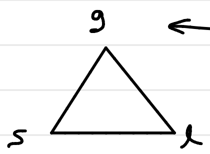
1411 - E3

CH 09 - Gases

9

Chapter 09: Gases



← ☑ comp → molecules far apart
☒ fixed vol
☒ fixed shape

Gas Pressure [9.1]

[P 448/456]

↳ atm pressure (1 atm) - pressure at sea level exerted by a column of air $1\,in^2$ and extending to space.

↳ def: $P = F/A$

Pressure Units

Unit Name and Abbreviation	Definition or Relation to Other Unit
pascal (Pa)	1 Pa = 1 N/m^2 recommended IUPAC unit
kilopascal (kPa)	1 kPa = 1000 Pa
pounds per square inch (psi)	air pressure at sea level is ~14.7 psi
atmosphere (atm)	1 atm = 101,325 Pa air pressure at sea level is ~1 atm
bar (bar, or b)	1 bar = 100,000 Pa (exactly) commonly used in meteorology
millibar (mbar, or mb)	1000 mbar = 1 bar
inches of mercury (in. Hg)	1 in. Hg = 3386 Pa used by aviation industry, also some weather reports
torr	$1\text{ torr} = \frac{1}{760}\text{ atm}$ named after Evangelista Torricelli, inventor of the barometer
millimeters of mercury (mm Hg)	1 mm Hg ~1 torr

Table 9.1

F = Newton, A in m^2, Pascal

$$P = \frac{F}{A} = \frac{1\ Kg \cdot m}{s^2} \bigg| \frac{1}{m^2} = \frac{1\ Kg}{s^2\,m} = 1\ Pa$$

Ex: Pressure Unit Conversions [Ex: 9.1b]

¿ A typical barometric pressure in Kansas City is 740 torr. What is this pressure in atmospheres, in millimeters of mercury, ~~in kilopascals~~, ~~and in bar~~?

(a) $\square$ atm = $\frac{740 \text{ torr}}{} \left| \frac{1 \text{ atm}}{760 \text{ torr}} \right.$ = **0.974** ~~4~~ ← book is wrong... ... only 2 s.f.

(b) $\square$ mm Hg = $\frac{740 \text{ torr}}{} \left| \frac{1 \text{ mm Hg}}{1 \text{ torr}} \right.$ = **740** mm Hg

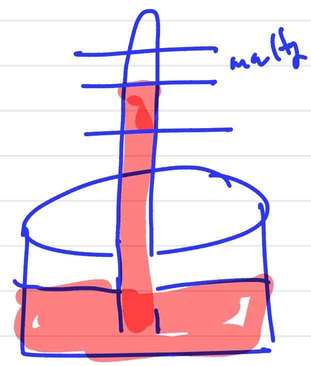
Barometer

Barometer – tube closed at one end, filled w/ NV Liquid, and inverted into bath of the same NV Liquid.

hydrostatic pressure – pressure fluid exerts due to pull of gravity

$$P = h\rho g$$

h = height ; ρ = density ; g = acceleration of gravity



EX: CALC COLUMN HEIGHT VIA PRESSURE [EX 9.26]

¿ Calculate the height of a column of water at 25 °C that corresponds to normal atmospheric pressure. The density of water at this temperature is 1.0 g/cm 3 .

1 atm = 760 torr

$P = h \rho g \Rightarrow h = \frac{P}{\rho g} = P / \rho / g$

$$\frac{\square\ m}{1} = \frac{1\ atm}{} \cdot \frac{cm^3}{1.0\ g} \cdot \frac{s^2}{9.81\ m} \cdot \frac{101{,}325\ Pa}{1\ atm} \cdot \frac{kg}{Pa \cdot m \cdot s^2} \cdot \frac{1^3\ m^3}{100^3\ cm^3} \cdot \frac{1000\ g}{kg} = 10.3287 = \boxed{10.3\ m}$$

P, ρ, g

MANOMETER

manometer – gas vessel connected to U-tube containing Non Volatile Liquid (NVL)
– may be open or closed end.

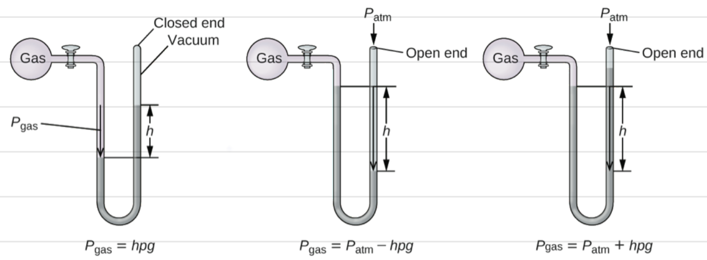


Figure 9.5 A manometer can be used to measure the pressure of a gas. The (difference in) height between the liquid levels (h) is a measure of the pressure. Mercury is usually used because of its large density.

