Stoichiometry

We cannot count molecules so instead we weigh them; however, it is extremely inconvenient to weigh gases. So, when adding gases to a reaction how do we measure the amount of gas? We use the Ideal Gas Law. How....

34.0 mL of a 6.0 M sulfuric acid solution is spilled on the floor Sodium hydrogen carbonate is poured on top of the spill to neutralize the acid. What is the volume, in L, of the carbon dioxide which is released? The gas being released is at 25 ˚C and 1 atm.

$$H_2SO_4(aq) + 2\ NaHCO_3(s) \longrightarrow Na_2SO_4(aq) + 2\ H_2O(l) + 2\ CO_2(g)$$

so how many moles of acid are neutralized...

$$34.0\ \cancel{\text{mL } H_2SO_4 \text{ soln}} \times \frac{6.0 \text{ mol } H_2SO_4}{1000\ \cancel{\text{mL } H_2SO_4 \text{ soln}}} \times$$

which which produces how many moles of CO_2...

$$34.0\ \cancel{\text{mL } H_2SO_4 \text{ soln}} \times \frac{6.0\ \cancel{\text{mol } H_2SO_4}}{1000\ \cancel{\text{mL } H_2SO_4 \text{ soln}}} \times \frac{2 \text{ mol } CO_2}{1\ \cancel{\text{mol } H_2SO_4}} = 0.408 \text{ mol } CO_2$$

which is how many liters? PV=nRT

$$(1 \text{ atm})\ V = (0.408 \text{ mol } CO_2)(0.08206 \text{ L•atm•K}^{-1}\text{•mol}^{-1})\ (298.15 \text{ K})$$

$$V = 9.98 \text{ L } CO_2$$

At constant temperature and pressure volumes of gas can be related directly to each other.

e.g.

If 2 L of H_2, which are at the same temperature and pressure as the Cl_2, are combined with 3 L of Cl_2, how many liters of HCl will form?

$$H_2(g) + Cl_2(g) \longrightarrow 2\,HCL(g)$$

Without knowing the temperature and pressure we cannot determine the number of moles of either H_2 or Cl_2 present. Since the temperature and pressure are constant we can relate volumes of gas as though they are moles of gas....watch.

$$(P_{H_2})(2\text{ L}) = (n_{H_2})RT \qquad \text{and} \qquad (P_{Cl_2})(3\text{ L}) = (n_{Cl_2})RT$$

So,

$$n_{H_2} = (2\text{ L})\frac{P_{H_2}}{RT} \qquad \text{and} \qquad n_{Cl_2} = (3\text{ L})\frac{P_{Cl_2}}{RT}$$

Normally, to relate H_2 to Cl_2 we must convert to moles...

$$(2\text{ L})\frac{P_{H_2}}{RT}\ \cancel{\text{mol } H_2} \times \frac{2\ \cancel{\text{mol HCl}}}{1\ \cancel{\text{mol } H_2}} \times \frac{\frac{(RT)}{P_{HCl}}\ \text{L HCl}}{1\ \cancel{\text{mol HCl}}} = 4\,\frac{P_{H_2}}{RT}\,\frac{RT}{P_{HCl}}\ \text{L HCl}$$

Since the temperatures and pressures of the gases are the same, the pressure of H_2 equals the pressure of HCl, so the numbers needed to perform the conversion from moles to L and L back to moles cancel out!

There is enough H_2 to produce 4 L of HCl, but what about the Cl_2?

This is really a limiting reagent problem hidden in a gas problem! There is enough Cl_2 to make 6 L HCl, but there is only enough H_2 to make 4 L of HCl.

Only 4 L of HCl can be made in this reaction.
We just found that
"At constant temperature and pressure volumes of gas can be related directly to each other."

A similar statement can be made about pressure and moles!

At constant temperature and volume, the pressure of gases can be related directly to each other.

Hydrogen reacts with acetylene to form ethane. A reactor is charged with 3 atm of acetylene, C_2H_2, and 10 atm of H_2. Determine the pressure inside the reactor after the reaction has finished.

$$C_2H_2(g) + 2\ H_2(g) \longrightarrow C_2H_6(g)$$

There is enough acetylene to make

$$3\text{ atm } C_2H_2 \times \frac{1\text{ atm } C_2H_6}{1\text{ atm } C_2H_2} = 3\text{ atm } C_2H_6$$

There is enough hydrogen to make

$$10\text{ atm } H_2 \times \frac{1\text{ atm } C_2H_6}{2\text{ atm } H_2} = 5\text{ atm } C_2H_6$$

So, 3 atm C_2H_6 will form. All of the C_2H_2 will be consumed, but only

$$3\text{ atm } C_2H_2 \times \frac{2\text{ atm } H_2}{1\text{ atm } C_2H_2} = 6\text{ atm } H_2 \text{ consumed}$$

leaving 4 atm of H_2.

