Gay-Lussac's Law of Combining Volumes of Gases

- In the 1800's Joseph Gay-Lussac studied gas volume relationships during chemical reactions

$2H_2 + O_2 \rightarrow 2H_2O$

hydrogen gas + oxygen gas ⟶ water vapor
2 L 1 L 2 L

* this shows a ratio of 2:1:2 and it applies to any proportions for volume

ex. 2 mL, 1 mL, 2 mL 600 L, 300 L, 600 L

Gay-Lussac's Law of Combining Volumes of Gases

⟶ at constant temperature and pressure, the volumes of gaseous reactants and products can be expressed as ratios of small whole numbers

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Avogadro's Law

- Equal volumes of gases at the same temperature and pressure contain equal numbers of molecules

constant

H_2	same V same P same T	O_2
1000 molecules		??? molecules 1000

Avogadro's Law and Gay-Lussac's Law of Combining Volumes of Gases, provided more understanding of how gases react and combine with each other

Molar Volume of Gases

- Recall that 1 mol of any molecular substance contains 6.02×10^{23} molecules

ex. 1 mol O_2 = 6.02×10^{23} molecules
1 mol H_2 = 6.02×10^{23} molecules

- Also recall that 1 mol of any molecular substance has a mass that corresponds to the atomic mass # on the periodic table (MOLAR MASS) → periodic table

ex. 1 mol O_2 = (15.99 x 2) = 31.98 g/mol
1 mol H_2 = (1.01 x 2) = 2.02 g/mol
1 mol S = 32.066 g/mol

- According to Avogadro, 1 mol of any gas will occupy the same volume as 1 mol of any other gas at the same temperature and pressure despite mass differences

Standard Molar Volume of a Gas

The volume occupied by 1 mol of gas at STP (0°C and 101.325 kPa) (273.15 K, 1 atm)

Standard Molar Volume of a Gas = **22.4 L**

conversion factor 1 mol / 22.4 L or 22.4 L / 1 mol

A chemical reaction produces 0.0680 mol of oxygen gas. What volume in liters is occupied by this gas sample @ STP?

$$\frac{0.0680 \text{ mol } O_2}{} \cdot \frac{22.4 \text{ L } O_2}{1 \text{ mol } O_2} = 1.52 \text{ L } O_2$$

A chemical reaction produced 98.0 mL of sulfur dioxide gas (SO_2) at STP. What was the mass (in grams) of gas produced?

$$\frac{98.0 \text{ mL } SO_2}{} \cdot \frac{1 \text{ L } SO_2}{1000 \text{ mL } SO_2} \cdot \frac{1 \text{ mol } SO_2}{22.4 \text{ L } SO_2} \cdot \frac{64.05 \text{ g } SO_2}{1 \text{ mol } SO_2}$$

What is the volume (L) of 77.0 grams of nitrogen dioxide gas at STP?

$$\frac{77.0 \text{ g } NO_2}{} \cdot \frac{1 \text{ mol } NO_2}{\text{g } NO_2} \cdot \frac{22.4 \text{ L } NO_2}{1 \text{ mol } NO_2}$$

The Ideal Gas Law

- we have already looked at 3 quantities used to describe a gas (temperature, pressure, and volume) $P_1V_1 = P_2V_2$ (B) / $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ (C) / $\frac{P_1}{T_1} = \frac{P_2}{T_2}$ (G-L) / $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ (CB)

- There is a 4th quantity that we use and it is the # of moles (n)

- the number of moles will always effect one of the other three quantities

The Ideal Gas Law

⟶ mathematical relationship between pressure, volume, temperature, and the number of moles of gas

$$PV = nRT$$

P = pressure (mm Hg, atm, Pa, kPa)
V = volume (L, mL, cm^3)
n = # of moles of gas
R = ideal gas constant
T = temperature (K)

possible values for R include....

$62.4 \frac{L * mm Hg}{mol * K}$ $0.0821 \frac{L * atm}{mol * K}$ $8.314 \frac{L * kPa}{mol * K}$

When choosing what R value to use, you must look at the units of the other variables

What the pressure in atm exerted by a 0.500 mol sample of nitrogen gas in a 10.0 L container at 298 K?