SPHYGMOMONOMETER : MEASURE HUMAN BLOOD PRESSURE

sphygmomanometer (Greek sphygmos = “pulse”). It consists of an inflatable cuff to restrict blood flow, a manometer to measure the pressure, and a method of determining when blood flow begins and when it becomes impeded (Figure 9.6)

Relating Pressure, Volume, Amount, and Temperature: The Ideal Gas Law [9.2]   [P 457/465]

Early scientist couldn't measure much, but they could:
- TEMPERATURE
- VOLUME
- PRESSURE ← 1644 Torricelli invented the mercury barometer (also, called empty space above the Hg a "vacuum")

$P = kT$

$P = kn$

Pressure and Temperature: Amontons's Law / Gay-Lussac's Law

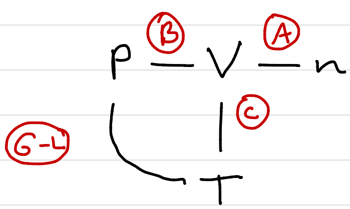
Volume and Temperature: Charles's Law

$PV = k$

Volume and Pressure: Boyle's Law

$\frac{P}{1} = \frac{1}{V}$

Moles of Gas and Volume: Avogadro's Law



The Ideal Gas Law

[P467/475]

$$PV = k$$
$$P = k'T$$
$$V = k''T$$
$$V = n k''$$

$$\boxed{PV = nRT}$$

* TEMP must be in KELVIN

$$R = 0.08206 \frac{\text{atm} \cdot \text{L}}{\text{mol} \cdot \text{K}} = 8.314 \frac{\text{kPa} \cdot \text{L}}{\text{mol} \cdot \text{K}} = 8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}} = 1.987 \frac{\text{cal}}{\text{mol} \cdot \text{K}}$$

THREE THINGS YOU NEED TO KNOW TO SOLVE ANY IGL PROBS:

(I) Standard Conditions of Temperature and Pressure

- ↳ "STP"
- ↳ T = 273.15 K (exact)
- ↳ P = 1 atm (exact) / 101.325 kPa

↳ @ STP, volume of IDEAL GAS = $\frac{22.4\,L}{mol}$ ← (i) @ STP (ii) ideal gas

(II) COMBINED IGL (BEFORE - AFTER SCENARIOS)

changing system

$$R = \frac{PV}{nT} = \frac{P'V'}{n'T'}$$

stationary system

EAST

③ SUBSTITUTE OTHER EQUATIONS FOR IGL VARIABLES

$PV = nRT$ → $P = \left(\frac{n}{V}\right) RT$

$n = \frac{g}{MW}$; $\frac{n}{V}$ ← density

$PV = \frac{g}{MW} RT$

$P = DRT$

Stoichiometry of Gaseous Substances, Mixtures, and Reactions [9.3]

Density of a Gas

+ OTHER SAMPLE CALCULATIONS

EX: IGL – CALC P & density [WQ: EOC 12-45]

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

(a) A chemist is preparing to carry out a reaction at high pressure that requires 36.0 mol of hydrogen gas. The chemist pumps the hydrogen into a ~~12.3~~ 15.5-L rigid steel container at 25°C. To what pressure (in atmospheres) must the hydrogen be compressed? (b) What would be the density of the high-pressure hydrogen?

