Gases
Topic#11
AMSAT Chem 1H

Teacher Edition

Gases

Topic#11

Gas Law Equations for Formula Card

Boyle's Law

$$P_1V_1 = P_2V_2$$

Charles' Law

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Gay-Lussac's Law

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

Combined Gas Law

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

Avogadro's Law

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

Ideal Gas Law

$$PV = nRT$$

Gas Density Equation

$$d = \frac{MP}{RT}$$

Dalton's Law of Partial Pressure

$$P_T = P_1 + P_2 + P_3 \ldots$$

$$P_T = P_{gas} + P_{H2O}$$

$$P_{Gas\,1} = (X_{Gas\,1}) \cdot (P_{Total})$$

Mole Fraction

$$X_{Gas\,1} = \frac{\text{moles Gas 1}}{\text{Total moles}}$$

$$X_1 = \frac{n_1}{n_1 + n_2} = \text{mole fraction of species 1}$$

$$X_2 = \frac{n_2}{n_1 + n_2} = \text{mole fraction of species 2}$$

$$X_1 + X_2 = 1$$

Mole Fraction:

$$\chi_1 = \frac{P_1}{P_{total}}$$

1 mol = 22.4L

Graham's Law

$$\frac{Rate_A}{Rate_B} = \sqrt{\frac{Molar\ Mass_B}{Molar\ Mass_A}}$$

Gases
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Kinetic Molecular Theory (KMT)

Kinetic Molecular Theory

1. Gases consist of large number of tiny particles that are far apart relative to their size, and are considered volumeless.
2. Collisions between gas particles and other particles or container walls are elastic collisions.
   - Particles are not attracted to each other or container.
3. Gas particles are in continuous, random motion. Possesses kinetic energy (KE) which energy of motion.
4. The temperature of a gas is directly proportional to the kinetic energy of the gas particles.

   $KE = \frac{1}{2}mv^2$ (all gases at the same temperature have the same average KE)

Gas Characteristics

1. Expand to fill their container - no definite shape
   (solids have a definite shape and liquids take the shape of part of their container.)
2. Take on the volume of their container.
   (solids and liquids have a definite volume.)
3. Are fluid (flow)
4. Very low density (1000 less dense than a liquid)
   (solids and liquids have a relatively high density.)
5. Very compressible
   (solids and liquids have very little to no compressibility.)
6. Diffusion - spontaneous mixing of two or more substances through random motion.
   (solids - ocurrs only on surface and is very low, liquids - diffuse but slower than gases.)

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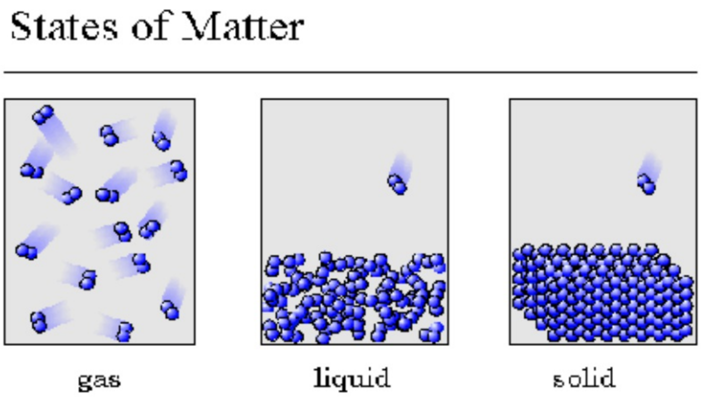
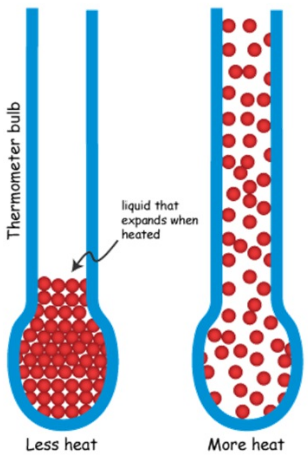
Kinetic Molecular Theory (KMT)



Kinetic Molecular Theory (KMT)



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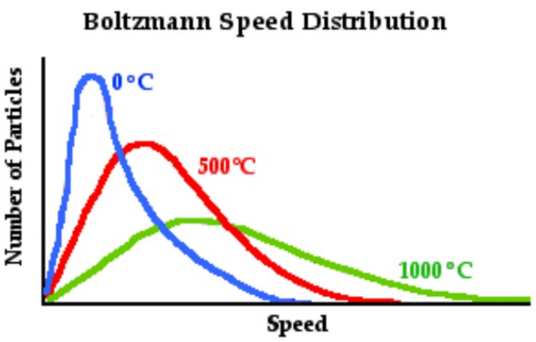
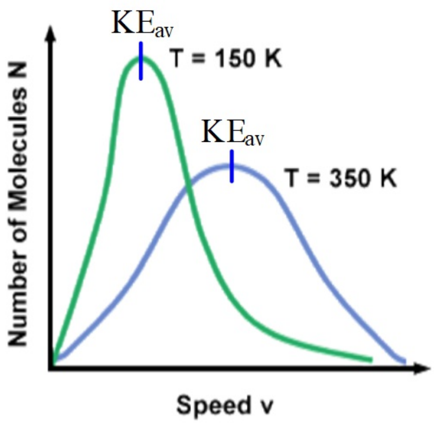
Kinetic Molecular Theory (KMT)



For any given temperature, then is a distribution of speeds with which particles within the sample can move. As the temperature is increased, there is a greater percentage of particles moving at the higher speeds.



Gases
Topic#11

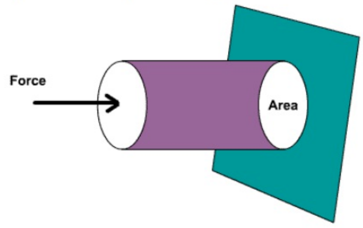
Pressure

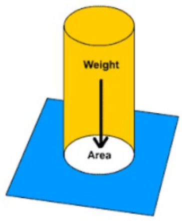
Gas Variables

P - pressure, *V* - volume, *n* - moles of gas, *R* - ideal gas constant, and *T* - temperature (Kelvin)

Pressure - Force over an area

- Force of gas hitting its container.
- Measurement: Force of air over 1cm^2 area
  - Barometer measures atmospheric pressure (invented by Evangelista Torricelli)
  - Manometer measures the pressure of an enclosed gas
  - the atmosphere (atm) is the most common unit for gas pressure
    - 1atm = 10.1N/cm^2 (A Newton is the force needed to move a 1kg object by 1m/s each second the force is applied)





1atm = 101.3kPa = 101,300Pa = 760torr = 760mmHg = 14.7psi

Gases
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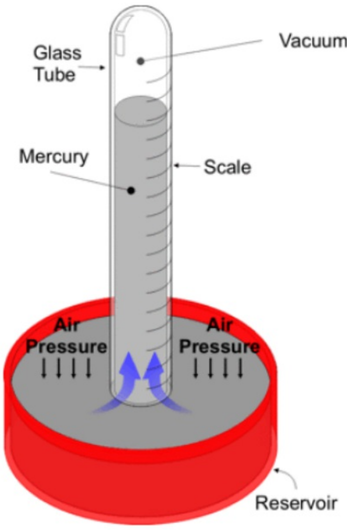
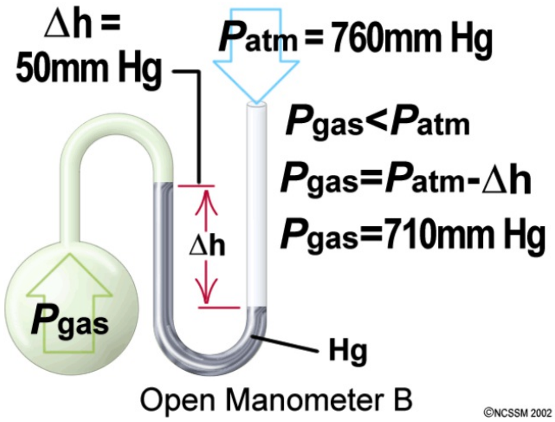
Pressure