P = ? atm
n = 0.500 mol
V = 10.0 L
T = 298 K
R = 0.0821 L atm / mol K

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

$P = \frac{(0.500\ mol)(0.0821\ \frac{L\ atm}{mol\ K})(298\ K)}{10.0\ L}$

P = 1.22 atm

What is the volume in liters of 0.250 mol of oxygen gas at 20.0 °C and 0.974 atm?

V = ? L
n = 0.250 mol
T = 293.2 K
P = 0.974 atm
R = 0.0821 L atm / mol K

$V = \frac{nRT}{P} = \frac{(0.250\ mol)(0.0821\ \frac{L\ atm}{mol\ K})(293.2\ K)}{(0.974\ atm)}$

V = 6.18 L

What mass of chlorine gas (Cl_2) is contained in a 10.0 L tank at 27°C and 3.50 atm of pressure?

V = 10.0 L
T = 300. K
P = 3.50 atm
R = 0.0821 L atm / mol K

$n = \frac{PV}{RT} = \frac{(3.50\ atm)(10.0\ L)}{(0.0821\ \frac{L\ atm}{mol\ K})(300.\ K)} = n \rightarrow 1.42$

1.42 mol Cl_2 | 70.90 g / 1 mol

I have 28.0 g of N_2 at STP. What volume of gas do I have?

T = 273.15 K
P = 1 atm
V = ? L
R = 0.0821 L atm / mol K
n = 0.999 mol N_2

28.0 g N_2 | 1 mol N_2 / 28.02 g

m = mass   n = moles
M = molar mass

Finding Molar Mass from the ideal gas law

* PV = nRT

n = m/M where m is the mass and M is the molar mass

m = 5.00 g of O_2 M = 15.99 g/mol $n = \frac{5.00\ g}{15.99\ g/mol}$

5 g O_2 | 1 mol / 32 g

so.... we can rewrite the ideal gas equation as

$$PV = \frac{mRT}{M}$$

At 28 °C and 0.974 atm, 1.0 L of gas has a mass of 5.16 g. What is the molar mass of this gas?

T = 301 K
P = 0.974 atm
V = 1.0 L
R = 0.0821 L atm / mol K
m = 5.16 g

M = ? $\frac{mRT}{PV} = M$

$\frac{(5.16\ g)(0.0821\ \frac{L\ atm}{mol\ K})(301\ K)}{(0.974\ atm)(1.0\ L)}$

M = 130 g/mol

What is the molar mass of a gas if 0.427 g of the gas occupy a volume of 125 mL at 20.0 °C and 0.980 atm?

Stoichiometry of Gases

Conversion factors: 1) molar mass 2) mol ratio 3) 22.4 L = 1 mol

Volume - Volume Problems

given is a volume (in L or mL) and the unknown is a volume (in L or mL)

1) balance the chemical equation
2) convert known substance to moles
3) look at the mol ratio between known and unknown substance
4) convert moles of unknown to a volume

Ex. How many L of O_2 are required to burn with 1.0 L of methane at STP

$CH_4 + 2O_2 \longrightarrow 2\ H_2O + CO_2$

1.0 L CH_4 | 1 mol CH_4 / 22.4 L CH_4 | 2 mol O_2 / 1 mol CH_4 | 22.4 L O_2 / 1 mol O_2

2.0 L O_2

What will be the volume in L of oxygen required for the complete combustion of 0.350 L of propane? The reaction takes place at STP

$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4\ H_2O$

$C_3H_8 + O_2 \rightarrow CO_2 + H_2O$ (5, 3, 4)

if you have 4.6 L of CO_2 how many L of H_2O will you produce... @ STP

4.6 L CO_2 | 1 mol CO_2 / 22.4 L CO_2 | 4 mol H_2O / 3 mol CO_2 | 22.4 L / 1 mol

6.1 L H_2O

2Na + Cl_2 → 2NaCl

If 2.3 L of Cl_2 are reacted @ STP how many L of NaCl are produced

2.3 L Cl_2 | 1 mol Cl_2 / 22.4 L Cl_2 | 2 mol NaCl / 1 mol Cl_2 | 22.4 L / 1 mol

Mass - Volume Problems

- given is a mass (in g / kg) and unknown is a volume (in mL or L)

1) balance the chemical equation
2) find the # of moles of given substance
3) use mole ratio of unknown to unknown
4) express moles of gas in terms of volume of gas (1 mol = 22.4 L)

(1) molar mass (2) mol ratio (3) 22.4 = 1 mol

What volume of hydrogen gas at STP can be produced from the reaction of 6.54 g of zinc with hydrochloric acid.