V –	15.5 L
n –	36.0 mol H_2
T =	298 K
P = ?	56.8 atm

(a) R

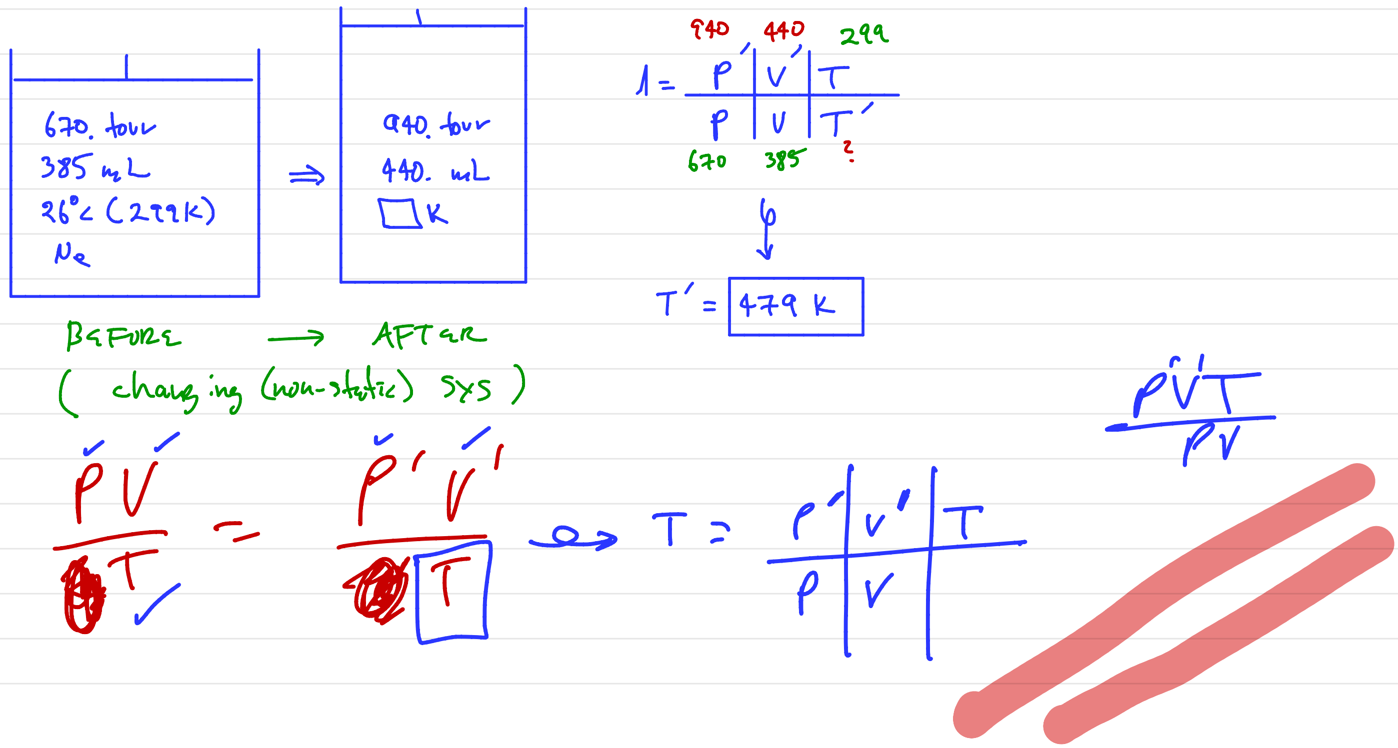
$$\frac{\square \text{ atm}}{1} = \frac{0.0821 \text{ atm} \cdot L}{mol \cdot K} \times \frac{1}{15.5 L} \times \frac{36.0 \text{ mol}}{1} \times \frac{298 K}{1} = \boxed{56.8 \text{ atm}}$$

(b) $d = \frac{m}{V} = \frac{\square g}{\square L} = \frac{36.0 \text{ mol}}{1} \times \frac{2.02 g}{1 \text{ mol}} \times \frac{1}{15.5 L} = \boxed{4.69 \text{ g/L}}$

H_2 is a gas

EX: COMBINED IGL [W9: 12-35]

A 280.-mL sample of neon exerts a pressure of 660. torr at 26°C. At what temperature in °C would it exert a pressure of 940. torr in a volume of 440. mL?



Molar Mass of a Gas

Ex: 16L - Calc MW [W9: 12-56 sec]

A cylinder was found in a storeroom of a manufacturing plant. The label on the cylinder was gone and no one remembered what the cylinder held. A 0.00500-gram sample was found to occupy 4.13 mL at 23°C and 745 torr. The sample was also found to be composed of only carbon and hydrogen. Identify the gas.

$PV = nRT \xrightarrow{n = g/MW} PV = \frac{gRT}{MW}$ $\quad C_xH_y$

$MW = \frac{g}{n}$ $\qquad \frac{MW}{1} = \frac{gRT}{PV}$

$n = \frac{g}{MW}$ $\qquad =$

(ANS next page)

Molar Mass of a Gas

Ex: IGL – Calc MW [W9: 12-56 soc]

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C_xH_y
(n) 0.00500 g
V 4.13 mL
P 745 torr
T 296 K (23°C)

Need MW !!!

$PV = nRT = \frac{gRT}{MW} \Rightarrow MW = \frac{gRT}{PV} \Rightarrow$

$MW = \frac{0.00500\ g \times 0.0821\ atm \cdot L \times 296\ K \times 760\ torr}{mol \cdot K \times 745\ torr \times 1\ atm \times 0.00413\ L}$

= 30.0 g/mL

C_1H_{18} ✗ impossible

C_2H_6 ✓

C_3H_{-6} ✗ impossible

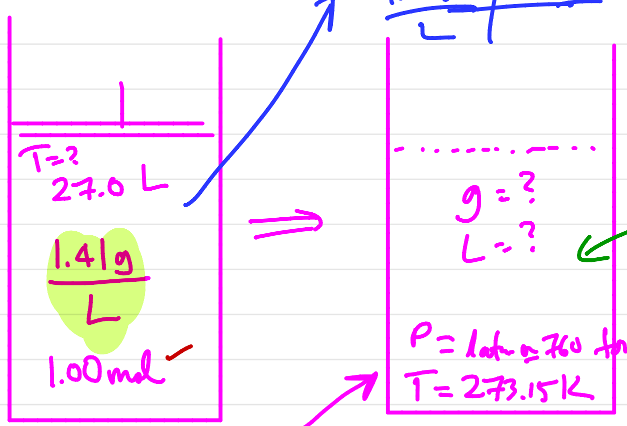
EX: IGL – MW & Density & STP

EAST

¿ 1.00 mol of an unknown gas ? at an unknown Temp & ? Pressure, occupies 27.0 Liters and has a density of 1.41 g/L. ⓐ What is its Density at STP ⓑ what is its MW?