So, the total pressure is

$$P_{tot} = P_{H_2} + P_{C_2H_6}$$

$$P_{tot} = 4\text{ atm } H_2 + 3\text{ atm } C_2H_6$$

$$P = 7\text{ atm}$$

Partial Pressure

$$P_{tot} = P_{H_2} + P_{C_2H_6}$$

In the previous example, the total pressure inside the "bomb" was 7 atm. We calculated that the pressures of the C_2H_6 and the H_2 were 3 and 4 atm respectively. The pressures of C_2H_6 and the H_2 are called partial pressures, because the pressures of the C_2H_6 and the H_2 add up to the total pressure.

The partial pressure, P_a, is related to the mole fraction of "a", and the total pressure.

Mole fraction is a means of measuring concentration and is defined as follows:

$$\chi_a = \frac{n_a}{n_a + n_b} \quad \text{and} \quad \chi_b = \frac{n_b}{n_a + n_b}$$

The mole fraction of “a”, χ_a, is defined as the number of moles of a, n_a, divided by the total number of moles of stuff present, $n_a + n_b$.

The partial pressure, Pa, of “a” is a result of all the "a" molecules present.

$$P_aV = n_aRT$$

The total pressure, P_{tot}, is a result of all the molecules present.

$$P_{tot} V = (n_a + n_b)RT$$

Divide one equation by the other...

$$\frac{P_a V}{P_{tot} V} = \frac{n_a RT}{(n_a + n_b)RT}$$

$$\frac{P_a}{P_{tot}} = \frac{n_a}{n_a + n_b}$$

$$\frac{P_a}{P_{tot}} = \chi_a$$

Incidentally, since a and b are both parts of the whole the mole fractions, χ_a and χ_b, must add up to 1.

$$\chi_a + \chi_b = \frac{n_a}{n_a + n_b} + \frac{n_b}{n_a + n_b}$$

$$\chi_a + \chi_b = \frac{n_a + n_b}{n_a + n_b}$$

$$\chi_a + \chi_b = 1$$

A balloon is filled with air at a pressure of 2 atm. Air is actually a mixture of gases, approximately 80% nitrogen and 20 % oxygen (by volume).

What is the pressure of the nitrogen in the balloon?

1.6 atm

NOT 2 atm....how come?

Because the total pressure is 2.0 atm, and the total pressure is the sum of the partial pressures.

$$\frac{P_{N_2}}{P_{tot}} = \chi_{N_2}$$

$$\frac{P_{N_2}}{2\text{ atm}} = 0.8$$

$$P_{N_2} = 1.6\text{ atm} \qquad P_{O_2} = 0.4\text{ atm}$$

$$P_{tot} = 1.6 + 0.4 = 2\text{ atm}$$

Collecting gases over water

Often a gas produced by a reaction can be collected over water; that is, a gas can be used to displace the water from and inverted container of water.

A graduated cylinder was filled with water and inverted in a tub of 22 ˚C water. H_2 produced from the reaction of Zn with HCl. With the water level inside and outside of the cylinder at the same level 90.0 mL H_2 were produced. The barometric pressure was 761 torr. How many moles H_2 were collected?

To determine moles of gas we need to know P, V, and T...

V = 90.0 mL
T = 22 ˚C = 295 K
P = ?

Level inside being equal to the level outside means the pressure inside is the same as the pressure outside...

$$P = 761 \text{ torr}$$

This is the pressure of what? Is 761 torr the pressure of the H_2 which was collected?

NO!

Wait...why not...

What gases are present in the graduated cylinder?

H_2 is present, but so is H_2O!

H_2O evaporates, right?
So, the H_2O in the cylinder will evaporate.
So, there is H_2O vapor mixed with the H_2.

Therefore,

$$P_{tot} = P_{H_2} + P_{H_2O}$$

$$761 = P_{H_2} + 21 \text{ torr}$$

$$P_{H_2} = 740 \text{ torr}$$

Now that the pressure of the H_2 is known, the problem is just a PV = nRT problem...

$$\left(\frac{740 \cancel{\text{torr}}}{760 \cancel{\text{torr}}} \text{ atm}\right)(0.090 \text{ L}) = n \text{ R } (295 \text{ K})$$

$$n = 0.0362 \text{ mol } H_2$$