GASES

Physical States of Matter

solid
liquid
gas

Chemistry of Gases

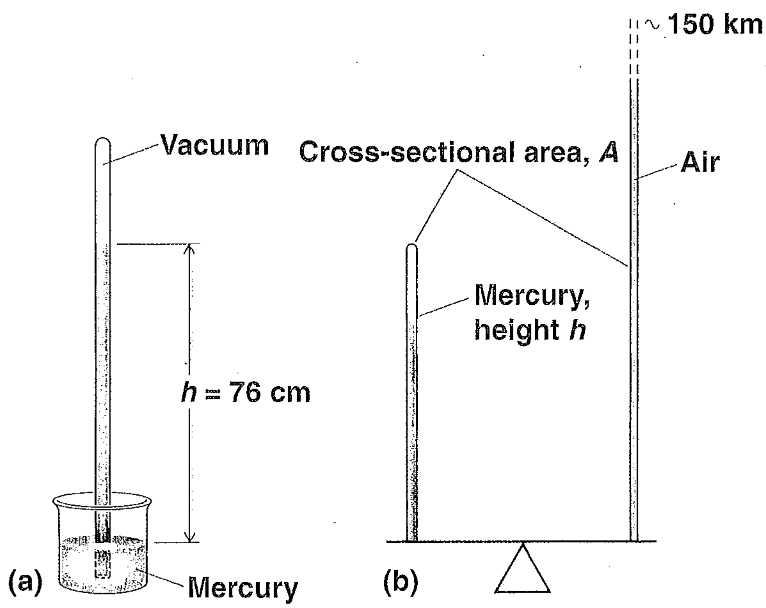
Simple: $PV=nRT$

Pressure

units:

1 atm $\equiv$ 760 **torr**
= 760 mm Hg (0°C)
= 29.92 in Hg (0°C)
= 101.325 kPa
= 14.69595 psi

FIG I. Torricelli's barometer



EX 1. What is the pressure when the height of a column of mercury is 76.0 cm? (d_{Hg} = 13.5951 g cm^{-3}, g = 9.80665 m s^{-2})

Boyle's Law ($V \propto 1/P$; n, T constant) (**FIG II**)

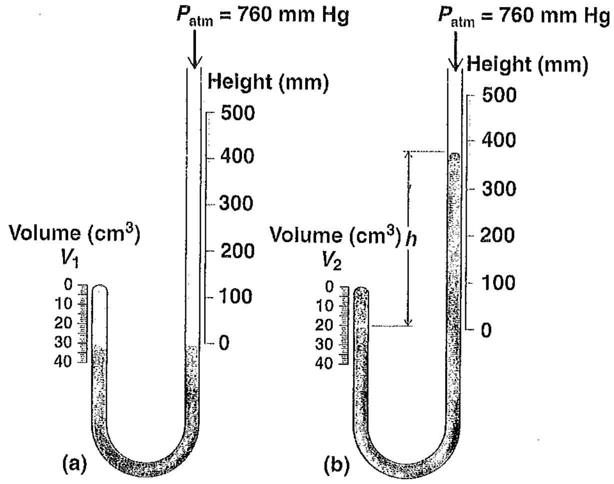
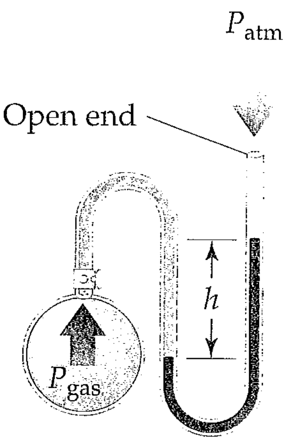
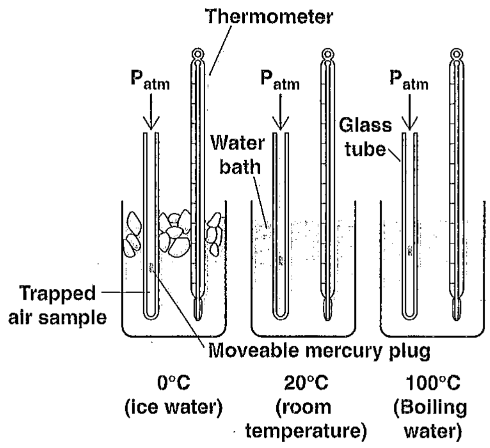