Gas Variables

P - pressure, *V* - volume, *n* - moles of gas, *R* - ideal gas constant, and *T* - temperature (Kelvin)



Barometer



Manometer

Pressure

1atm = 101.3kPa = 101,300Pa = 760 torr = 760mmHg = 14.7psi

Sample WS#1 - Pressure Unit Conversions

(1) The average atmospheric pressure in Denver, Colorado, is 0.830atm. Express this pressure

(a) in mmHg (Ans: 631mmHg, 84.1kPa)

GVN: 0.830 atm

NTK: 1 atm = 760 mmHg

UNK: P_{mmHg} = 631 mmHg

SOLUTION:

$$\frac{0.830\ \text{atm} \times 760\ \text{mmHg}}{1\ \text{atm}} = \boxed{631\ \text{mmHg}}$$

(b) in kPa

GVN: 0.830 atm

NTK: 1 atm = 101.3 KPa

UNK: P_{KPa} = 84.1 KPa

SOLUTION:

$$\frac{0.830\ \text{atm} \times 101.3\ \text{KPa}}{1\ \text{atm}} = \boxed{84.1\ \text{KPa}}$$

Pressure

1atm = 101.3kPa = 101,300Pa = 760 torr = 760mmHg = 14.7psi

(2) Convert a pressure of 570.torr to atms and kPa. (Ans: 0.750atm, 76.0kPa)

GVN: 570. torr

NTK: 1 atm = 760 torr; 101.3 KPa = 760 torr

UNK: P_{atm} = 0.750 atm; P_{KPa} = 76.0 KPa

SOLUTION:

$$\frac{570.\ \text{torr}}{} \left| \frac{1\ \text{atm}}{760\ \text{torr}} \right. = \boxed{0.750\ \text{atm}}$$

$$\frac{570.\ \text{torr}}{} \left| \frac{101.3\ \text{KPa}}{760\ \text{torr}} \right. = \boxed{76.0\ \text{KPa}}$$

Pressure

1atm = 101.3kPa = 101,300Pa = 760 torr = 760mmHg = 14.7psi

(3) (OYO) Do the following pressure conversions.

(a) Convert 0.790atm to mmHg, and kPa. (Ans: 600.mmHg, and 80.0kPa)

(b) Convert 674mmHg to kPa, and atm. (Ans: 89.8kPa, and 0.887atm)

Pressure

Assignment:
Topic#11 Gases

WS#1: Pressure, Volume, and Temperature

Demo: water tr
(1) Write an

Pressure

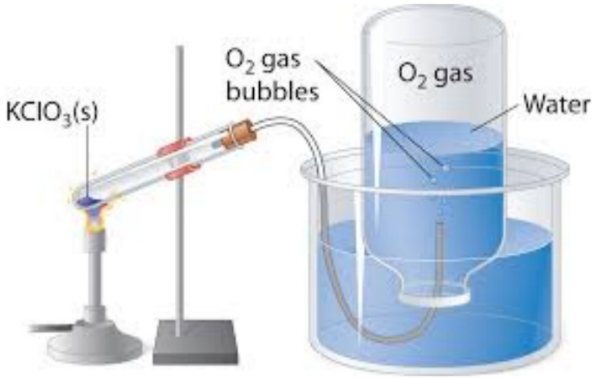
Dalton's Law of Partial Pressure

- the sum of each individual gas pressure, in a mixture, equals the total pressure of the system.

$$P_T = P_1 + P_2 + P_3 + \ldots$$

- Gas collected by water displacement
    - the total pressure is equal to the pressure of the gas plus the pressure of the water vapor above the liquid water.
    - the pressure due to water vapor is directly related to the temperature of the water

$$P_T = P_{gas} + P_{H2O}$$



Gases
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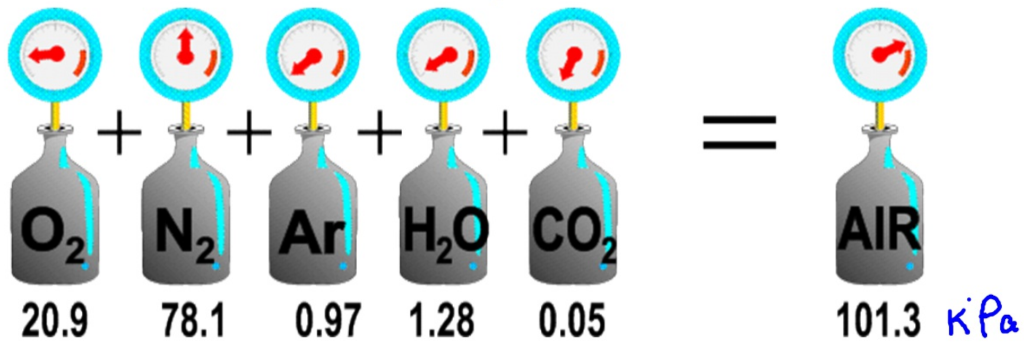
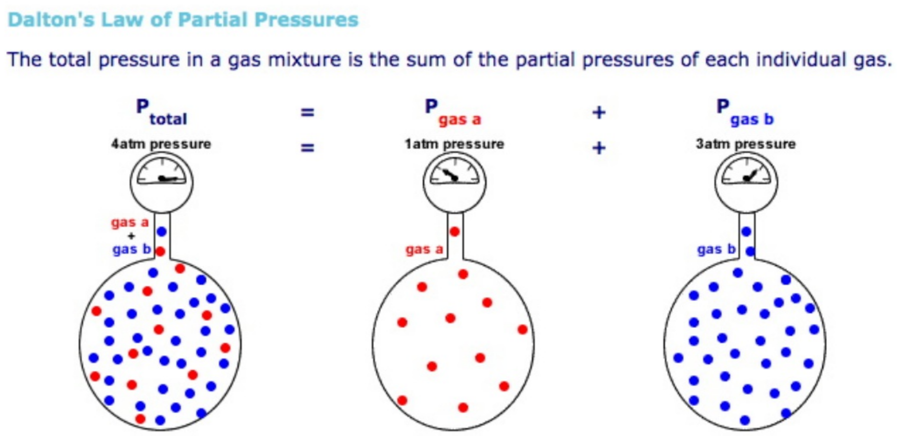
Pressure

Demo:
(1)





Gases
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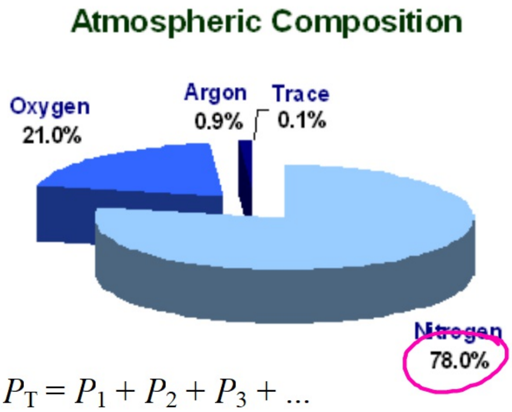
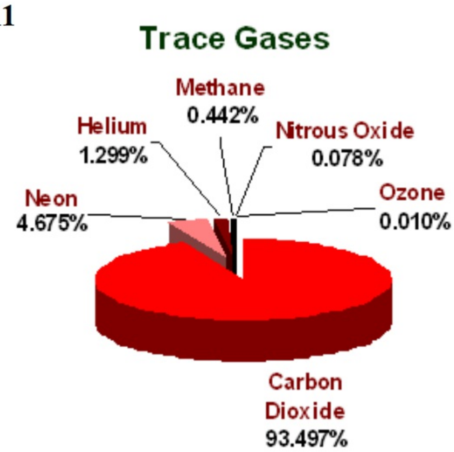
Pressure





760mmH

$P_T = P_1 + P_2 + P_3 + \ldots$

$_{O2} + P_{Ar}$ +

760mmHg = (760) (0.

