Partial Pressures

Unit: Gases

MA Curriculum Frameworks (2016): HS-PS1-7

Mastery Objective(s): (Students will be able to…)

- Calculate partial pressures based on conservation of matter.

Success Criteria:

- Solutions have the correct quantities substituted for the correct variables.
- Mole fractions are paired correctly with their partial pressures.
- If the problem requires the ideal gas law, chosen value of the gas constant has the same units as the other quantities in the problem.
- Algebra and rounding to appropriate number of significant figures is correct.

Tier 2 Vocabulary: mole

Language Objectives:

- Describe the pairing of each gas with its mole fraction and pressure.

Notes:

Partial Pressure: the partial pressure of a gas is the amount of pressure that would result from *only* the molecules of that gas. The partial pressure of a substance is denoted by the variable *P* (for pressure) and the chemical formula of the substance as a subscript. For example, the partial pressure of carbon dioxide in a sample would be denoted by P_{CO_2}.

Dalton's Law of Partial Pressures: the sum of all of the partial pressures in a sealed container equals the total pressure.

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

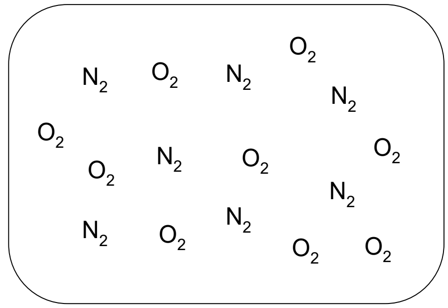
(To make things more clear, we will use P_T to mean the total pressure.)

mole fraction (χ): the fraction of the total moles (or molecules) that are the compound of interest. For example, if we have 20 moles of gas, and 9 moles are N_2, the mole fraction of N_2 is:

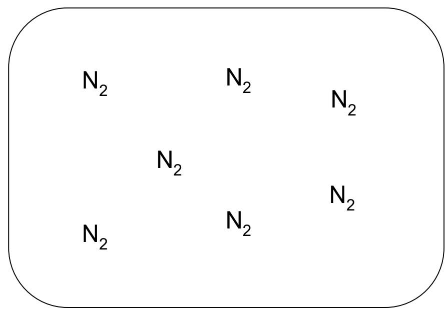
$$\chi_{N_2} = \frac{9\,\text{mol}\,N_2}{20\,\text{mol total}} = 0.45$$

Use this space for summary and/or additional notes:

Suppose we had the following tank, with a total pressure of 1.00 atm:



If we ignore all of the molecules except for nitrogen, the tank would look like this:



If 45 % of the molecules are nitrogen ($\chi_{N_2} = 0.45$), then the pressure just from these nitrogen molecules (the partial pressure of nitrogen) must be 0.45 times the total pressure of 1 atm. This means:

$$P_{N_2} = \chi_{N_2} P_T$$

$$P_{N_2} = (0.45)(1\text{ atm}) = 0.45\text{ atm}$$

Similarly, because 55 % of the molecules are oxygen, this means:

$$\chi_{O_2} = 0.55$$

$$P_{O_2} = \chi_{O_2} P_T \qquad P_{O_2} = (0.55)(1\text{ atm}) = 0.55\text{ atm}$$

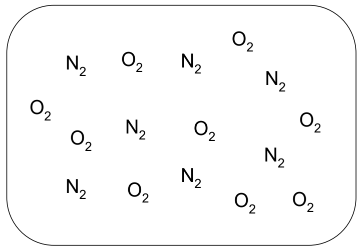
Note that the two partial pressures add up to the total pressure:

$$P_T = P_{N_2} + P_{O_2} \quad = \quad 0.45\text{ atm} + 0.55\text{ atm} = 1\text{ atm}$$

Use this space for summary and/or additional notes:

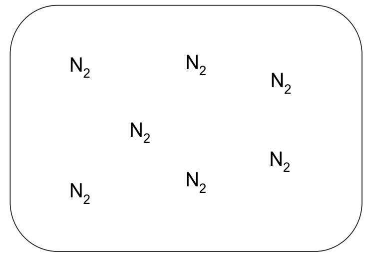
Using Dalton's Law with the Ideal Gas Law

Recall the two tanks from our example. Assuming N_2 and O_2 are behaving like ideal gases, the ideal gas law must be true in both tanks.