$2\ HCl + Zn \longrightarrow H_2 + ZnCl_2$

6.54 g Zn | 1 mol Zn / 65.39 g Zn | 1 mol H_2 / 1 mol Zn | 22.4 L H_2 / 1 mol H_2

2.24 L H_2

Calculate the volume of oxygen produced at STP by the decomposition of 10. g of potassium chlorate?

$2\ KClO_3 \longrightarrow 2\ KCl + 3\ O_2$

10. g $KClO_3$ | 1 mol $KClO_3$ / 122.55 g $KClO_3$ | 3 mol O_2 / 2 mol $KClO_3$ | 22.4 L O_2 / 1 mol O_2

2.7 L O_2

How many mL of H_2 are produced if 4.0 g of Zn react with excess HCl at STP?

$Zn + 2\ HCl \longrightarrow ZnCl_2 + H_2$

4.0 g Zn | 1 mol Zn / 65.39 g Zn | 1 mol H_2 / 1 mol Zn | 22.4 L H_2 / 1 mol H_2 | 1000 mL / 1 L H_2

1400 mL H_2   1370.65

Volume - Mass Problems

- given is a volume (in mL or L) and unknown is a mass (in g / kg)

1) balance the chemical equation
2) find the # of moles of given substance
3) use mole ratio of known to unknown
4) express moles of gas in terms of mass of gas

① 22.4 L = 1 mol
② mol ratio
③ molar mass

How many grams of NaCl can be produced by the reaction of 112 mL of Cl_2 at STP with excess sodium

$2Na + Cl_2 \longrightarrow 2NaCl$

$$112\ mL\ Cl_2 \times \frac{1\ L\ Cl_2}{1000\ mL} \times \frac{1\ mol\ Cl_2}{22.4\ L\ Cl_2} \times \frac{2\ mol\ NaCl}{1\ mol\ Cl_2} \times \frac{58.44\ g\ NaCl}{1\ mol\ NaCl}$$

0.584 g NaCl

How many grams of copper (II) oxide can be reduced to copper metal with 10.0 L of H_2 at STP

$CuO + H_2 \longrightarrow Cu + H_2O$

$$10.0\ L\ H_2 \times \frac{1\ mol\ H_2}{22.4\ L\ H_2} \times \frac{1\ mol\ CuO}{1\ mol\ H_2} \times \frac{79.5\ g\ CuO}{1\ mol\ CuO}$$

35.5 g CuO

How many g of calcium carbonate must be decomposed to produce 5.00 L of carbon dioxide gas at STP

$CaCO_3 \longrightarrow CaO + CO_2$

$$5.00\ L\ CO_2 \times \frac{1\ mol\ CO_2}{22.4\ L\ CO_2} \times \frac{1\ mol\ CaCO_3}{1\ mol\ CO_2} \times \frac{100.09\ g\ CaCO_3}{1\ mol\ CaCO_3}$$

22.3 g CaCO₃

Non-Standard Conditions

- So far all of the stoichiometry problems have been at STP, but sometimes the reaction will take place in non-standard conditions

- If this occurs, you must account for the non-standard conditions using the ideal gas law equation

Mass - Volume

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

1) write balanced equation
2) solve for the volume if it would be at STP
3) use the combined gas law to solve for the new volume

How many L of Cl_2 would need to react with 2.5 g of Ag to produce AgCl if the reaction took place at 24°C and a pressure of 99.2 kPa

