Properties of Gases: Gas Pressure

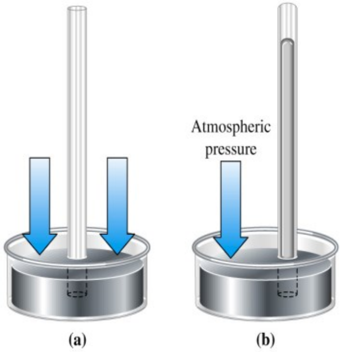
- Gas Pressure

$$P\ (\text{Pa}) = \frac{\text{Force (N)}}{\text{Area (m}^2\text{)}}$$

- Liquid Pressure

$$P = g \cdot h \cdot d$$

Barometric Pressure



Standard Atmospheric Pressure

1.00 atm

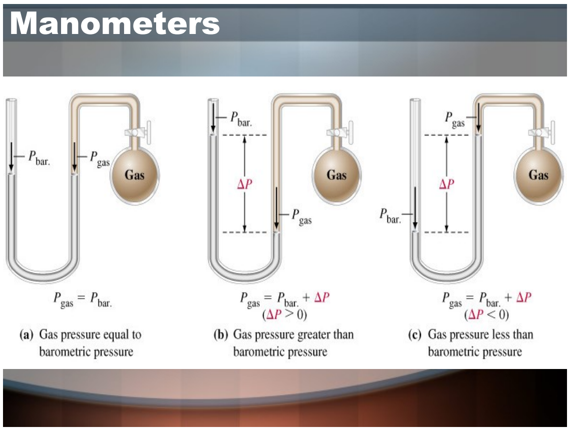
760 mm Hg, 760 torr

101.325 kPa

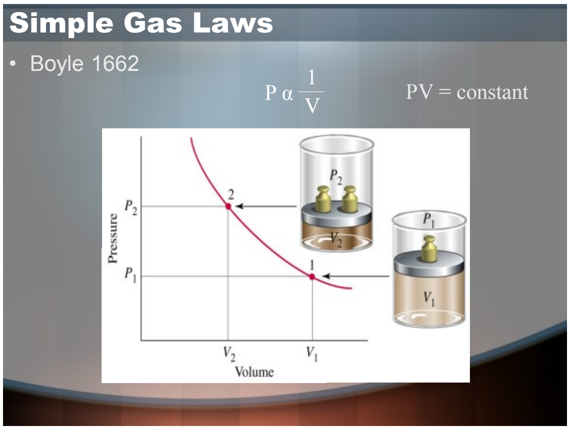
1.01325 bar

1013.25 mbar

The standard atmosphere is defined as the pressure exerted by a mercury column of exactly 760 mm in height when the density equals 13.6 g/cc.



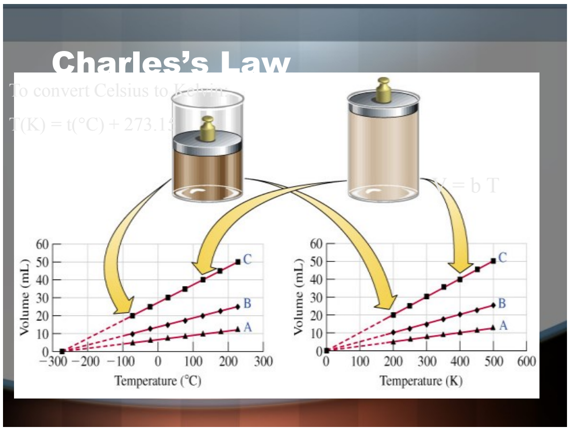
Manometers



Simple Gas Laws

- Boyle 1662

$$P \propto \frac{1}{V} \qquad PV = \text{constant}$$

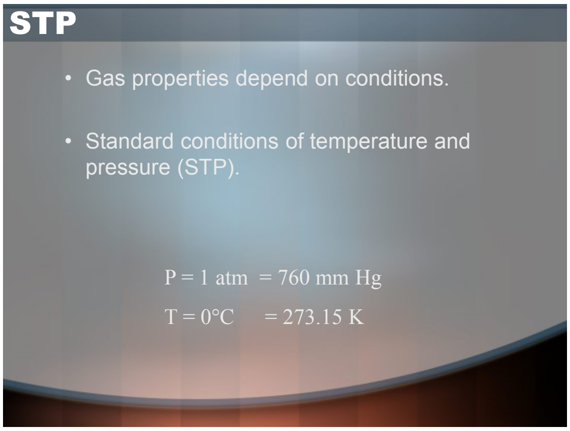


Charles's Law

To convert Celsius to Kelvin:

$T(K) = t(°C) + 273.15$

$V = b\,T$

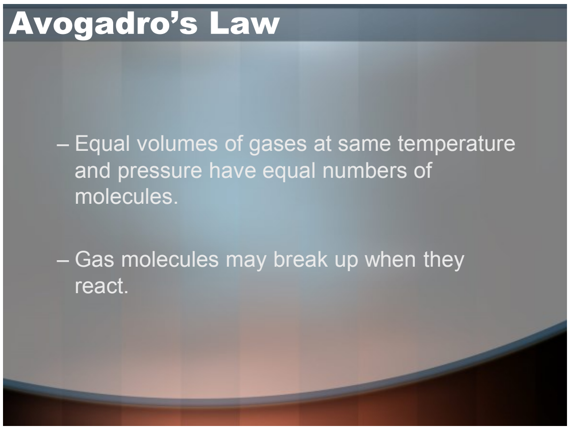


STP

- Gas properties depend on conditions.
- Standard conditions of temperature and pressure (STP).

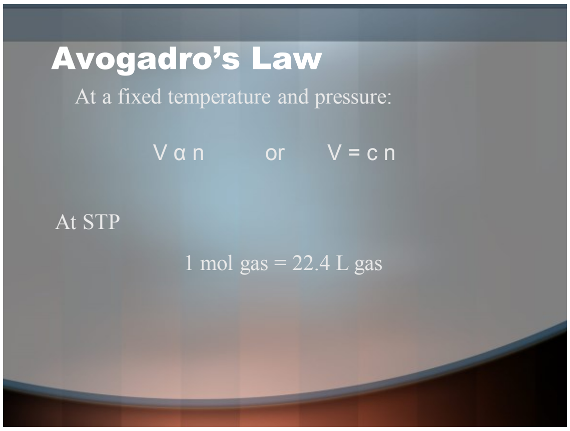
$P = 1$ atm $= 760$ mm Hg

$T = 0°C = 273.15$ K



Avogadro's Law

- Equal volumes of gases at same temperature and pressure have equal numbers of molecules.
- Gas molecules may break up when they react.



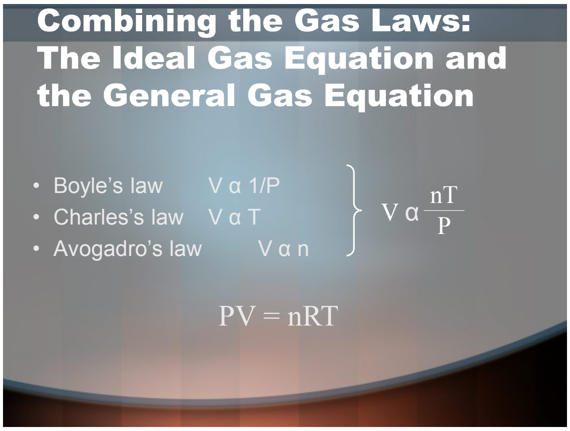
Avogadro's Law

At a fixed temperature and pressure:

$V \alpha n$ or $V = c n$

At STP

1 mol gas = 22.4 L gas

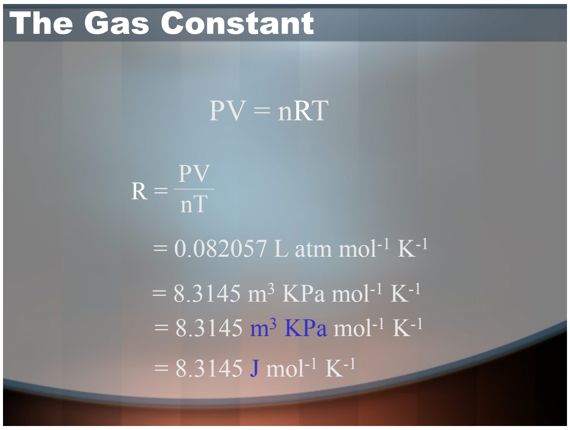


Combining the Gas Laws: The Ideal Gas Equation and the General Gas Equation

- Boyle's law $V \propto 1/P$
- Charles's law $V \propto T$
- Avogadro's law $V \propto n$

$$\left.\begin{matrix} V \propto 1/P \\ V \propto T \\ V \propto n \end{matrix}\right\} V \propto \frac{nT}{P}$$

