Name _____ Chemistry ___/___/___

Combined Gas Law, Ideal Gas Law & Graham's Law

Combined Gas Law

The first law for today is the **Combined Gas Law**. As the name implies, this law combines a number of the laws we studied earlier, specifically Boyle's Law, Charles' Law and Gay-Lussac's Law. The formula for the Combined Gas Law is:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Again**, it is of the utmost importance that matching variables have the same units**; meaning, if the initial pressure is in atm and the final pressure is torr, you have to convert one of the variables so that it matches the other. The same is true about volume. Temperature must always be in Kelvin.

Lets try a sample problem. The volume of a gas-filled balloon is 30.0 L at 40 ºC at 150 kPa pressure. What volume will the balloon have at standard temperature and pressure (STP)?

Standard temperature is 0 ºC; standard pressure is 101.3 kPa.

P_1: 150 kPa
V_1: 30.0 L
T_1: 40 ºC + 273 = 313 K

P_2: 101.3 kPa
V_2: X
T_2: 0 ºC + 273 = 273 K

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{(150)(30.0)}{313} = \frac{(101.3)(X)}{273}$$

$$(150)(30)(273) = (101.3)(X)(313)$$

$$1228500 = 31706.9\,X$$

38.7 L = X

Ideal Gas Law

So far we have only looked at changing the variables temperature, pressure and volume. We have not looked at the amount of gas being used. In chemistry we measure amount in moles. Yep, moles; but don't worry. This is law is just as easy as the rest. The formula we will use for the ideal gas law is: **PV = nRT**

P: pressure, can be in kPa or atm
V: volume, must be in liters (L) or cubic decimeters (dm^3) – both units mean the same thing
n: moles
R: ideal gas constant = 8.31 (L kPa) / (mol K) or 0.0821 (L atm) / (mol K)
T: temperature, must be in Kelvin

Please note that if your pressure is in kPa, you MUST use 8.31(L kPa) / (mol K) as your value for R. If your pressure is in atm you MUST use 0.0821 (L atm) / (mol K) as your value for R.

Lets try a sample problem. You fill a rigid steel cylinder with a volume of 20.0 L with nitrogen gas to a final pressure of 20,000 kPa at 27 ºC. How many moles of N_2 gas does the cylinder contain? How many grams of N_2 are in the container?

P: 20,000 kPa
V: 20.0 L
n: X
R: 8.31 L kPa/mol K
T: 27 ºC + 273 = 300 K

PV = nRT
(20,000)(20) = (X)(8.31)(300)
400,000 = 2493 X
160.4 moles = X

To change our answer from moles to grams we have to multiply by the molar mass. (When going from grams to moles you would divide by the molar mass.)
N_2: 2 x 14.0 = 28.0 g/mol
160.4 x 28.0 = **4491.2 grams**

Graham's Law of Effusion

Graham's Law is named for Scottish chemist Thomas Graham (1805 – 1869). Graham studied rates of **effusion**, *which occurs as a gas escapes through a tiny hole in a container of gas*. Graham observed that the lower the molecular mass, the faster the gas effused. Further investigation led to **Graham's Law of Effusion**: *the rate of effusion is inversely proportional to the square root of its molar mass*. Later, it was found that this law was also applicable to **diffusion,** *the tendency of molecules and*

ions to move from an area of high concentration to areas of low concentration until the concentration is uniform throughout the system. An example of **diffusion** would be breaking a bottle of cologne and having the smell spread throughout the room. An example of **effusion** would be a gas pouring out of a hole in a balloon or tire.

The formula for Graham's Law is**:** $\mathbf{Rate_A / Rate_B = \sqrt{molar\ mass_B} / \sqrt{molar\ mass_A}}$

Example: Compare the rates of effusion of nitrogen and helium. If helium takes 20 seconds to effuse, how long will it take for nitrogen to effuse?