$$\frac{1.41\,g}{L} \Big| \frac{27.0\,L}{} = 38.1\,g$$

Know → calc → look up



$PV = nRT$

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

$$V = \frac{nRT}{P} = \frac{1.00\,mol}{} \Big| \frac{0.0821\,atm \cdot L}{mol \cdot K} \Big| \frac{273.15\,K}{} \Big| \frac{}{1\,atm}$$

$$\frac{\square\,g}{\square\,L} = \frac{38.1\,g}{1} \Big| \frac{1}{22.4\,L} = \boxed{1.70\,g/L} = 22.4\,L$$

$$MW = \frac{\square\,g}{\square\,mol} = 38.1 = MW$$

(ANS next page)

Ex: IGL – MW & Density & STP

i 1.00 mol of an unknown gas, at an unknown Temp & Pressure, occupies 27.0 Liters and has a density of 1.41 g/L. (a) What is its Density at STP. (b) What is its MW?

	gas	⇒	gas
n	1.00 mol		1 atm
V	27.0 Liters		273.15 K
	1.41 g/L		□ g/L, 1 mol

$$d = \frac{\square\,g}{\square\,L} = \frac{38.1\,g}{22.4\,L} = \boxed{1.70\,g/L}$$

(i) $$\square\,g = \frac{1.41\,g}{L}\,\Big|\,27.0\,L = 38.1\,g$$

(ii) $$MW = \frac{\square\,g}{\square\,mol} = \frac{1.41\,g \,|\, 27.0\,L}{1.00\,mol \,|\, L} = \boxed{38.1\,g/mol}$$

(iii) $$V = \frac{nRT}{P} = \frac{1.00\,mol \,|\, 0.0821\,atm\cdot L \,|\, 273.15\,K}{\quad\,|\, mol\cdot K \,|\, 1\,atm} = 22.4\,L$$

EX: 16L — STATIC SYS, CALC VOL [W9: EX 12-9, in TEXT]

¿ What is the volume of a gas balloon filled with 4.00 moles of He when the atmospheric pressure is 748 torr and the temperature is 30.°C?

748 torr = 0.984 atm

He: 4.00 mol, 748 torr, 303.15 K

$$\frac{\square\ L}{1} = \frac{4.00\ \text{mol}}{} \Big| \frac{0.0821\ \text{atm}\cdot\text{L}}{\text{mol}\cdot\text{K}} \Big| \frac{303.15\ \text{K}}{} \Big| \frac{}{0.984\ \text{atm}}$$

$$= \boxed{101\ \text{L}}$$

$PV = nRT$ ← STATIC

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

$$\frac{\square\ L}{1} = \frac{0.0821\ \text{atm}\cdot\text{L}}{\text{mol}\cdot\text{K}} \Big| \frac{}{0.984\ \text{atm}} \Big| \frac{4.00\ \text{mol}}{} \Big| \frac{303.15\ \text{K}}{}$$

(ANS next pg)

EX: 16L — STATIC SYS, CALC VOL [W9: EX 12-9, in TEXT]

¿ What is the volume of a gas balloon filled with 4.00 moles of He when the atmospheric pressure is 748 torr and the temperature is 30.°C?

He
4.00 mol
748 torr (0.984 atm)
30.°C (303 K)

$V = \frac{nRT}{P} = \frac{4.00\ \text{mol} \times 0.0821\ \text{atm L} \times 303\ \text{K}}{0.984\ \text{atm} \times \text{mol} \cdot \text{K}} = \boxed{101\ \text{L}}$

If "static" problem, go ahead and make conv. to match "R"

EX: IGL – STATIC SYS – CALC "g" [W9: 12-10, in text]

practice

¿ A helium-filled weather balloon has a volume of 7240 cubic feet. How many grams of helium would be required to inflate this balloon to a pressure of 745 torr at 21°C? (1 ft^3 = 28.3 L)

(ANS ⇓)

EX: IGL – STATIC Sys – CALC "g" [W9: 12-10, in text]

¿ A helium-filled weather balloon has a volume of 7240 cubic feet. How many grams of helium would be required to inflate this balloon to a pressure of 745 torr at 21°C? (1 ft^3 = 28.3 L)

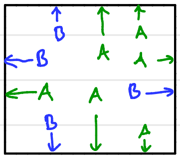
He
7240 ft^3
745 torr (0.980 atm)
21°C (294 K)