$$PV = nRT$$



The Gas Constant

$$PV = nRT$$

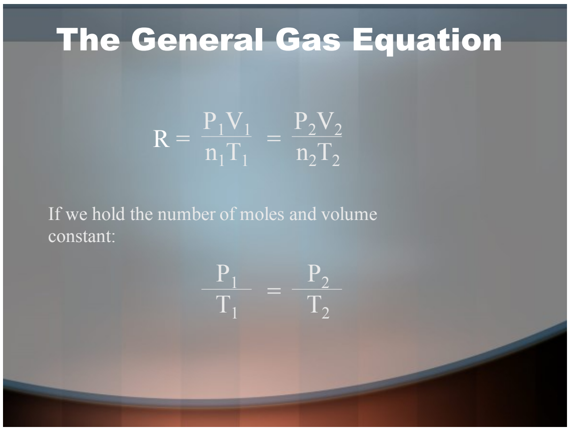
$$R = \frac{PV}{nT}$$

$$= 0.082057 \text{ L atm mol}^{-1} \text{ K}^{-1}$$

$$= 8.3145 \text{ m}^3 \text{ KPa mol}^{-1} \text{ K}^{-1}$$

$$= 8.3145 \text{ m}^3 \text{ KPa mol}^{-1} \text{ K}^{-1}$$

$$= 8.3145 \text{ J mol}^{-1} \text{ K}^{-1}$$

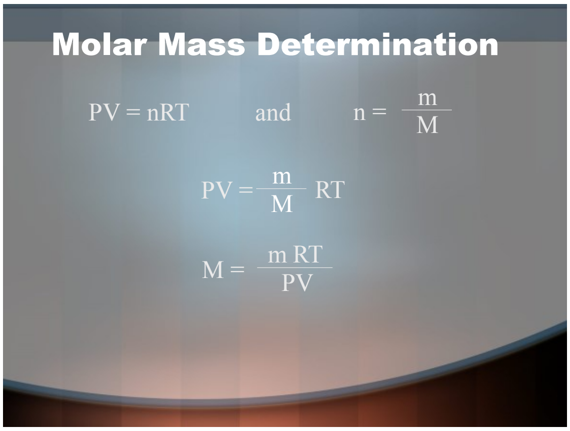


The General Gas Equation

$$R = \frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

If we hold the number of moles and volume constant:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

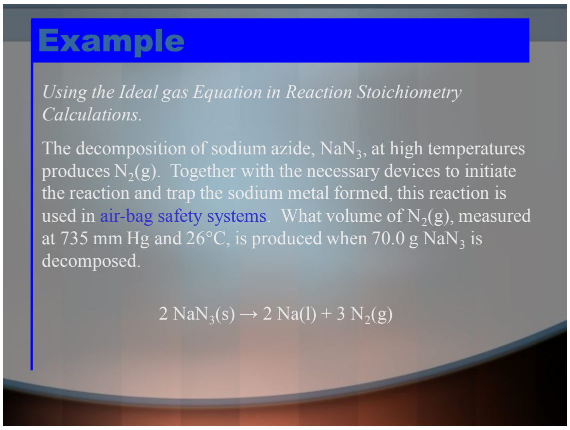


Molar Mass Determination

$PV = nRT$ and $n = \dfrac{m}{M}$

$$PV = \frac{m}{M} RT$$

$$M = \frac{m\,RT}{PV}$$

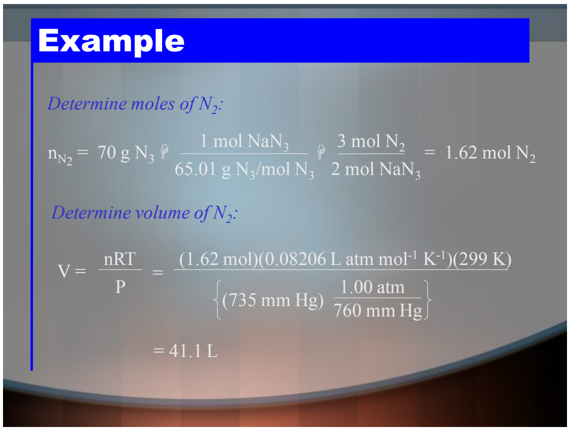


Example

Using the Ideal gas Equation in Reaction Stoichiometry Calculations.

The decomposition of sodium azide, NaN_3, at high temperatures produces $N_2(g)$. Together with the necessary devices to initiate the reaction and trap the sodium metal formed, this reaction is used in air-bag safety systems. What volume of $N_2(g)$, measured at 735 mm Hg and 26°C, is produced when 70.0 g NaN_3 is decomposed.