P_{N2} = (760) (0.780)

P_{O2} = (760)(0.210)

P_{Ar} = (760) (0.009)

P_{other} = (760) (0.001)

P_{N2} = 592.8 mmHg
P_{O2} = 159.6 mmHg
P_{Ar} = 6.8 mmHg
P_{other} = 0.76 mmHg

P_T = 759.96 mmHg

Pressure

$$P_T = P_1 + P_2 + P_3 + \ldots$$

Dalton's Law of Partial Pressure Practice Problems

4. What is the total pressure of the system when the gaseous mixture contains 57mmHg of carbon dioxide, 381mmHg of oxygen, 82mmHg of water, and 14mmHg of methane? (Ans: 534mmHg)

Extra: What is the percent of O_2 in the mixture? If the total moles of the mixture is 18.4moles, how many moles of oxygen are in the mixture?

Gvn

$P_{CO_2} = 57$ mmHg

$P_{O_2} = 381$ mmHg

$P_{H_2O} = 82$ mmHg

$P_{CH_4} = 14$ mmHg

Ntk

$P_T = P_{CO_2} + P_{O_2} + P_{H_2O} + P_{CH_4}$

Unk

$P_T =$ 534 mmHg

Solution:

$P_T = 57 + 381 + 82 + 14 =$ **534 mmHg**

$\%O_2 = \frac{381}{534} \times 100\% = 71.3\%$

$(\%O_2)\, n_T = n_{O_2}$

$(0.713)(18.4) = 13.1$ moles O_2

Pressure

$$P_T = P_{gas} + P_{H2O}$$

5. Oxygen gas from the decomposition of potassium chlorate, $KClO_3$, was collected by water displacement. The barometric pressure and the temperature during the experiment were 731.00torr and 20.0°C, respectively. What was the partial pressure of the oxygen collected? (Ans: 713.7torr)

GVN

P_T = 731.00 torr

T = 20°C

NTK

$P_T = P_{gas} + P_{H_2O}$

UNK

P_{gas} = 713.7 torr

SOLUTION:

$731\text{ torr} = (2.3 * \frac{760}{101.3}) + P_{O_2}$

$P_{O_2} = 731 - (2.3 * \frac{760}{101.3}) = 713.7\text{ torr}$

Vapor Pressure of Water

Temperature (°C)	Pressure (kPa)	Temperature (°C)	Pressure (kPa)	Temperature (°C)	Pressure (kPa)	Temperature (°C)	Pressure (kPa)
0	0.6	18	2.1	26	3.4	50	12.3
5	0.9	20	2.3	27	3.6	60	19.9
8	1.1	21	2.5	28	3.8	70	31.2
10	1.2	22	2.6	29	4.0	80	47.3
12	1.4	23	2.8	30	4.2	90	70.1
14	1.6	24	3.0	35	5.6	100	101.3
16	1.8	25	3.2	40	7.4		

Gases
Topic#11

Pressure

$P_T = P_{gas} + P_{H2O}$

6. (OYO) Some hydrogen gas is collected over water at 20.0°C. The levels of the water inside and outside the gas-collection bottle are the same. The partial pressure of hydrogen is 742.5torr. What is the barometric pressure at the time the gas is collected? (Ans: 759.8torr)

Vapor Pressure of Water

Temperature (°C)	Pressure (kPa)	Temperature (°C)	Pressure (kPa)	Temperature (°C)	Pressure (kPa)	Temperature (°C)	Pressure (kPa)
0	0.6	18	2.1	26	3.4	50	12.3
5	0.9	20	2.3	27	3.6	60	19.9
8	1.1	21	2.5	28	3.8	70	31.2
10	1.2	22	2.6	29	4.0	80	47.3
12	1.4	23	2.8	30	4.2	90	70.1
14	1.6	24	3.0	35	5.6	100	101.3
16	1.8	25	3.2	40	7.4		

Pressure

Mole Fraction - the fraction of each part in the whole based on moles

$$X_1 = \frac{n_1}{n_T}$$

n_1 - moles of substance 1

n_T - total mole of all components

Mole fraction (*X_1*) and partial pressure (*P_1*) are directly proportional.

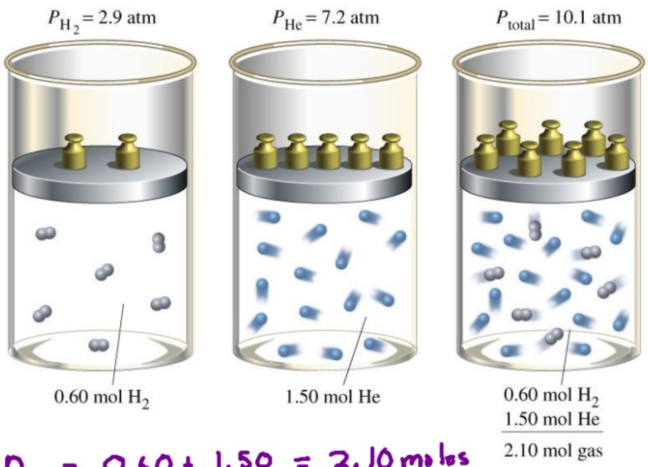
Dalton's Law:

$$P_{total} = P_1 + P_2$$

Mole Fraction:

$$\chi_1 = \frac{P_1}{P_{total}}$$

P_1 and P_2 are the partial pressures of each gas in the binary mixture.



$n_T = 0.60 + 1.50 = 2.10$ moles

$X_1 = \frac{n_1}{n_T} = \frac{0.60}{2.10} = 0.286$

$X_2 = \frac{n_2}{n_T} = \frac{1.50}{2.10} = 0.714$

$X_1 + X_2 = 1.00$

Pressure

Mole Fraction:
$X1 = n1/nT$
$n1$ - moles of substance 1
nT - total mole of all components

Dalton's Law:
$$P_{total} = P_1 + P_2$$

Mole Fraction:
$$\chi_1 = \frac{P_1}{P_{total}}$$

7. A chamber contains four gases at a pressure of 1048torr. The mixture is 4.25moles of oxygen, 0.785 moles of helium, 2.78 moles of methane, and 1.31 moles of carbon dioxide. What is the partial pressure of each gas? (Ans: O_2 = 488torr, He = 90.1torr, CH_4 = 320.torr, and 151torr CO_2)

GVN

P_T = 1048 torr
4.25 mol O_2
0.785 mol He
2.78 mol CH_4
1.31 mol CO_2

NTK

$X_a = \frac{n_a}{n_T}$; $P_a = P_T(X_a)$

n_T = 4.25 + 0.785 + 2.78 + 1.31 = 9.125

UNK

P_{O_2} = 488 torr
P_{He} = 90.1 torr
P_{CH_4} = 319 torr
P_{CO_2} = 150 torr

SOLUTION:

$X_{O_2} = \frac{n_{O_2}}{n_T} = \frac{4.25}{9.125} = 0.466(1048) = 488$ torr

$X_{He} = \frac{n_{He}}{n_T} = \frac{0.785}{9.125} = 0.086(1048) = 90.1$ torr

$X_{CH_4} = \frac{n_{CH_4}}{n_T} = \frac{2.78}{9.125} = 0.305(1048) = 319$ torr

$X_{CO_2} = \frac{n_{CO_2}}{n_T} = \frac{1.31}{9.125} = 0.144(1048) = 150$ torr

*Check:
P_T = 488 + 90.1 + 319 + 150
= 1047.1 torr ✓

Pressure

Mole Fraction:

$X_1 = n_1/n_T$

n_1 - moles of substance 1

n_T - total mole of all components

Dalton's Law:

$$P_{total} = P_1 + P_2$$

Mole Fraction:

$$X_1 = \frac{P_1}{P_{total}}$$

P_1 and P_2 are the partial pressures of each gas in the binary mixture.

