HONORS CHEMISTRY

UNIT 06: Gases

General properties and kinetic theory

Gases are made up of particles that have (relatively) large amounts of energy. A gas has no definite shape or volume and will expand to fill as much space as possible. As a result of the large amount of empty space in a volume of gas, gases are easily compressed.

Pressure

A pressure is exerted when the gas particles collide with the walls of any container it is held in. Pressure can be measured in a number of units, for example;

1.00 atm = 760. mmHg = 760. Torr

Task 6a

Perform the following conversions

1 657 mmHg to atm
2. 830 torr to atmospheres

Kinetic theory

The Kinetic theory is the basis for many properties of gases. The five postulates are;

1. Gases are composed of tiny particles (atoms or molecules) whose size is negligible compared to the average distance between them. This means that the volume of the **actual individual particles** in a gas can be assumed to be negligible compared to the volume of the container, and therefore the total volume that the gas fills is almost all empty space. The observation that gases are compressible agrees with the assumption that the actual gas particles have a small volume compared to the total volume (the volume of the container).

2. The gas particles move randomly, in straight lines in all directions and at various speeds.

3. The forces of attraction or repulsion between two gas particles are extremely weak or negligible, except when they collide.

4. When particles collide with one another, the collisions are elastic (no kinetic energy is lost). The collisions with the walls of the container create the gas pressure. Elastic collisions agree with the observation that gases, when left alone in a container, do not seem to lose energy and do not spontaneously convert to the liquid.

5. The average kinetic energy of a molecule is proportional to the Kelvin temperature and as a result, **all calculations involving gases should be carried out with temperatures converted to K**. (Using Kelvin eliminates the problem of negative temperatures leading to negative energies and negative volumes etc.)

These assumptions have limitations. For example, gases can be liquefied if cooled enough. This means "real" gas particles DO attract one another to some extent; otherwise the particles would never stick to one another and therefore never condense to form a liquid.

Pressure and Volume relationships: Boyle's Law

Boyle's Law states that, at constant temperature, pressure is inversely proportional to volume. This means that as the pressure increases the volume decreases and vice versa.

$$P\ V = \text{a constant}$$

This makes sense. If the volume is increased the gas particles collide with the walls of the container less often and the pressure is reduced.

If we know the volume and pressure of a gas at a given temperature, and then volume or pressure is changed, Boyle's law allows us to calculate the new volume or pressure by applying the simple relationship below.

$$P_1\ V_1 = P_2\ V_2$$

P_1 and V_1 are the original conditions and P_2 and V_2 are the new conditions.

Task 6b

1. ***If a 1.23 L sample of a gas at 53.0 torr is put under pressure up to a value of 240. torr at a constant temperature, what is the new volume?***

2. ***The pressure on a 411 mL sample of gas is decreased from 812 mmHg to 790 mmHg. What will the new volume of the gas be?***

Volume and Temperature relationships: Charles' Law

Charles' Law states that, at constant pressure, volume is directly proportional to temperature. This means the volume of a gas increases with increasing temperature and vice versa.

$$\frac{V}{T} = \text{a constant}$$

This makes sense. If the temperature is increased the gas particles gain kinetic energy, move around more and occupy more space.

If we know the volume and temperature of a gas at a given pressure, and then volume or temperature is changed, Charles' law allows us to calculate the new volume or temperature by applying the simple relationship below.

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

V_1 and T_1 are the original conditions and V_2 and T_2 are the new conditions.

Task 6c

1. ***An 11.0 L sample of a gas is collected at 276 K and then cooled by 14 K. The pressure is held constant at 1.20 atm. Calculate the new volume of the gas.***

2. ***A gas has a volume of 0.572 L at 35.0 ^{o}C and 1.00 atm pressure. What is the temperature inside a container where this gas has a volume of 0.535 L at 1.00 atm?***

Volume and Moles relationships: Avogadro's Law

Avogadro's Law states that, at constant temperature and pressure, volume is directly proportional to the number of moles of gas present. This means the volume of a gas increases with increasing number of moles and vice versa.

$$\frac{V}{n} = \text{a constant}$$

This makes sense. As more moles of a gas are placed into a container if conditions of temperature and pressure are to remain the same, the gas must occupy a larger volume.

If we know the volume and number of moles of a gas at a given temperature and pressure and then volume or the number of moles is changed, Avogadro's law allows us to calculate the new volume or number of moles by applying the simple relationship below.

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

V_1 and n_1 are the original conditions and V_2 and n_2 are the new conditions.

