/mol = 0.02802 kg/mol**

***R* = 8.314 J/mol·K**

$$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3 \times 8.314 \dfrac{\text{J}}{\text{mol} \cdot \text{K}} \times 298\ \text{K}}{0.02802 \dfrac{\text{kg}}{\text{mol}}}} = 515\sqrt{\frac{\text{J}}{\text{kg}}}$$

$$515\sqrt{\frac{\text{kg} \cdot \text{m}^2 / \text{s}^2}{\text{kg}}} = 515\sqrt{\frac{\text{m}^2}{\text{s}^2}} = 515\ \frac{\text{m}}{\text{s}}$$

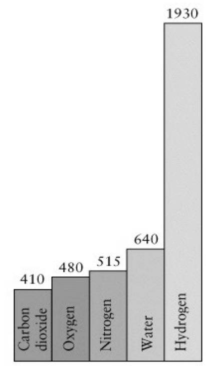

Fig. 5.27

$$\overline{E}_k = \frac{1}{2} m\overline{v^2} =$$

$$= \frac{1}{2} m v_{rms}^2 = \frac{1}{2} m\left(\frac{3RT}{M}\right) =$$

$$= \frac{m3RT}{2mN_A} = \frac{3RT}{2N_A}$$

v_{rms} depends on *T* and *M*

`E_k depends only on *T*

5.14 The Maxwell Distribution of Speeds

- Gives the fraction of particles moving at each particle speed
- Gas molecules travel with a wide range of speeds
- The range of speeds widens and the average speed increases with increasing the temperature and decreasing the molar mass of the gas

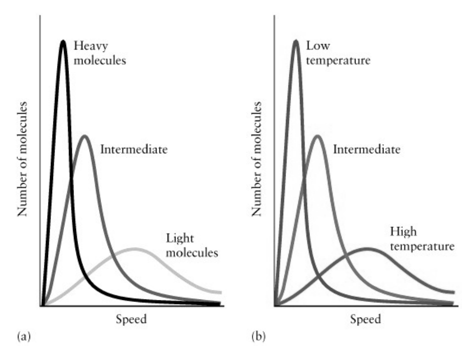

Fig. 5.28

5.15 Real Gases

- Real gases deviate from ideal behavior
- Compression factor (*Z*)

Z* = *PV*/*nRT

- For ideal gases:

***PV* = *nRT* ⇒ Z = *PV*/*nRT* = 1**

- A plot of ***Z*** versus ***P*** gives a straight line for ideal gases, but not for real gases

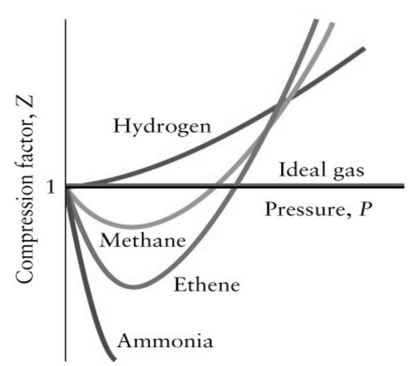

Fig. 5.30

- Van der Waals equation:

$$\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT$$

a, b - van der Waals constants (zero for ideal gases)

an^2/V^2 - pressure correction (***a*** depends on the attractive forces between molecules)

nb - volume correction (***b*** is a measure for the actual volume of the gas molecules)

- Real gases approach ideal behavior at low pressures and high temperatures (away from conditions of condensation)

Assignments:

- **Homework:** Chpt. 5/5, 9, 13, 15, 19, 21, 29, 33, 35, 39, 43, 45, 49, 55, 57, 63, 67, 69, **71, 73, 77, 81, 85, 87**

- **Student Companion: 5.1, 5.2, 5.3, 5.4**