8. A gas mixture is created by blending 0.2 mols CO_2, 2.0 mols O_2 and 7.8 mols N_2. If the total pressure is 750 mmHg, calculate the partial pressure of oxygen. (Ans: 150mmHg O_2)

Gvn

0.2 mol CO_2

2.0 mol O_2

7.8 mol N_2

P_T = 750 mm Hg

NTK

$\frac{n_{O_2}}{n_T} = X_{O_2}$

$P_{O_2} = (X_{O_2})(P_T)$

Unk

P_{O_2} = 150 mmHg

Solve: n_T = 0.2 + 2.0 + 7.8 = 10 moles

$\frac{n_{O_2}}{n_T} = \frac{2.0}{10} = 0.200$; P_{O_2} = (0.200)(750)

P_{O_2} = 150 mmHg

Assignment:
Topic#11 Gases

WS#2: Dalton's Law and Mole Fractior

Gas Laws

Boyle's Law

The pressure (P) of a gas and the volume (V) it occupies are inversely proportional. The number of moles (n) of the gas and temperature (T) are held constant.

$$P_1V_1 = P_2V_2$$

$P_1V_1 = k$

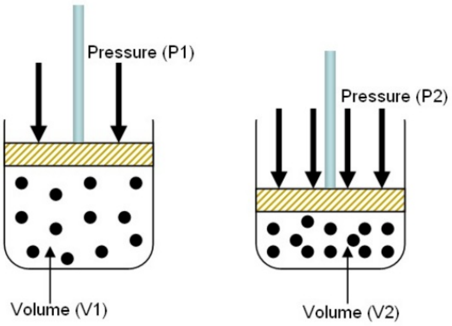
$P_2V_2 = k$

$P_3V_3 = k$

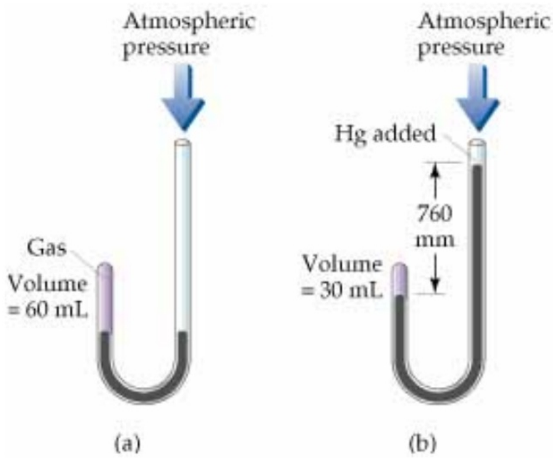
So, $P_1V_1 = P_2V_2 = P_3V_3$

Gas Laws

Boyle's Law



$$P_1V_1 = P_2V_2$$



Gas Laws

Boyle's Law

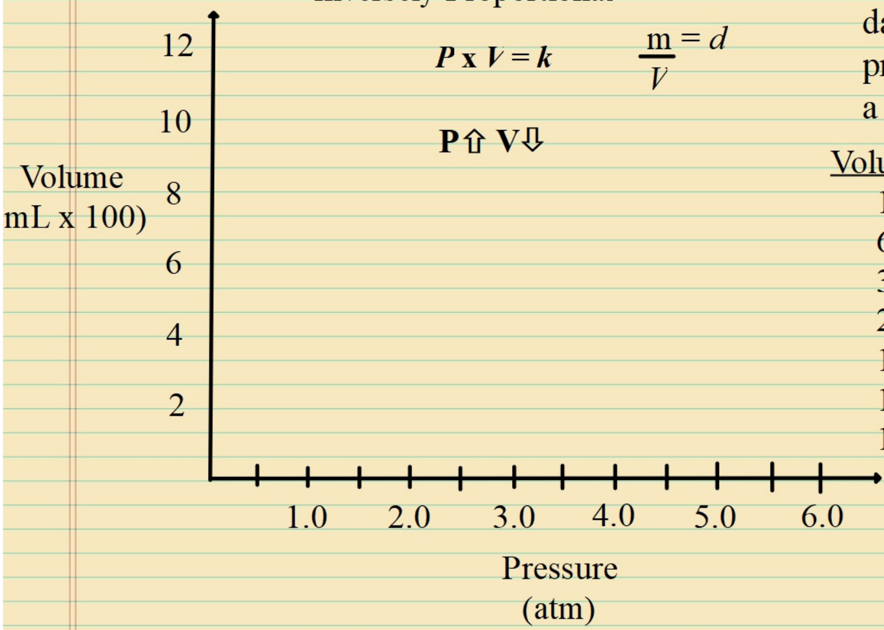
$$P_1V_1 = P_2V_2$$

Held Constant: *n* and *T*

Inversely Proportional

$P \times V = k$ $\frac{m}{V} = d$

P⇧ V⇩



Question

Please graph the follwoing data. What can be done to the *P*/*V* data to change an inverse proportion (curved) graph into a straight line?

Volume(mL)	Pressure (atm)	1/P
1200	0.5	
600	1.0	
300	2.0	
200	3.0	
150	4.0	
120	5.0	
100	6.0	

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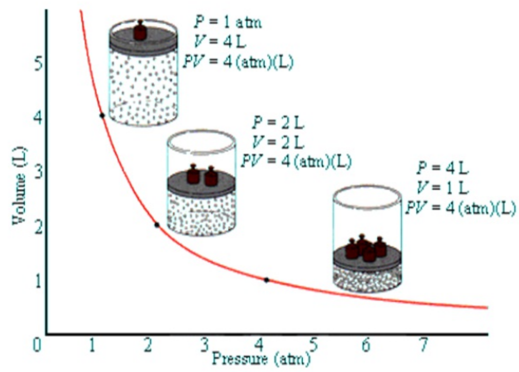
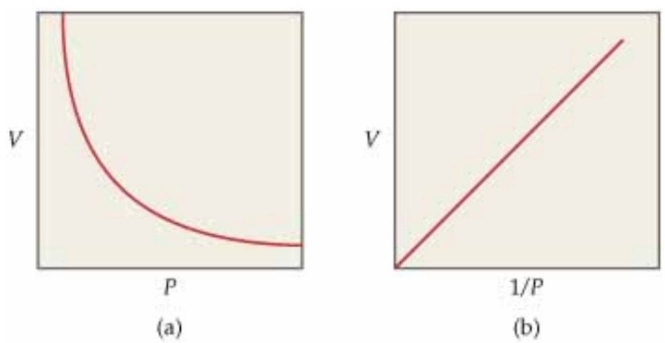
Gas Laws

Boyle's Law





Questions (Boyles Law): :

(1) What happens to the volume if the pressure is tripled?

(2) If the pressure is halved, what happens to the volume?

Gas Laws

Boyle's Law **STP -** standard temperature (0°C/273K) and pressure (1atm) $P_1V_1 = P_2V_2$

Sample WS#2- Gas Law Practice Problems

1. A sample of oxygen gas has a *V* of 150.mL when its *P* is 0.947atm. At constant *T* and *n*, what is the *V* of the gas at a *P* of 0.987atm? (Ans: 144mL)

GVN
$V_1 = 150.\text{ mL}$
$P_1 = 0.947\text{ atm}$
$P_2 = 0.987\text{ atm}$

NTK
$P_1V_1 = P_2V_2$; $V_2 = \frac{P_1V_1}{P_2}$

$V_2 =$ 144 mL

	1	2
V	150 mL	? mL
P	0.947 atm	0.987 atm

Solve:
$$V_2 = \frac{(0.947)(150)}{(0.987)}$$
$V_2 = 144\text{ mL}$

Gas Laws

Boyle's Law

STP - standard temperature (0°C/273K) and pressure (1atm) $P_1V_1 = P_2V_2$

2. (OYO) A balloon filled with He gas has a *V* of 500.mL at a *P* of 1.0atm. The balloon is released and reaches an altitude of 6.5km, where the volume is 1.5 liters. Assuming that the *T* has remained the same, what is the pressure of the gas? (Ans: 0.33atm)

	1	**2**

Gas Laws

Charles' Law

The volume (V) of a gas and the temperature (T) it occupies are directly proportional. Where pressure (P) and number of moles (n) of gas are held constant.