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



Example

Determine moles of N_2:

$$n_{N_2} = 70\text{ g }N_3 \text{ ☟ } \frac{1\text{ mol }NaN_3}{65.01\text{ g }N_3/\text{mol }N_3} \text{ ☟ } \frac{3\text{ mol }N_2}{2\text{ mol }NaN_3} = 1.62\text{ mol }N_2$$

Determine volume of N_2:

$$V = \frac{nRT}{P} = \frac{(1.62\text{ mol})(0.08206\text{ L atm mol}^{-1}\text{ K}^{-1})(299\text{ K})}{\left\{(735\text{ mm Hg})\ \dfrac{1.00\text{ atm}}{760\text{ mm Hg}}\right\}}$$

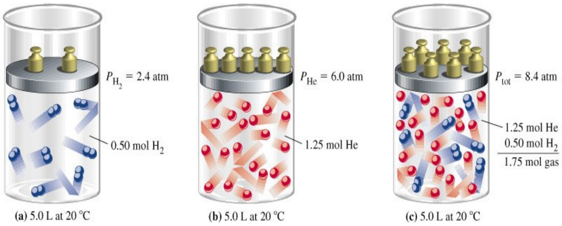
$$= 41.1\text{ L}$$

Problem

If all gases are measured at the same temperature and pressure, what volume of $NH_{3(g)}$ is produced when 225 L $H_{2(g)}$ is consumed in the reaction $N_{2(g)} + H_{2(g)} \rightarrow NH_{3(g)}$?

Dalton's Law of Partial Pressure

It states that the total pressure of a mixture of gases is the sum of the partial pressures of the components of the mixture.



(a) 5.0 L at 20 °C (b) 5.0 L at 20 °C (c) 5.0 L at 20 °C

Partial Pressure

$$P_{tot} = P_a + P_b + \ldots$$

$$V_a = n_aRT/P_{tot} \quad \text{and} \quad V_{tot} = V_a + V_b + \ldots$$

$$\frac{V_a}{V_{tot}} = \frac{n_aRT/P_{tot}}{n_{tot}RT/P_{tot}} = \frac{n_a}{n_{tot}}$$

$$\frac{n_a}{n_{tot}} = \chi_a$$

$$\downarrow$$

Mole fraction of component A

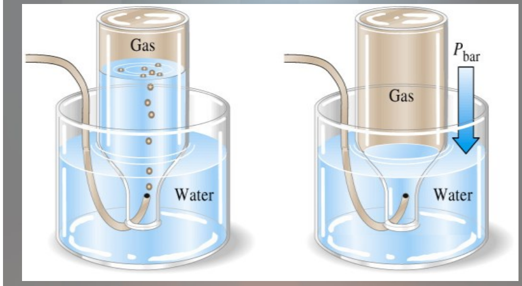
$$\frac{P_a}{P_{tot}} = \frac{n_aRT/V_{tot}}{n_{tot}RT/V_{tot}} = \frac{n_a}{n_{tot}}$$

$$P_a = \chi_a \bullet P_{tot} \qquad P_b = \chi_b \bullet P_{tot}$$

Problem

The percent composition of air by volume is 78.08% N_2, 20.95% O_2, 0.93% Ar and 0.036% CO_2. What are the partial pressures of these four gases in a sample of air at a barometric pressure of 748 mm Hg?