Substance A: He: molar mass = 4.0 grams
Substance B: N_2: molar mass = 28.0 grams
(Hint: Always call your lighter molecule Substance A)

$\mathbf{Rate_A / Rate_B = \sqrt{molar\ mass_B} / \sqrt{molar\ mass_A}}$

$Rate_A / Rate_B = \sqrt{28.0} / \sqrt{4.0}$
$Rate_A / Rate_B = 5.3 / 2.0$
$\mathbf{Rate_A / Rate_B = 2.7}$
Helium effuses 2.7 times faster than nitrogen at the same temperature.
20 seconds x 2.7 = **54 seconds. N_2 takes 54 seconds to effuse.**

Homework:

Combined Gas Law: Fill in the missing information.

1. What formula is used for the combined gas law?

	P_1	V_1	T_1	P_2	V_2	T_2
2	1.5 atm	3.0 L	20 ºC	2.5 atm		30 ºC
3	720 torr	256 mL	25 ºC		250 mL	50 ºC
4	600 mm Hg	2.5 L	22 ºC	760 mm Hg	1.8 L	
5		750 mL	0 ºC	2.0 atm	500 mL	25 ºC
6	95 kPa	4.0 L		101 kPa	6.0 L	471 K
7	650 torr		100 ºC	900 torr	225 mL	150 ºC
8	850 mm Hg	1.5 L	15 ºC		2.5 L	30 ºC
9	125 kPa	125 mL		100 kPa	100 mL	75 ºC

10. The volume of a gas-filled balloon is 50.0 L at 20 ºC and 742 torr. What volume will it occupy at standard temperature and pressure (STP)?

11. 15.00 liters of gas at 45.0 ºC and 800 torr is heated to 400 ºC and the pressure changed to 300 torr. What is the new volume?

Ideal Gas Law

1. What is the ideal gas law formula?

2. What does each letter in the formula represent?

3. What are the two values for R?

4. How many moles of oxygen gas will occupy a volume of 2.5 liters at 1.2 atm and 25 ºC?

5. What volume will 2.0 moles of nitrogen gas occupy at 720 torr and 20 ºC?

6. What pressure will be exerted by 25 grams of carbon dioxide at a temperature of 25 ºC and a volume of 500 mL?

7. At what temperature will 5.0 grams of Cl_2 exert a pressure of 900 torr at a volume of 750 mL?

8. What is the volume of 2 moles of NH_3 at STP?

9. What is the mass of 3.2 liters of oxygen at STP?

10. How many moles of nitrogen gas will occupy a volume of 347 mL at 6680 torr and 25 ºC?

11. What volume will 454 grams of hydrogen gas occupy at 1.05 atm and 25 ºC?

12. Find the number of grams of CO_2 that exert a pressure of 785 torr at a volume of 32.5 L and a temperature of 32 ºC?

13. At what pressure will 4.8 moles of fluorine gas have a volume of 60.0 liters and a temperature of 298K?

Graham's Law

1. What is Graham's Law?

2. What is effusion?

3. Give an example of effusion.

4. What is diffusion?

5. Give an example of diffusion.

6. What is the formula used to calculate Graham's Law?

7. Under the same conditions of temperature and pressure, how many times faster will hydrogen effuse compared to carbon dioxide?

8. If the carbon dioxide in problem 7 takes 32 seconds to effuse, how long will hydrogen take?

9. What is the rate of diffusion of NH_3 compared to He? Does NH_3 effuse faster or slower than He?

10. If the He in problem 9 takes 20 seconds to effuse, how long will NH_3 take?

11. An unknown gas diffuses 0.25 times as fast as He. What is the molecular mass of the unknown gas?

12. Hydrogen sulfide, H_2S, has a very strong rotten egg odor. H_2S particles travel at about 650 m/s. Methyl salicylate, $C_8H_8O_3$, has a wintergreen odor and benzaldehyde, C_7H_6O has an almond odor. Calculate the rates of diffusion for both methyl salicylate and benzaldehyde