$$\frac{V_1}{T_1} = k$$

$$\frac{V_2}{T_2} = k$$

$$\frac{V_3}{T_3} = k$$

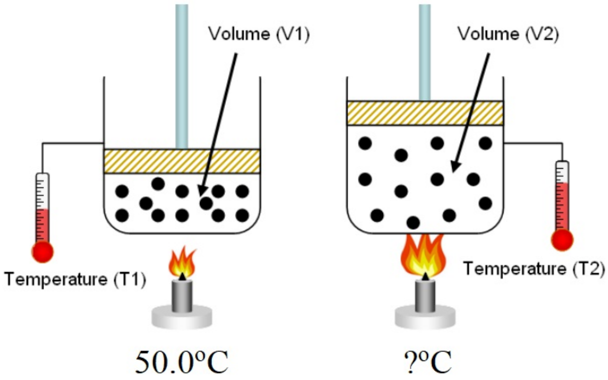
So, $\frac{V_1}{T_1} = \frac{V_2}{T_2} = \frac{V_3}{T_3}$

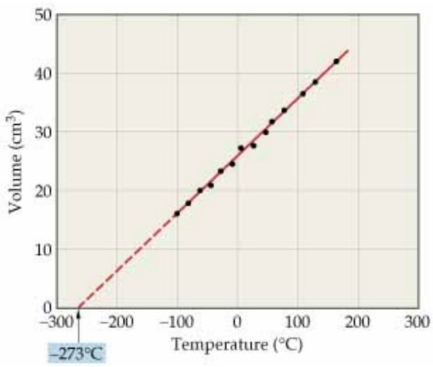
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Gas Laws

Charles' Law

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$





Gas Laws

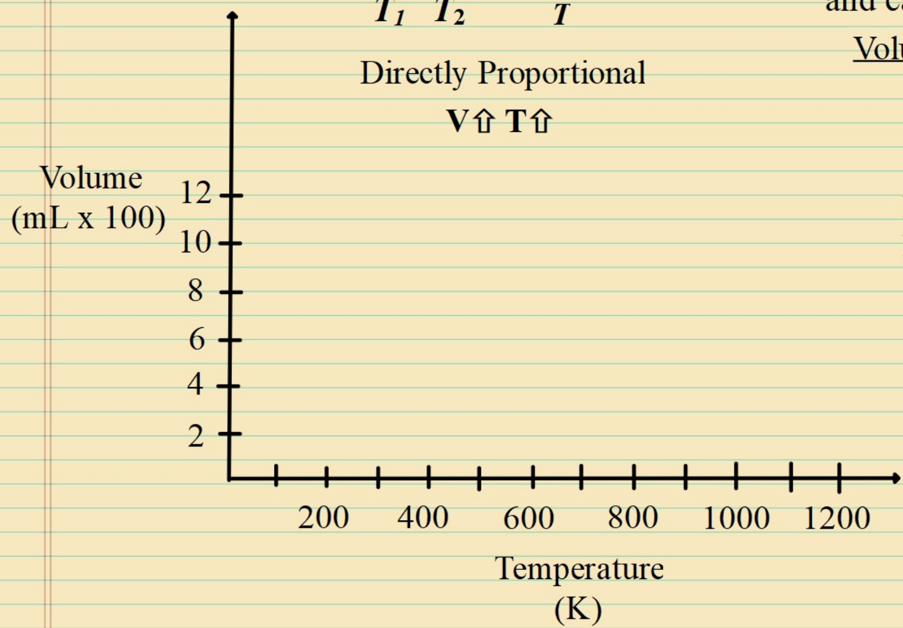
Charles' Law

Held Constant: *n* and *P*

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \qquad \frac{V}{T} = k$$

Directly Proportional

V⇧ T⇧



Question: Graph the following data and calculate the slope.

Volume(mL)	Temperature (K)
250	200
500	400
750	600
1000	800
1200	?

Gas Laws

Charles' Law

STP - 0°C/273K and pressure 1atm.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

3. A sample of neon gas occupies a *V* of 752mL at 25°C. What *V* will the gas occupy at 50°C if the *P* remains constant? (Ans: 815mL)

Gvn
$V_1 = 752mL$
$T_1 = 25 + 273 = 298K$
$T_2 = 50 + 273 = 323$

Ntk
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$
$$V_2 = \frac{V_1(T_2)}{T_1}$$

Unk
$V_2 =$ 815 mL

	1	2
V	752 mL	?
T	298 K	323 K

Solve:
$$V_2 = \frac{(752)(323)}{(298)}$$
$$= \boxed{815mL}$$

Gases
Topic#11

Gas Laws

Charles' Law

STP - 0°C/273K and pressure 1atm.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

4. (OYO) A helium filled balloon has a volume of 2.75L at 20°C. The volume of the balloon decreases to 2.46L after it is placed outside on a cold day. What is the temperature in K and °C?
(Ans: 262K, -11°C)

	1	**2**

Gas Laws

Gay-Lussac's Law

The pressure and temperature of a confined gas are directly proportional when the number of moles (n) and volume (V) are held constant.

$\frac{P_1}{T_1} = k$

$\frac{P_2}{T_2} = k$

$\frac{P_3}{T_3} = k$

So, $\frac{P_1}{T_1} = \frac{P_2}{T_2} = \frac{P_3}{T_3}$

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

Gas Laws

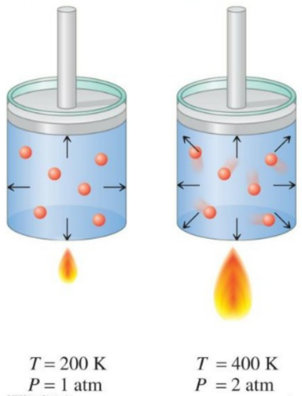
Gay-Lussac's Law

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

Gay-Lussac's Law: P and T

- the pressure exerted by a gas is directly related to the Kelvin temperature.
- V and n are constant.

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



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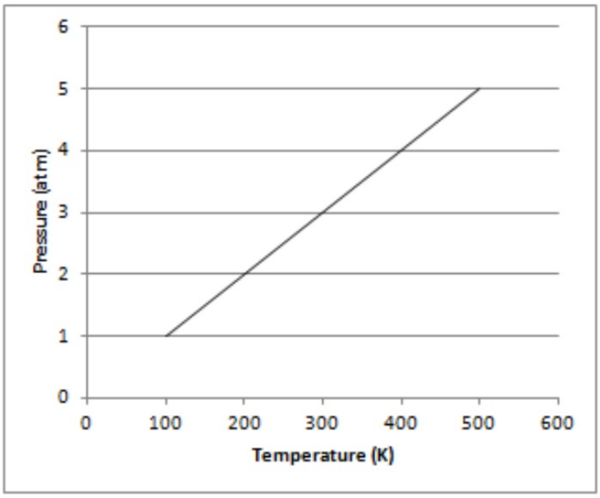
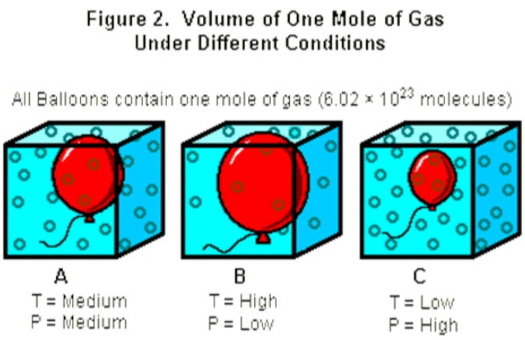


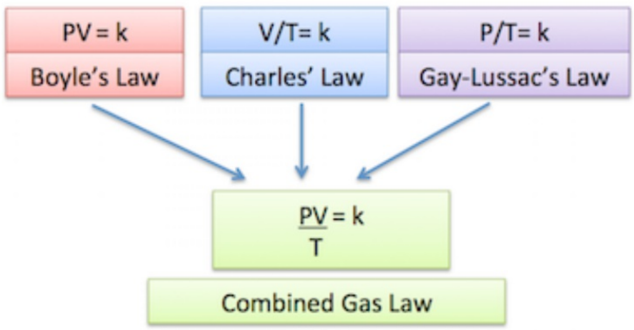
Gas Laws

Combined Gas Law

The pressure, volume, and temperature of a contained gas are related to each other when the number of moles (*n*) is held constant.

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





Gas Laws

Combined Gas Law

Combined Gas Law

Law	Variables Held Constant	Relationship	Equation
Boyle's	T, n	Inverse	$P_1V_1 = P_2V_2$
Charles's	P, n	Direct	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
Gay-Lussac's	V, n	Direct	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$
Combined	n	n/a	$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

Gas Laws

Combined Gas Law

STP - 0°C/273K and pressure 1atm.