$PV = nRT = \frac{g}{MW}RT \Rightarrow g = \frac{P\,V\,MW}{RT}$

$g = \frac{0.980\ atm}{294\ K} \cdot \frac{mol \cdot K}{0.0821\ atm \cdot L} \cdot 7240\ ft^3 \cdot \frac{28.3\ L}{1\ ft^3} \cdot \frac{4.00\ g}{mol} = 33{,}300\ g$

The Pressure of a Mixture of Gases: Dalton's Law

*



$$P_T = \sum P_i = P_a + P_b + P_c \ldots$$

PARTIAL PRESSURE: pressure exerted by each individual gas

MOLE FRACTION (χ): $\left(\frac{\text{part}}{\text{whole}} \times 100\right)$ where part, whole expressed in MOLES

$$\chi_i = \frac{n_i}{n_{TOTAL}} = \frac{P_i}{P_T}$$

$P_i V_i = n_i R T_i$

$n_i = \frac{P_i V_i}{R T_i}$

$P_T V_T = n_T R_T T_T$

$$\chi_i = \frac{P_i V_i}{R T_i} \cdot \frac{R T_T}{P_T V_T}$$

for gas mixture

$$\begin{cases} P_T V_T = n_T R T \\ P_i V_i = n_i R T \end{cases}$$

EX: IGL + DALTON — CALC P AND P_i [W9: EX 12-15]

EASY

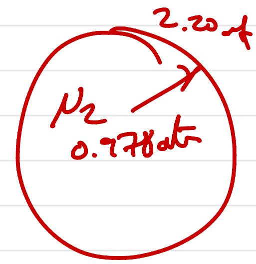
A 10.0-liter flask contains 0.200 mole of methane, 0.300 mole of hydrogen, and 0.400 mole of nitrogen at 25°C. (a) What is the pressure, in atmospheres, inside the flask? (b) What is the partial pressure of N2?

0.200 mol CH_4
0.300 " H_2
0.400 " N_2
298 K
10.0 L

(a) $PV = nRT \Rightarrow P = \frac{nRT}{V}$

$$P = \frac{(0.200 + 0.300 + 0.400 \text{ mol})}{10.0 \text{ L}} \cdot \frac{0.0821 \text{ atm} \cdot \text{L}}{\text{mol} \cdot \text{K}} \cdot 298 \text{ K} = \boxed{2.20 \text{ atm}}$$

(b) $\frac{n_N}{n_T} = X_N = \frac{P_N}{P_T} \Rightarrow P_N = X_N P_T = \frac{0.400}{0.900} \cdot 2.20 \text{ atm} = \boxed{0.978 \text{ atm}}$



= OR =

$$P_N V_N = n_N RT \Rightarrow P_N = \frac{n_N RT}{V_N} = \frac{0.400 \text{ mol}}{} \cdot \frac{0.0821 \text{ atm} \cdot \text{L}}{\text{mol} \cdot \text{K}} \cdot \frac{298 \text{ K}}{10.0 \text{ L}} = \boxed{0.979 \text{ atm}}$$

Collection of Gases over Water

↳ PROBLEM: collected gas is contaminated with water vapor

↳ $P_T = \Sigma P_i = P_{gas} + P_{WATER}$

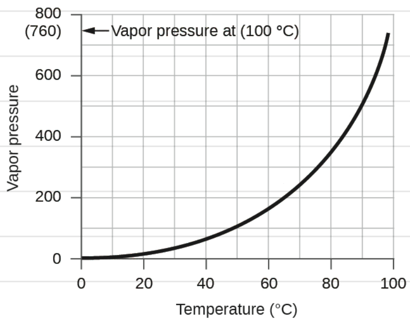


FIG. 9.22

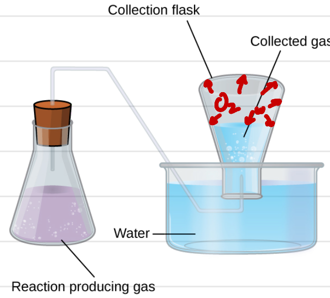
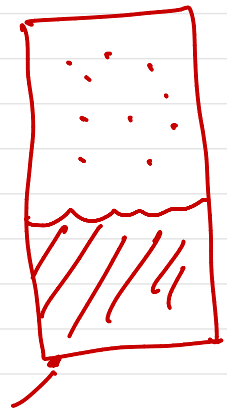


FIG. 9.21



$$P_T = P_{O_2} - P_w$$

$$(P_T - P_w) = P_{O_2}$$

IGL — COLLECTED OVER WATER [w9.ex12-19, in text]

(EX) ¿Hydrogen was collected over water (Figure 12-7) at 21°C on a day when the atmospheric pressure was 748 torr. The volume of the gas sample collected was 300. mL. <(a) How many moles of H 2 were present? (b) How many moles of water vapor were present in the moist gas mixture? (c) What is the mole fraction of hydrogen in the moist gas mixture?> What would be the mass of the gas sample if it were dry?