$2Ag + Cl_2 \longrightarrow 2AgCl$

$$2.5\ g\ Ag \times \frac{1\ mol\ Ag}{107.87\ g\ Ag} \times \frac{1\ mol\ Cl_2}{2\ mol\ Ag} \times \frac{22.4\ L\ Cl_2}{1\ mol\ Cl_2} = 0.26\ L\ Cl_2 \text{ @ STP}$$

STP: $P_1 = 101.325$ kPa, $V_1 = 0.26$ L, $T_1 = 273$ K

non standard: $P_2 = 99.2$ kPa, $V_2 = ?$ L Cl_2, $T_2 = 297$ K

$$\frac{P_1V_1T_2}{P_2T_1} = V_2$$

$$\frac{(101.325\ kPa)(0.26\ L)(297\ K)}{(99.2\ kPa)(273\ K)} = V_2$$

$V_2 = 0.29$ L Cl_2

~~Volume - Mass~~

1) write balanced equation
2) solve for the volume if it would be at STP
3) use the combined gas law to solve for the new volume
4) convert to the new mass using mole conversions and mole ratios

How many grams of carbon are required to produce 544 L of CO if the reaction took place at 27°C and a pressure of 0.247 atm?

$2C + O_2 \longrightarrow 2CO$

Diffusion and Graham's Law

Diffusion = the random scattering of gas particles

Diffuse from high conc. to low conc.

- All gases do not diffuse at the same rate

- At the same temperature, the lower mass molecules diffuse more quickly than large mass molecules

Graham's Law of Diffusion

- The relative rates of two gases under identical conditions vary inversely as the square roots of their molecular masses

*** pressure and temperature must be constant***

M = molar mass

v = velocity (m/s)

$$\frac{v_1}{v_2} = \frac{\sqrt{M_2}}{\sqrt{M_1}}$$

When looking at relative rate put the larger # on top (molar mass)

Ex. What is the relative rate of diffusion between O_2 and N_2

$$\text{Rel. rate} = \frac{\sqrt{M_2}}{\sqrt{M_1}}$$

slower $M_{O_2} = 31.98$ g/mol

faster $M_{N_2} = 28.02$ g/mol

$$\text{rel rate} = \frac{\sqrt{31.98}}{\sqrt{28.02}}$$

1.07

* N_2 diffuses 1.07 times faster than O_2

At a constant temperature, the velocity of N_2 molecules is 0.076 m/s. What is the velocity of He atoms at the same temperature?

v?

$M_{N_2} = 28.02$

$M_{He} = 4.00$ g

$$\frac{V_1}{V_2} = \frac{\sqrt{M_2}}{\sqrt{M_1}}$$

$$\frac{V_1}{0.076} = \frac{\sqrt{28.02}}{\sqrt{4.00}}$$

$V_1 = 0.20$

A sample of gas has a molar mass of 108.4 g/mol. This gas is at a volume of 2.3 L, 5.3 mm Hg, and 289 K. What is the mass of this gas?

$P = 5.3$ mm Hg

$V = 2.3$ L

$n = ?$ mol

$R = 62.4 \frac{L\ mmHg}{mol\ K}$

$T = 289$ K

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

$$n = \frac{(5.3\ mmHg)(2.3\ L)}{(62.4\ \frac{L\ mmHg}{mol\ K})(289\ K)}$$

$n = 6.8 \times 10^{-4}$ mol

$$\frac{108.4\ g}{mol} \times 6.8 \times 10^{-4}\ mol = 0.074\ g$$

$P = 5.3$ mm Hg

$V = 2.3$ L

$R = 62.4 \frac{L\ mmHg}{mol\ K}$

$T = 289$ K

$M = 108.4$ g/mol

$m = ?$ g

$$MPV = mRT$$

$$\frac{MPV}{RT} = m$$

$$m = \frac{MPV}{RT}$$

$$PV = \frac{mRT}{M}$$

$$m = \frac{(108.4\ g/mol)(5.3\ mmHg)(2.3\ L)}{(62.4\ \frac{L\ mmHg}{mol\ K})(289\ K)}$$

m = 0.073 g

$$n = \frac{m}{M}$$

$$n \cdot M = m$$

$$6.0\ g\ O \times \frac{1\ mol}{15.99\ g\ O}$$