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

5. The volume of a gas is 27.5mL at 22.0°C and 0.974atm. What will the volume be at 15.0°C and 0.993atm? (Ans: 26.3mL)

GVN

$V_1 = 27.5\ mL$

$T_1 = 273 + 22 = 295K$

$P_1 = 0.974\ atm$

$T_2 = 273 + 15 = 288K$

$P_2 = 0.993\ atm$

NTK

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ $\quad V_2 = \left(\frac{P_1V_1}{T_1}\right)\left(\frac{T_2}{P_2}\right)$

UNL

$V_2 =$ 26.3 mL

	1	**2**
P	0.974 atm	0.993 atm
V	27.5 mL	? mL
T	295 K	288 K

Solve:

$$V_2 = \frac{(0.974)(27.5)(288)}{(295)(0.993)}$$

$= 26.3\ mL$

Gas Laws

Combined Gas Law

STP - 0°C/273K and pressure 1atm.

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

6. (OYO) A 700.mL gas sample at STP is compressed to a volume of 200.mL, and the temperature is increased to 30.0°C. What is the new pressure of the gas in Pa?

(Ans: 3.94 x 10^5Pa)

	1	**2**

Gases
Topic#11

Gas Laws

Combined Gas Law

STP - 0°C/273K and pressure 1atm.

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

7. A gas is collected over water at 28°C. The total pressure of the gas collected over water is 1.89atm. If the original volume of the gas is 160.mL, what is the pressure of the gas with a volume of 80.0mL and a temperature of 89°C? (Ans: 4.45atm)

Gvn

$T_1 = 273 + 28 = 301K$

*$P_T = 1.89 = P_{gas} + P_{H_2O}$

$V_1 = 160mL$

$V_2 = 80.0mL$

$T_2 = 273 + 89 = 362K$

$P_{gas} = P_T - P_{H_2O}$
$= 1.89 - \left(\frac{3.8(1)}{101.3}\right)$
$= 1.85$

NTK

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$; $P_2 = \frac{P_1V_1}{T_1}\left(\frac{T_2}{V_2}\right)$

	1	2
P	1.85 atm	?
V	160 mL	80 mL
T	301 K	362 K

UNK

$P_2 =$ 4.45 atm

Solve:

$P_2 = \frac{(1.85)(160)(362)}{(301)(80)}$

$P_2 = 4.45atm$

Vapor Pressure of Water

Assignment:
Topic#11 Gases

WS#3: Boyle's, Charles', and Combinec
Gas Laws

Gas Laws

Questions Regarding WS#3 on Boyle's, Charles', or Combined Gas Laws?

WS#2: Boyles Law

(1) (a) 106mL (b) 48.2mL (c) 472mL
(2) 126kPa
(3) 266mL
(4) (a) $2.5x10^4$ (b) $1.7x10^4$ (c) $1.0x10^5$
(5) 2.03L
(6) 211kPa

WS#2: Charles's Law

(7) (a) $2.00x10^4$L (b) $5.00x10^3$L
(8) (a) 294.2mL (b) 67.3mL (c) 91.00mL
(9) 7.7°C (281K)

WS#2: Combined Gas Law

(10) (a) 552mL (b) 213mL (c) 111mL
(11) (a) 173mL (b) 115mL
(12) 567mL
(13) 42mL
(14) 220.8kPa

Gases
Topic#11

Avogadro's Law

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

hydrogen gas + oxygen gas --> water vapor

$2H_2(g)$ +	**$O_2(g)$**	**-->**	**$2H_2O(g)$**
2mol	**1mol**		**2mol**
2volumes +	**1volume**	**=**	**2volumes**

Sample WS#3 - Avogadros's Law Practice Problems

1. How many liters of $H_2(g)$ are needed to completely react with two liters of $N_2(g)$?

(Ans: 6 liters H_2)

GVN
2 L N_2

NTR

$$3H_2(g) + N_2(g) \rightarrow 2NH_3(g)$$

? L 2 L

UNK
V_{H_2} = 6 L

Solve: $2\text{ L } N_2 \left(\frac{(3)(H_2)}{(1)(N_2)}\right) = 6\text{ L } H_2$

Avogadro's Law

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

2. (OYO) How many liters of $CC_2(g)$ are produced if 75L of CO are burned in $O_2(g)$? How many liters of $O_2(g)$ are necessary? (Ans: 75L and 37.5L)

Molar Volume

1mol = 22.4L

Molar Volume

1 mole of any gas at STP (0°C and 1 atm) has a volume of 22.4L

Conversion factor

1mol = 22.4L

Molar Volume

3. A chemical reaction produces 0.0680 mol of $O_2(g)$. What *V* in L is occupied by this gas at STP? Ans: 1.52L

GVN: 0.0680 mol O_2

NTK: 1mol = 22.4L @ STP

UNK: V_{O_2} = 1.52 L

SOLVE: $\frac{0.0680 \text{ mol } O_2 \mid 22.4L}{\mid 1 \text{ mol}} = 1.52 \text{ L } O_2$

4. A sample of $H_2(g)$ occupies 14.1L at STP. How many moles of the gas are present? (Ans: 0.629 mol)

GVN: 14.1L H_2

NTK: 1mol = 22.4L

UNK: mol_{H_2} = 0.629 mol

SOLVE: $\frac{14.1L\ H_2 \mid 1mol}{\mid 22.4L} = 0.629 \text{mol } H_2$

<u>Molar Volume</u>

1mol = 22.4L

5. (OYO) At STP, a sample of Neg) occupies 550.cm^3. How many moles of Ne(*g*) does this represent?
(Ans: 0.0246 mol)

Molar Volume

1mol = 22.4L

Molar Volume Practice Problems

6. Find the mass of sugar ($C_6H_{12}O_6$) required to produce 1.82L of carbon dioxide gas at STP from the reaction described by the following equation. $C_6H_{12}O_6(s) \rightarrow C_2H_6O(s) + CO_2(g)$ (Ans: 7.32g $C_6H_{12}O_6$)

GVN: 1.82L CO_2

NTK: $C_6H_{12}O_6 \rightarrow 2C_2H_6O + 2CO_2$

? g ($C_6H_{12}O_6$) … 1.82L (CO_2)

MM = 180.18 g/mol

UNK: mass ($C_6H_{12}O_6$) = 7.32 g

SOLVE:

$$\frac{1.82\text{L } CO_2}{} \times \frac{1\text{ mol}}{22.4\text{L}} \times \frac{C_6H_{12}O_6}{2CO_2} \times \frac{180.18\text{g}}{\text{mol}} = 7.32\text{g } C_6H_{12}O_6$$

Liters → moles (gas) → mole ratio → * MM → grams of unknown

Molar Volume

1mol = 22.4L

7. (OYO) How many liters of oxygen are necessary for the combustion of 425g of sulfur, assuming that the reaction occurs at STP? $S_8(s) + O_2(g) \rightarrow SO_2(g)$ (Ans: 297L O_2)

Assignment:
Topic#11 Gases

WS#4: Molar Volume

Gases
Topic#11

<u>Molar Volume</u>

1mol = 22.4L

Questions Regarding WS#4 on Molar Volume?