FIG III. manometer



$$P_{gas} = P_{atm} + P_h$$

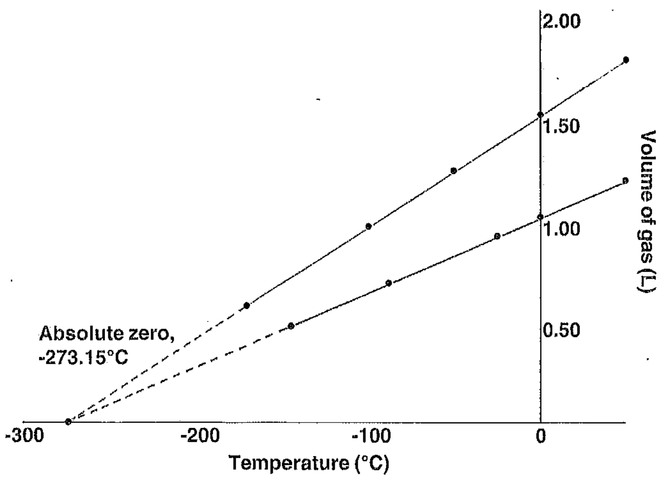
Charles's Law ($V \propto T$; n, P constant) (**FIG IV**)



Gay-Lussac

Avogadro's hypothesis

FIG V. Charles's Law Experiment for Two Gases



$$V = V_0 + \alpha V_0 t$$
$$\alpha = 1/273.15(^{\circ}C)^{-1}$$
$$V = V_0\left(1 + \frac{t}{273.15^{\circ}C}\right)$$

Ideal Gas Equation - $R = 0.082057 \text{ L atm mol}^{-1} \text{ K}^{-1} = 8.3145 \text{ J mol}^{-1} \text{ K}^{-1}$

EX 2. What is the volume occupied by one mole of an ideal gas at STP conditions?

EX 3. A fixed quantity of gas at 23°C has a pressure of 748 torr and occupies a volume of 10.3 L.

a) What would be the volume if the pressure is increased to 1.88 atm?

b) What would be the volume if the temperature is increased to 165°C?

EX 4. Hydrogen fills a 250-L reaction vessel at 100°C and 1.00 atm pressure. Determine the volume of the same quantity of hydrogen at 0°C and 1.50 atm.

density and **molar mass**

EX 5. If the density of air is 1.29 g L^{-1} at STP what is its average molar mass?

EX 6. The composition of a liquid is 25.23% S and 74.77% F. It boils at 29°C where the density of the vapor is 9.95 g L^{-1} at a pressure of 738 mm Hg. What is its molecular formula?

EX 7. You have a 2-L and a 3-L flask, both at the same temperature. The gas in the 2-L flask has a mass of 4.8 g, while the mass in the 3-L flask is 0.36 g. If the pressure in the 2-L flask is 10 times greater than the pressure in the 3-L flask, do the two gases have the same molar mass? If not, which contains the gas of higher molar mass?

Gas Laws and Chemical Reactions

EX 8. Calcium hydride reacts with water to form hydrogen gas

$$CaH_2(s) + 2\ H_2O(l) \rightarrow Ca(OH)_2(aq) + 2\ H_2(g)$$

How many grams of CaH_2 are needed to generate 64.5 L of H_2 gas if the pressure of H_2 is 814 torr at 32°C?

Dalton's Law of Partial Pressure

mole fraction, X

EX 9. 0.250 mol of N_2, 0.500 mol of O_2, and 0.250 mol of CO are in a vessel at 1 atm and 25°C. The container is heated to 50°C.

a) What is the pressure of the gas mixture?

b) What is the partial pressure of O_2?

collecting gas over water:

EX 10. 15.00 g of sodium azide is decomposed by heating and the nitrogen gas which evolves is collected over water at 25°C at a barometric pressure of 745 mm Hg. What volume of dry gas is collected if the vapor pressure of water at 25°C is 24 mm Hg?

$$2\ NaN_3(s) \rightarrow 2\ Na(s) + 3\ N_2(g)$$

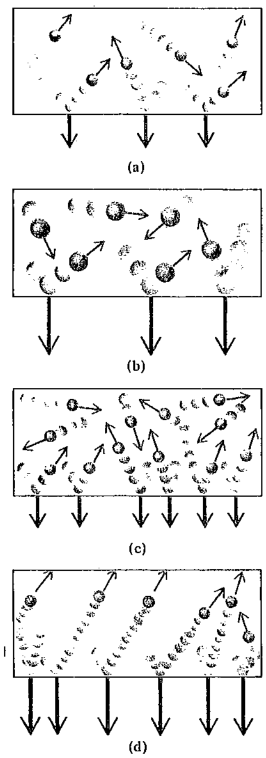
Kinetic-Molecular Theory of Gases

$PV = nRT$ - empirical, no molecular information

use postulates to relate PV to m, u (speed) **(FIG VI)**

postulates of kinetic theory:

- large number of molecules
- size is small compared to the distance between them
- random motion
- straight line motion between collisions (billiard balls)
- all collisions are elastic (no energy lost)



conclusions

1. $PV = nRT = \frac{1}{3} Nm\langle u^2 \rangle$
2. $\frac{1}{2} N_o m\langle u^2 \rangle = \frac{3}{2} RT$

average kinetic energy (T)

3. $\langle u^2 \rangle = \frac{3RT}{M}$

root-mean-square (rms) speed, $u_{rms} = \sqrt{\langle u^2 \rangle} = \sqrt{\frac{3RT}{M}}$

EX 11. What is u_{rms} for helium at -73°C?

distribution of molecular speeds

FIG VII. effect of **temperature**

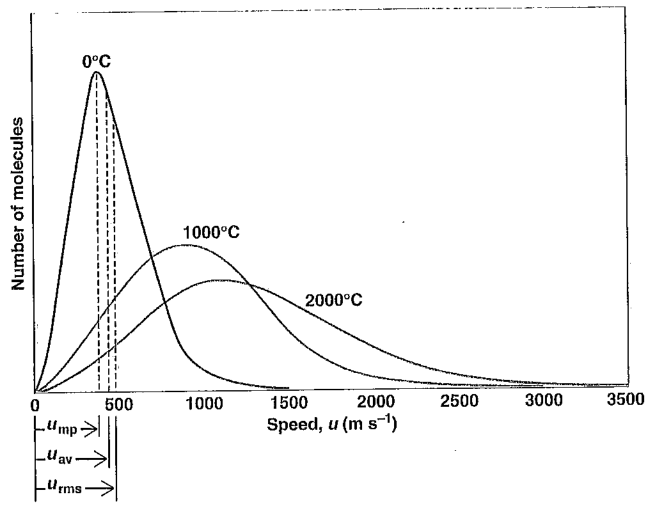
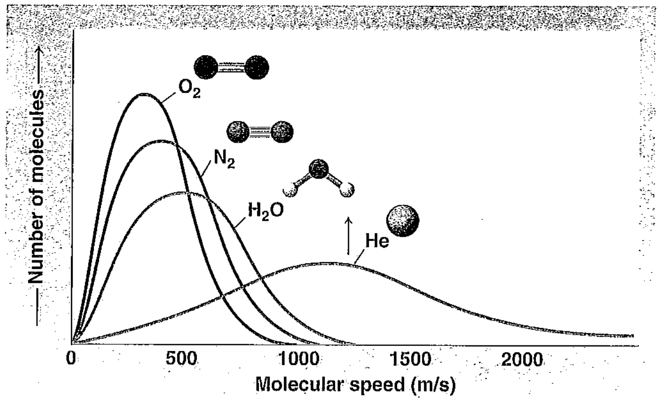


FIG VIII. effect of **molar mass**



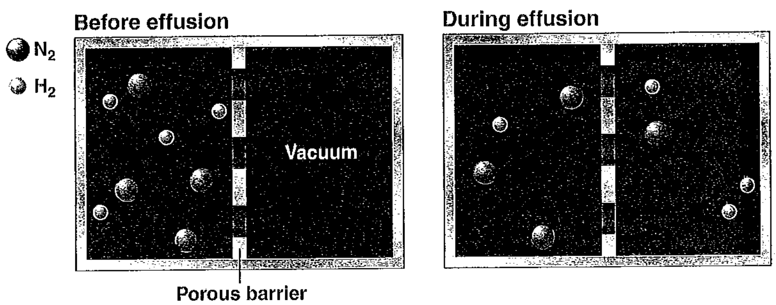
Graham's law of effusion

OBSERVATION: effusion rate for escape of a gas through a tiny hole into a vacuum $\propto 1 / \sqrt{M}$

KINETIC THEORY INTERPRETATION: two gases at same T, P, V contain equal numbers of molecules (Avogadro) so

$$\frac{\text{effusion rate of A}}{\text{effusion rate of B}} = \frac{u_{rms}(A)}{u_{rms}(B)}$$

$$= \sqrt{\frac{M_B}{M_A}}$$



EX 12. A sample of nitrogen effuses through a tiny hole twice as fast as an unknown gas. Determine the molar mass of the unknown gas.