$P_H V_H = n_H RT = \frac{g_{H_2} RT}{MW_{H_2}}$ — 1 eq, 2 unk

wet
T: 21°C (294 K)
P: 748 torr (0.984 atm)
V: 300. mL (0.300 L)
□ g, H

① $P_T = P_{H_2} + P_w$

$P_{H_2} = P_T - P_w$
$= 748 \text{ torr} - 18.7 \text{ torr}$
$= 729 \text{ torr} = 0.960 \text{ atm}$

② $g_{H_2} = \frac{P_{H_2} V_{H_2} MW_{H_2}}{RT}$

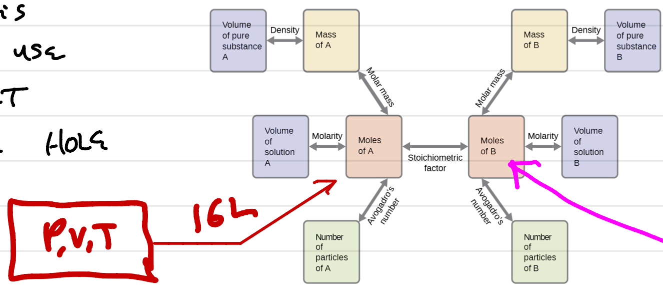
$g_{H_2} = \frac{0.960 \text{ atm}}{294 \text{ K}} \cdot 0.300 \text{ L} \cdot \frac{2.02 \text{ g}}{\text{mol}} \cdot \frac{\text{mol} \cdot \text{K}}{0.0821 \text{ atm} \cdot \text{L}} = 0.0241 \text{ g}, H_2$

Thur, Nov 21

Chemical Stoichiometry and Gases

[P478 / 486]

↳ Translation of this section: CAN use PV=nRT TO GET INTO THE MOLE HOLE



$$PV = nRT$$

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

Avogadro's Law Revisited

[P478/486]

↳ Punchline: moles gas ∝ volume

↳ for Ideal Gas: 22.4L/mol

$$\frac{14.22\,L \mid 1\,mol}{\mid 22.4\,L}$$

(EX) STOICHIOMETRY OF A GAS USING VOLUME. [ex9.17b]

¿An acetylene tank for an oxyacetylene welding torch provides 9340 L of acetylene gas, C2H2 , at 0 °C and 1 atm. How many tanks of oxygen, each providing 7.00 × 10^3 L of O2 at 0 °C and 1 atm, will be required to burn the acetylene?

H–C≡C–H

STP = (22.4 L / mol)

CF "simple ratio"

(9340 L / tank, Ac) (7.00E3 L / tank O2)

$C_2H_2 + \frac{5}{2} O_2 \rightarrow 2CO_2 + H_2O$

9340 L — Liters

$2C_2H_2 + 5O_2 \rightarrow 4CO_2 + 2H_2O$

C2H2
273 K
1 atm

$\frac{\square \text{ tank } O_2}{1} = \frac{9340 \text{ L Ac}}{1} \Big| \frac{5 \text{ L } O_2}{2 \text{ L Ac}} \Big| \frac{1 \text{ Tank } O_2}{7.00E3 \text{ L } O_2} = $ 3.34 tanks O2

$\frac{9340 \text{ L}}{} \Big| \frac{1 \text{ mol Ac}}{22.4 \text{ L Ac}} \Big| \frac{5 \text{ mol } O_2}{2 \text{ mol Ac}} \Big| \frac{22.4 \text{ L } O_2}{1 \text{ mol } O_2} \Big| \ldots$

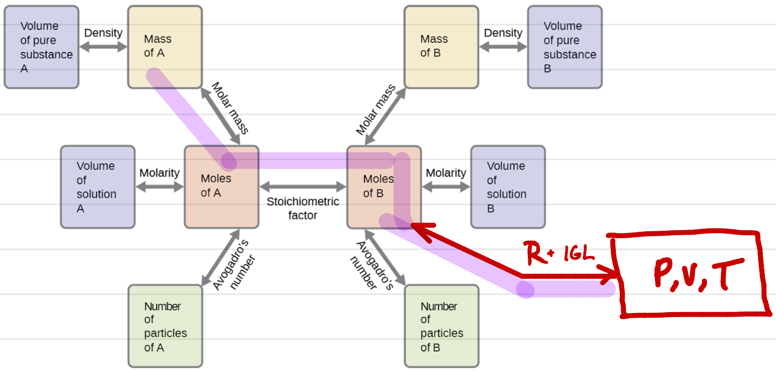
CAVEAT #1: ASSUMES IDEAL GASES

CAVEAT #2: ALL GASES AT SAME TEMP & PRESSURE

$\ldots \frac{1 \text{ tank } O_2}{7.00 \times 10^3 \text{ L } O_2}$

ex: Stoichiometry of Gases: mol A → vol B [ex 9.196]

¿Sulfur dioxide is an intermediate in the preparation of sulfuric acid. What volume of SO2 at 343 °C and 1.21 atm is produced by burning l. 00 kg of sulfur in oxygen?