Ideal Gas Law

Ideal Gas

- Follows Kinetic Molecular Theory (KMT)
- 100% elastic collisions, no attraction to anything, T and KE are directly proportional, gas particles have no volume, and particles are in fast, constant, random motion.)

$$PV = nRT$$

Prove: 1mol = 22.4L and R = 0.0821

STP
n = 1mol
V = 22.4L
P = 1atm
T = 273K

$PV = nRT$

$$R = \frac{PV}{nT} = \frac{(1)(22.4)}{(1)(273)} \frac{atm \cdot L}{mol \cdot K}$$

$= 0.082051282$

= 0.0821 (P is in atm)
8.31 (P is in kPa)
62.4 (P is in mmHg or torr)

Ideal Gas Law

$PV = nRT$

Sample WS#4 - Ideal Gas Law

1. What is the volume, in liters, of 0.250mol of oxygen gas at 20.0°C and 0.974atm of pressure? (Ans: 6.17L)

GVN
$P = 0.974$ atm
* $V = ?$ L
$n = 0.250$ mol
* $R = 0.0821$
* $T = 20.0 + 273 = 293$ K

NTK
$PV = nRT$
$V_{O_2} = \frac{nRT}{P}$

UNK
$V_{O_2} =$ 6.17 L

Solve:
* V in liters
* P in atm
* T in Kelvins

$V_{O_2} = \frac{nRT}{P} = \frac{(0.250)(0.0821)(293)}{(0.974)}$

$V_{O_2} = \boxed{6.17 L}$

Gases
Topic#11

Ideal Gas Law

$$PV = nRT$$

2. (OYO) What is the P in atmospheres exerted by 0.500mol sample of nitrogen gas in a 10.0L container at 298K? (Ans: 1.22atm)

Ideal Gas Law

PV = nRT

3. What mass of chlorine gas in grams, is contained in a 10.0L tank at 27°C and 3.50atm of pressure?

(Ans: 101g Cl_2)

GUN

$P = 3.50\text{ atm}$

$V = 10.0L$

$n = g/MM$

$R = 0.0821$

$T = 27 + 273 = 300K$

NTK

$PV = nRT$ $\quad MM_{Cl_2} = 70.90\ g/mol$

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

$g/MM = \frac{PV}{RT}$; $g = \frac{PVMM}{RT}$

UNK

$mass_{Cl_2}$: 101 g

SOLVE:

$$g = \frac{(3.50)(10)(70.90)}{(0.0821)(300)}$$

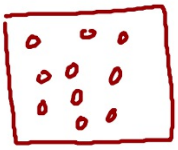
$$g = 100.75\,g = \boxed{101\,g\ Cl_2}$$

Gases
Topic#11

Gas Density

$d = m/V$

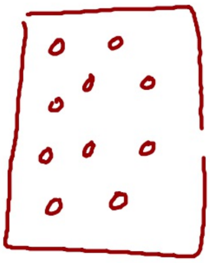
1 atm
273 K



$d_{CO_2} = 2.70 \text{ g/L}$

$\frac{2.70\text{g}}{1\text{L}}$

1 atm
273 K



$PV = nRT$

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

$\frac{PmmV}{RT} = g$

$\frac{P \times mm}{R \times T} = \frac{g}{V} = d_{gas}$

$\frac{MM \text{x} PV}{RT} = \text{g}$

$\frac{MM \text{ x } P}{R \text{ x } T} = \text{g/V} = d$

$PV = nRT$

$PV = \text{g}/MM \text{ x } R \text{ x } T$

$\frac{PV}{RT} = \text{g}/MM$

Gas Density

$$d_{gas} = \frac{g}{V} = \frac{MM \times P}{R \times T}$$

Gas Density Practice Problems

4. At 28°C and 0.974atm, the density of a gas is 5.15g/L. What is the molar mass of this gas?

(Ans: 131g/mol)

GVN

d_{gas} = 5.15 g/L

T = 28 + 273 = 301 K

P = 0.974 atm

R = 0.0821

NTK

$$d = \frac{g}{V} = \frac{P \times MM}{R \times T}$$

UNK

MM = 131 g/mol

SOLVE:

$$\frac{5.15}{1} = \frac{(0.974)(MM)}{(0.0821)(301)}$$

$$MM = \frac{(5.15)(0.0821)(301)}{(1)(0.974)}$$

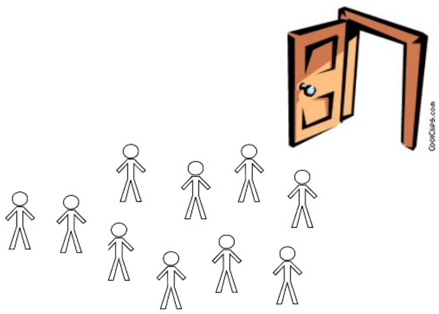
MM = 130.66 = 131 g/mol

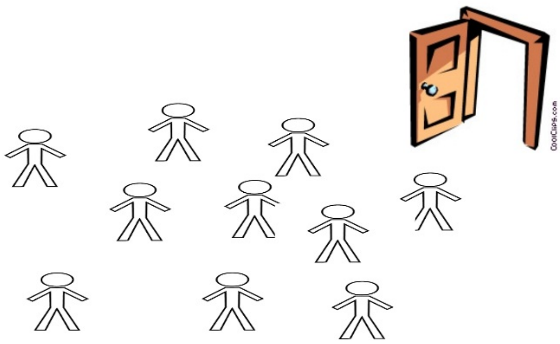
Gas Density

$$d_{gas} = \frac{g}{V} = \frac{MM \times P}{R \times T}$$

5. (OYO)What is the *density* of a sample of ammonia gas, NH_3, if the *P* is 0.928atm and the *T* is 63.0°C? (Ans: 0.573g/L NH_3)

Graham's Law





Graham's Law

UF_6 = 352g/mol
HF = 20.01g/mol

Talk about the gases in the room:

Mass of each gas?
Speed of each gas?
Temperature of gases?
Compare smart car to semi.
What about KE of the gases in the room?
KMT?
What is the formula for KE?
Baseball bat and baseball.
Ex: Speed of HF vs. UF_6.

$$\frac{rate_A}{rate_B} = \sqrt{\frac{mm_B}{mm_A}}$$

Derivation of Graham's Law Equation

KE = 1/2mv[2]

@Same T

$$KE_{H_2} = \frac{1}{2}mv^2$$

$$KE_{UF_6} = \frac{1}{2}mv^2$$

$$KE_{H_2} = KE_{UF_6}$$

$$\frac{1}{2}m_{H_2}v_{H_2}^2 = \frac{1}{2}m_{UF_6}v_{UF_6}^2$$

$$\sqrt{\frac{v_{H_2}^2}{v_{UF_6}^2}} = \sqrt{\frac{m_{UF_6}}{m_{H_2}}}$$

$$\frac{v_{H_2}}{v_{UF_6}} = \sqrt{\frac{mm_{UF_6}}{mm_{H_2}}}$$

Graham's Law

Diffusion - the movement of a gas through another gas (or a liquid/solid through a liquid/solid).
Effusion - the movement of gaseous particles through a small hole.

Graham's Law of Effusion

- the rate a gas moves (effusion) through a small hole is inversely proportional to the square root *MM* of the gases at constant *T* and *P*.

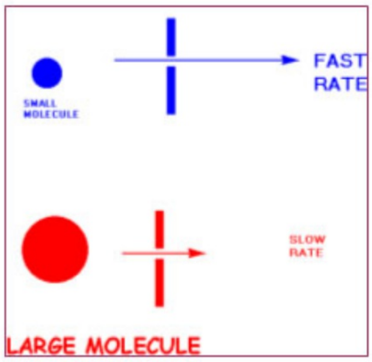
$$\frac{Rate_A}{Rate_B} = \sqrt{\frac{Molar\ Mass_B}{Molar\ Mass_A}}$$

Graham's Law of Diffusion

$$\frac{v_1}{v_2} = \sqrt{\frac{m_2}{m_1}}$$

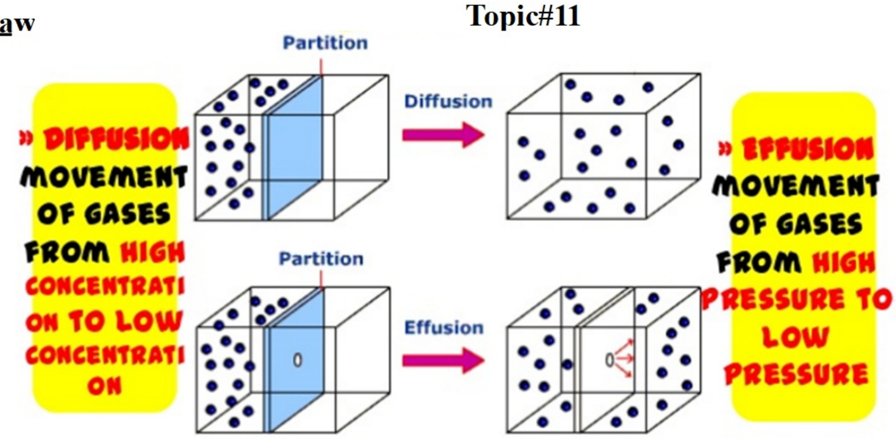
Where v is velocity of molecules and m is molecular mass of the molecules.