Pneumatic Trough

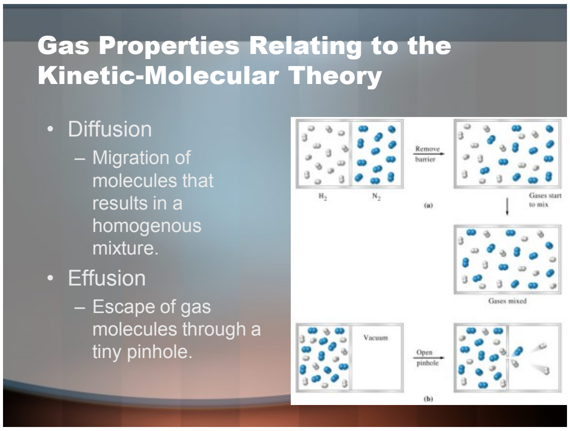


$$P_{tot} = P_{bar} = P_{gas} + P_{H_2O}$$

Kinetic Molecular Theory

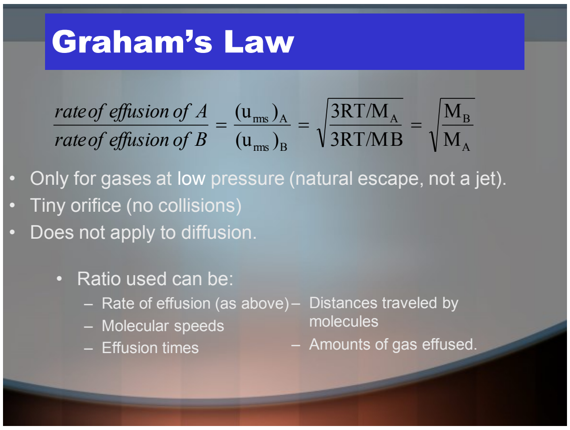
- Particles are point masses in constant, random, straight line motion.
- Particles are separated by great distances.
- Collisions are rapid and elastic.
- No force between particles.
- Total energy remains constant.

Average kinetic energy is directly proportional to temperature!!



Gas Properties Relating to the Kinetic-Molecular Theory

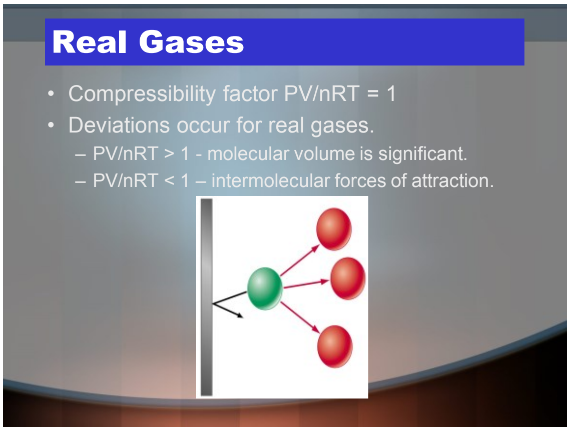
- Diffusion
  - Migration of molecules that results in a homogenous mixture.
- Effusion
  - Escape of gas molecules through a tiny pinhole.



Graham's Law

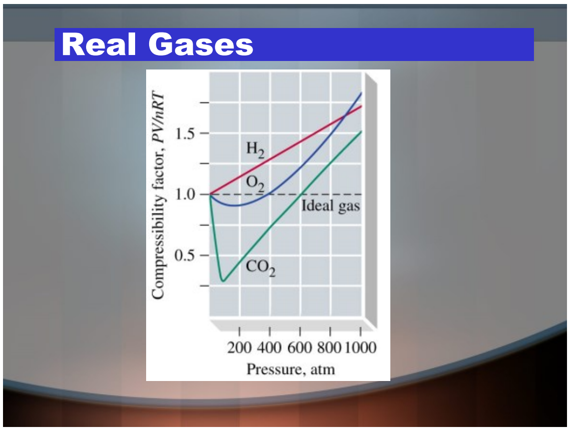
$$\frac{\textit{rate of effusion of A}}{\textit{rate of effusion of B}} = \frac{(u_{rms})_A}{(u_{rms})_B} = \sqrt{\frac{3RT/M_A}{3RT/MB}} = \sqrt{\frac{M_B}{M_A}}$$

- Only for gases at low pressure (natural escape, not a jet).
- Tiny orifice (no collisions)
- Does not apply to diffusion.
  - Ratio used can be:
    - Rate of effusion (as above)
    - Molecular speeds
    - Effusion times
    - Distances traveled by molecules
    - Amounts of gas effused.

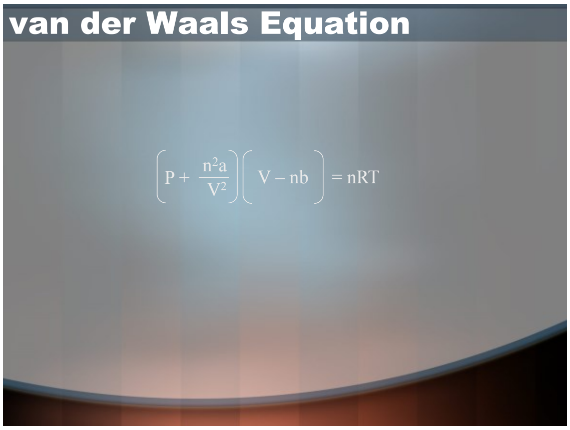


Real Gases

- Compressibility factor PV/nRT = 1
- Deviations occur for real gases.
  - PV/nRT > 1 - molecular volume is significant.
  - PV/nRT < 1 – intermolecular forces of attraction.



Real Gases



van der Waals Equation

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