1.00 kg, excess

$S + O_2 \longrightarrow SO_2 \xrightarrow{IGL} Vol$

$$\square_{g,SO_2} = \frac{1.00\,kg\,S}{} \left| \frac{1000\,g,S}{1\,kg,S} \right| \frac{mol,S}{32.1\,g\,S} \left| \frac{1\,mol\,SO_2}{1\,mol,S} \right\| \frac{0.0821\,atm\cdot L}{mol_{SO_2}\cdot K} \left| \frac{(343+273)K}{1.21\,atm} \right. = \boxed{1.30\times10^{2}}$$

use "R" as 1st factor

Effusion and Diffusion of Gases [9.4]

mean free path – avg. distance between collisions

diffusion – dispersal of molecules in space due to differences in concentration

$$\text{rate of diffusion} = \frac{\text{amt of gas passing through an area}}{\text{unit of time}}$$

effusion – escape of gas into lower pressure area through a pinhole

Graham's Law of Effusion

↳ heavier the molecule, the slower it moves

$$\text{rate of effusion} \propto \frac{1}{\sqrt{M}}$$

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

Ex: Calc MW from Graham

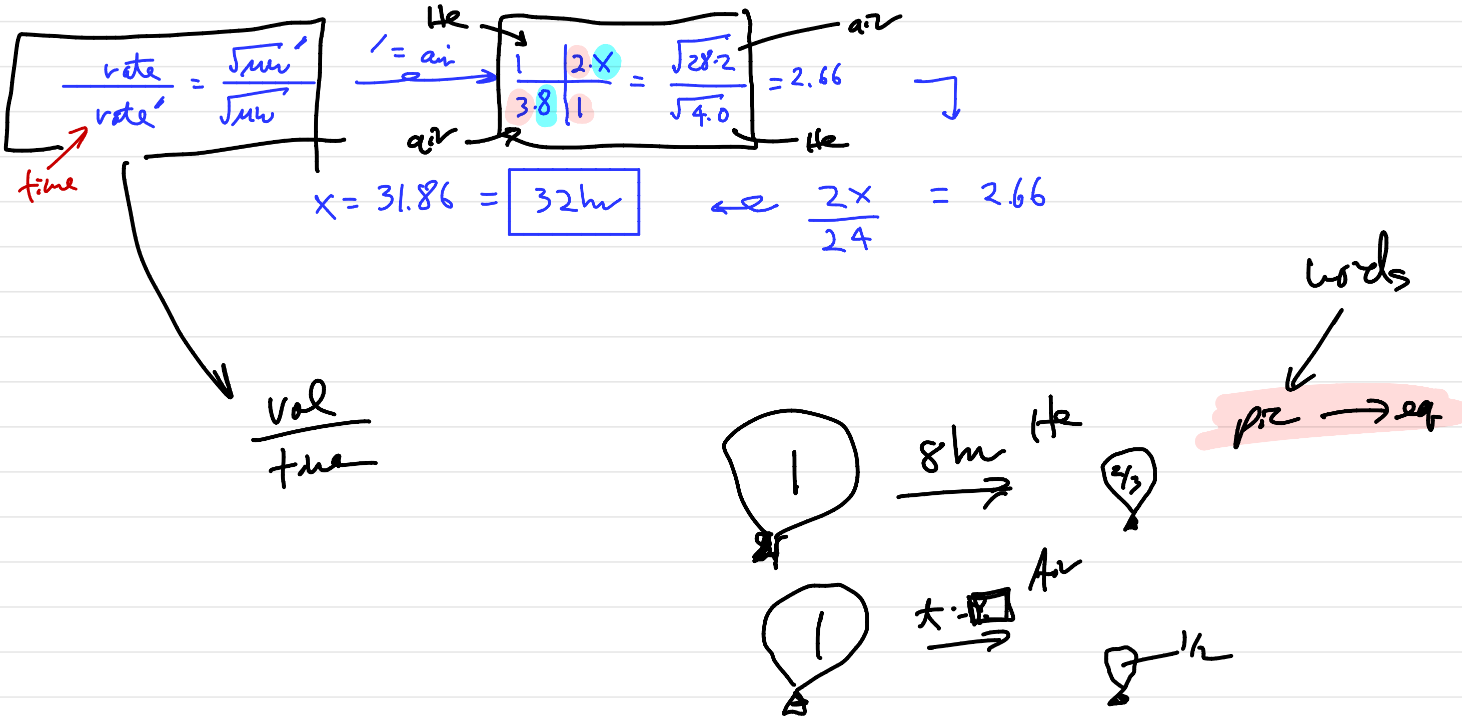
[Collins Outlines, Ex 6.26, p 132]

¿ An unknown gas effuses at a rate of 0.632 time that of O_2. What is the MM of the unknown gas?

$$\frac{\text{rate } O_2}{\text{rate unk}} = \frac{\sqrt{MW_{unk}}}{\sqrt{MW_{O_2}}} \Rightarrow \frac{1}{0.632} = \frac{\sqrt{x}}{\sqrt{32.0}} \Rightarrow x = \left(\frac{\sqrt{32}}{0.632}\right)^2 = \boxed{80.1 \text{ g/mol}}$$

(EX) CALC EFFUSION TIME [ex9.21b]

¿A party balloon filled with helium deflates to 2/3 of its original volume in 8.0 hours. How long will it take an identical balloon filled with the same number of moles of air (M = 28.2 g/mol) to deflate to 1/2 of its original volume?