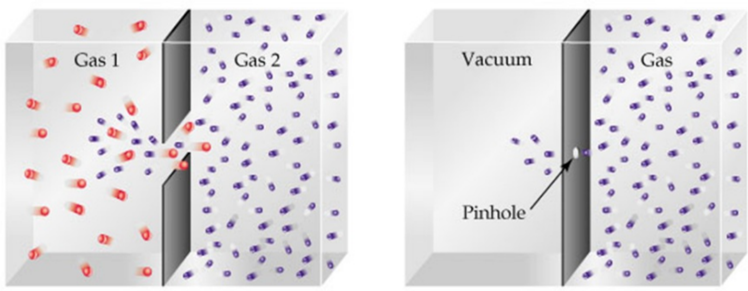
Figure 5.6.2 This Figure demonstrates Graham's Law.



http://www.cat.cc.md.us

Graham's Law





(a) (b)

<u>Graham's Law</u>

$$\frac{Rate_A}{Rate_B} = \sqrt{\frac{Molar\ Mass_B}{Molar\ Mass_A}}$$

<u>Graham's Law Practice Problems</u>

6. Compare the rates of effusion of hydrogen (A) and oxygen (B). (Ans: 3.98)

Gvn
Gas$_A$ H_2 (2.02)
Gas$_B$ O_2 (32.00)

NTK

$$\frac{rate_A \ (m/s)}{rate_B \ (m/s)} = \sqrt{\frac{MM_B}{MM_A}} = \sqrt{\frac{32.00}{2.02}} = \boxed{3.98 : 1}$$

10sec
H_2 ⟶
O_2 →

10m Dash

H_2: $10\,m \times \frac{1s}{3.98m} = 2.51\,sec$

O_2: $10\,m \times \frac{1s}{1m} = 10\,sec$

Gases
Topic#11

Graham's Law

$$\frac{Rate_A}{Rate_B} = \sqrt{\frac{Molar\ Mass_B}{Molar\ Mass_A}}$$

7. A sample of hydrogen effuses through a porous container 9.0 times faster than an unknown gas. Estimate the molar mass of the unknown gas. (Ans: 160g/mol)

Gvn

Gas_A H_2 (2.02)

Gas_B ? (?)

NTK

$$\frac{rate_A}{rate_B} = \sqrt{\frac{MM_B}{MM_A}}$$

Solve:

$$\left(\frac{9}{1}\right)^2 = \left(\sqrt{\frac{MM_B}{2.02}}\right)^2$$

$$2.02\left(\frac{81}{1}\right) = MM_B$$

$$MM_B = 160\ g/mol$$

Graham's Law

$$\frac{Rate_A}{Rate_B} = \sqrt{\frac{Molar\ Mass_B}{Molar\ Mass_A}}$$

8. (OYO) Compare the rate of effusion of carbon dioxide with that of hydrogen chloride at the same temperature and pressure. (Ans: CO_2 0.9 times as fast as HCl)

Graham's Law

$$\frac{Rate_A}{Rate_B} = \sqrt{\frac{Molar\ Mass_B}{Molar\ Mass_A}}$$

9. If a molecule of neon gas travels at an average of 400.m/s at a given *T*, estimate the average speed of a molecule of butane gas, C_4H_{10}, at the same *T*. (Ans: 235 m/s)

Gvn

Gas_A Ne (20.18)

Gas_B C_4H_{10} (58.14)

NTK

$$\frac{rate_A}{rate_B} = \sqrt{\frac{MM_B}{MM_A}}$$

Solve

$$\frac{400\ m/s}{rate_B} = \sqrt{\frac{58.14}{20.18}} = 1.70$$

$$rate_B = \frac{400}{1.70} = \boxed{235\ m/s}$$

Graham's Law

$$\frac{Rate_A}{Rate_B} = \sqrt{\frac{Molar\ Mass_B}{Molar\ Mass_A}}$$

Assignment:

Topic#11 Gases

WS#5: Ideal Gas Law, Density, and
Graham's Law

Gases
Topic#11

<u>Graham's Law</u>

$$\frac{Rate_A}{Rate_B} = \sqrt{\frac{Molar\ Mass_B}{Molar\ Mass_A}}$$

Questions Regarding WS#5 on Ideal Gas Law, Density, and Graham's Law?

Gas Stoichiometry

Sample WS#5 - Gas Stoichiometry

1. Propane, C_3H_8, is a gas that is sometimes used as a fuel for cooking and heating. The complete combustion occurs according to the following reaction:

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

a. What is the volume, in liters, of oxygen required for the complete combustion of 0.350L of propane? (Ans: 1.75L O_2)

Gvn: 0.350L C_3H_8, Assume STP

NTK: equation

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

Solve: $\frac{0.350L\ C_3H_8 \times 5\ O_2}{1\ C_3H_8} = 1.75\ L\ O_2$

b. What will be the volume of carbon dioxide produced in the reaction? (Ans: 1.05L CO_2)

Solve: $\frac{0.350L\ C_3H_8 \times 3\ CO_2}{1\ C_3H_8} = 1.05L\ CO_2$

Gas Stoichiometry * (s) or (l) to gas

Gas Stoichiometry Practice Problems

2. Tungsten, W, a metal used in light-bulb filaments, is produced industrially by the reaction of tungsten (VI) oxide with hydrogen. $WO_3(s) + H_2(g) \rightarrow W(s) + H_2O(l)$ (unbalanced).

   a. How many liters of hydrogen gas at 35°C and 0.980atm are needed to react completely with 875g of tungsten (VI) oxide? (Ans: 292L H_2)

Given:

P = 0.980 atm

V = ? H_2

n = ? H_2

R = 0.0821

T = 273 + 35 = 308K

$m_{(s)}$ = 875g WO_3

$WO_3 + 3H_2 \rightarrow W + 3H_2O$

875g, ?L

MM = 231.85g/mol

Solve:

875g WO_3	1 mol	3 H_2
	231.85g	1 WO_3

= 11.32 moles H_2

Use PV=nRT to calculate V_{H_2}:

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

$$= \frac{(11.32)(0.0821)(308)}{(0.980)} = 292 \text{ L } H_2$$

Gas Stoichiometry

b. How many grams of tungsten can be produced with 349mL of hydrogen gas at 35°C and 0.980atm of pressure? (Ans: 0.829g W)

Gvn

P = 0.980 atm
V = 349mL = 0.349 L
n = ? H_2
R = 0.0821
T = 273+35 = 308K

NTK

$WO_3 + 3H_2 \rightarrow W + 3H_2O$

349mL H_2; ?g W (MM_W = 183.85 g/mol)

Unk

$mass_W$ = ____ g

Solve: $n_{H_2} = \frac{PV}{RT} = \frac{(0.980)(0.345)}{(0.0821)(308)}$ = **0.01353 moles H_2**

Use n_{H_2} to solve for $mass_W$: $\frac{0.01353 \text{ mol } H_2}{} \cdot \frac{1 W}{3 H_2} \cdot \frac{183.85g}{mol}$ = **0.829g W**

Gas Stoichiometry

3. (OYO) Assume that 13.5 grams of solid aluminum react with HCl(*aq*) according to the following equation at STP: $2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$
    a. How many moles of Al react? (0.5 moles)
    b. How many moles of H_2 are produced? (0.75 moles)
    c. How many liters of H_2 are produced? (16.8L)

Gas Stoichiometry

4. (OYO) If 45.0L of natural gas, CH_4, undergoes complete combustion at 730mmHg and 20.0°C, how many grams of each product are formed?

$CH_4(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$ (Ans: 79.1g CO_2 and 64.8g H_2O)