Task 6d

1. ***A 13.1 L sample of 0.502 moles of O_2 is held under conditions of 1.00 atm and 25.0 °C. If all of the O_2 is then converted to Ozone (O_3) what will be the volume of ozone?***

2. ***If 2.11 g of Neon gas occupies a volume of 12.0 L at 28.0 °C. What volume will 6.58 g of Neon occupy under the same conditions?***

Pressure and Temperature relationships: Gay-Lussac's Law

Gay-Lussac's Law states that, at constant volume, pressure is directly proportional to temperature. This means that temperature increases with increasing pressure and vice versa.

$$\frac{P}{T} = \text{a constant}$$

This makes sense. If the temperature of a gas is raised then the particles will have more energy and collisions with the walls of the container will be more forceful and the pressure will increase.

If we know the pressure and temperature of a gas at a given volume and then pressure or the temperature is changed, Gay-Lussac's law allows us to calculate the new pressure or temperature by applying the simple relationship below.

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

P_1 and T_1 are the original conditions and P_2 and T_2 are the new conditions.

Task 6e

1. ***A gas at 25^{o}C in a closed container has its pressured raised from 150. atm to 160. atm. What is the final temperature of the gas?***

2. ***A gas exerts a pressure of 900 mmHg at 20^{o}C. What temperature would be required to lower the pressure to 1.00 atm?***

The Ideal Gas Law

The combination of laws above leads to the formulation of the Ideal Gas Law. Most gases obey this law at temperatures above 273 K and at pressures of 1.00 atm or lower.

$$PV = nRT$$

R = the universal gas constant = 0.0821 L atm K^{-1} mol^{-1}.

This equation is useful because it can be manipulated to include other variables.

For example, n can be replaced by $\frac{\text{mass}}{\text{molar mass}}$ and then manipulated further to include density.

In addition to the Ideal gas equation other equations can be derived such as the General Gas equation

$$\frac{P_1 V_1}{n_1 T_1} = \frac{P_2 V_2}{n_2 T_2}$$

If the number of moles of gas in an experiment is constant (frequently the case) the expression becomes the Combined Gas Law equation;

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

Task 6f

1. ***Assuming ideal behavior, how many moles of Helium gas are in a sample that has a volume of 8.12 L at a temperature of 0.00 ^oC and a pressure of 1.20 atm?***

2. ***A sample of aluminum chloride weighing 0.100 g was vaporized at 350. ^oC and 1.00 atm pressure to produce 19.2 mL of vapor. Calculate a value for the Molar Mass of aluminum chloride.***

Dalton's Law of Partial Pressures

Dalton's Law states that in a mixture of gases the total pressure exerted by the mixture is equal to the sum of the individual partial pressures of each gas.

$$P_{total} = P_1 + P_2 + P_3 \text{ etc.}$$

Assuming ideal behavior the equation can be simplified to;

$$P_{total} = n_{total}\left(\frac{RT}{V}\right)$$

Task 6g

1. ***Calculate the number of moles of Hydrogen present, in a 0.641 L mixture of Hydrogen and water vapor, at 21.0 ^{o}C, that has a total pressure of 750. torr, given that the vapor pressure of water at this temperature is 20.0 torr.***

2. ***3.00 L of Carbon monoxide gas at a pressure of 199. kPa, and 1.00 L of Carbon dioxide gas at a pressure of 300. kPa are injected into a 1.25 L container. Assuming no reaction between the two gases, what is the total pressure in the container?***

Molar Volume and gas stoichiometry

We have seen how Avogadro's law states that equal volumes of all gases at constant temperature and pressure will contain equal numbers of moles. The volume of one mole of any gas is called its molar volume and can be calculated using the ideal gas equation.

$$PV = nRT$$

By applying the data, pressure (P) = 1.00 atm, temperature (T) = 273 K, the gas constant (R) = 0.0821 L atm K^{-1} mol^{-1}, number of moles (n) = 1.00 mol, the volume (V) can be found.

A simple calculation finds its value to be = 22.4 L. That is to say;

One mole of any ideal gas at standard temperature and pressure (s.t.p) will occupy a volume of 22.4 L

Task 6h

Assume conditions of standard temperature and pressure in the questions below.

1. ***Calculate the mass of ammonium chloride required to produce 11.6 L of ammonia gas in the reaction below.***

$$2NH_4Cl_{(s)} + Ca(OH)_{2(s)} \rightarrow 2NH_{3(g)} + CaCl_{2(s)} + 2H_2O_{(g)}$$

2. ***Calculate the volume of carbon dioxide gas produced when 9.85 g of barium carbonate is completely decomposed in the reaction below.***

$$BaCO_{3(s)} \rightarrow BaO_{(s)} + CO_{2(g)}$$