The Kinetic-Molecular Theory [9.5]

[P488 / 496]

Kinetic molecular theory (KMT) - Simple model to explain gas law obs. — rationalize $\frac{PV}{nT} = R$

Basic Tenets

① STRAIGHT-LINE MOTION, except when hit wall or another
② DISCRETE, SMALL PARTICLES, far, far apart ← ∴ no interaction of influence of other molecules.
③ PRESSURE = particles hitting container wall
④ PARTICLES ARE UN-INFLUENCED, feel no attraction/repulsion w/ others ←
⑤ $\overline{KE} \propto$ TEMP (in K)

2 Factors
① Collision Frequency (often) ← n
② Collision Vigor (hard) ← T

Kinetic-Molecular Theory Explains the Behavior of Gases, Part I

lecular Velocities and Kinetic Energy

Kinetic-Molecular Theory Explains the Behavior of Gases, Part II

ɔn-Ideal Gas Behavior [9.6]

Root Mean Square Velocity

KE of a particle of mass (m) and speed (u) =

(1a) $$KE = \frac{1}{2} m u^2$$

$$u_{rms} = \sqrt{\bar{u}^2} = \sqrt{\frac{u_1^2 + u_2^2 + u_3^2 \ldots}{n}}$$

phys. chem.

(1b) $$KE_{AVG} = \frac{1}{2} m u_{RMS}^2$$

chemistry

(2) $$KE_{AVG} = \frac{3}{2} RT$$

$$\frac{1}{2} m u_{rms}^2 = \frac{3}{2} RT$$

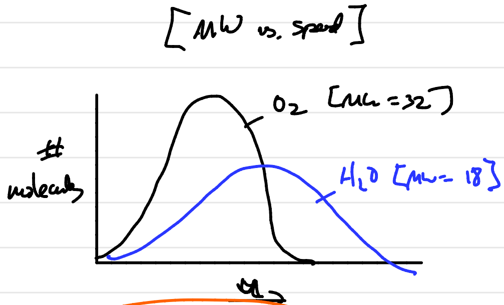
(3) $$u_{rms} = \sqrt{\frac{3RT}{m}}$$

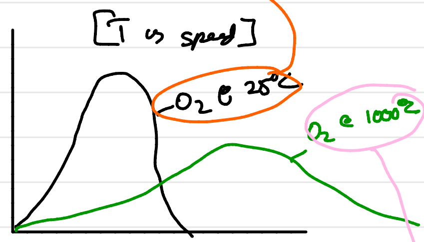
ENERGY vs. SPEED

ⓐ $KE = \frac{1}{2} m u^2$ (m ← mass, u ← speed)

ⓑ $T \propto KE = \frac{1}{2} m u^2$ (m ← MW)

④ $\boxed{u \propto \sqrt{\frac{T}{MW}}}$ (u ← speed)





O_2 @ 25°C, $\bar{u} = \frac{400\,m}{s} = 895$ mph

O_2 @ 1000°C, $\bar{u} = \frac{1600\,m}{s} = 3,580$ mph

Effusion Rate vs. Mass
(derivation of GRAHAM's Law)

$$\frac{\text{effusion rate } A}{\text{effusion rate } B} = \frac{u_{rms\,A}}{u_{rms\,B}} = \frac{\sqrt{\frac{3RT}{m_a}}}{\sqrt{\frac{3RT}{m_b}}} = \sqrt{\frac{m_B}{m_A}}$$ (5)

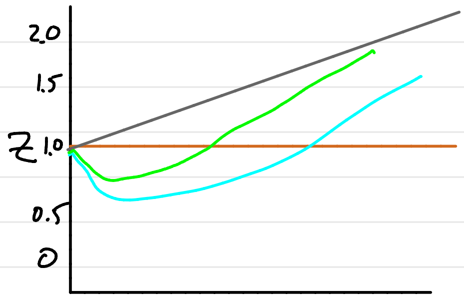
↑ Graham's Law

- rate (u, "rate")
- Temp
- KE
- m / MW

NON-IDEAL CASES ("REAL WORLD")

$PV = nRT$

$Z = n = \frac{PV}{RT}$



Beware!!!
High Pressure
Low Temp

$PV = nRT$

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

corrects for molec attraction

corrects for volume of molecule

"a" + "b" are constants.