$P = P_T \qquad n = n_T$

$P_T V = n_T RT$



$P = P_{N_2} \qquad n = n_{N_2}$

$P_{N_2} V = n_{N_2} RT$

In other words, the ideal gas law can be used either with the total moles and total pressure, or with the moles of one specific gas and the partial pressure of that gas.

Use this space for summary and/or additional notes:

Vapor Pressure

<u>vapor pressure</u> (P_{vap}) the partial pressure of a substance due to evaporation.

Because liquids are continually forming and breaking bonds, when a liquid molecule at the surface breaks its bonds with other liquids, it can escape the attractive forces of the other liquid molecules and become a vapor molecule. The tendency for molecules to do this, when expressed as a partial pressure, is called the vapor pressure.

Vapor pressure is a function of the kinetic energy of the molecules, which means vapor pressure increases with temperature. At the boiling point, all of the molecules have enough energy to enter the gas phase. This means that at the boiling point, the vapor pressure must be equal to the ambient (atmospheric) pressure.

The following table shows the vapor pressure of water at different temperatures.

Vapor Pressure of Water

Temp (°C)	P_{vap} (kPa)	Temp (°C)	P_{vap} (kPa)	Temp (°C)	P_{vap} (kPa)
0.01	0.61173	30	4.2455	70	31.176
1	0.65716	35	5.6267	75	38.563
4	0.81359	40	7.3814	80	47.373
5	0.87260	45	9.5898	85	57.815
10	1.2281	50	12.344	90	70.117
15	1.7056	55	15.752	95	84.529
20	2.3388	60	19.932	100	101.32
25	3.1691	65	25.022	105	120.79

Relative humidity is the actual partial pressure of water in air as a percentage of its vapor pressure.

For example, suppose air at 30 °C (86 °F) has a partial pressure of 2.8 kPa. The vapor pressure of air at 30 °C is 5.6 kPa. 2.8 kPa is half of 5.6 kPa, so the relative humidity would be 50 %.

Use this space for summary and/or additional notes:

Sample problem:

A 12.0 L tank of gas has a temperature of 30.0 °C and a total pressure of 1.75 atm. If the partial pressure of oxygen in the tank is 0.350 atm, how many moles of oxygen are in the tank? How many total moles of gas are in the tank?

Solution:

For oxygen:

P_{O_2} = 0.350 atm   n = n

V = 12.0 L   R = $0.0821 \frac{\text{L·atm}}{\text{mol·K}}$

T = 30.0 °C + 273 = 303.0 K

$$P_{O_2}V = n_{O_2}RT$$

$$(0.350)(12.0) = n_{O_2}(0.0821)(303.0)$$

$$n_{O_2} = 0.169\ \text{mol}$$

You could figure out the total moles two ways. One is to use the ideal gas law on the total moles:

P = 1.75 atm   n = n

V = 12.0 L   R = $0.0821 \frac{\text{L·atm}}{\text{mol·K}}$

T = 30.0 °C + 273 = 303.0 K

$$PV = nRT$$

$$(1.75)(12.0) = n(0.0821)(303.0)$$

$$n = 0.844\ \text{mol}$$

Use this space for summary and/or additional notes:

The other way to find the total moles is to use the mole fraction and the partial pressure:

$$P_{O_2} = \chi_{O_2} P_T$$

We know that

$$P_{O_2} = 0.350\text{ atm}$$

$$P_T = 1.75\text{ atm}$$

$$0.350\text{ atm} = \chi_{O_2}(1.75\text{ atm})$$

$$\chi_{O_2} = \frac{0.350\text{ atm}}{1.75\text{ atm}} = 0.200$$

Now that we know the mole fraction of O_2, we can figure out the total moles:

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

$$0.200 = \frac{0.169\text{ mol } O_2}{n_T}$$

$$n_T = \frac{0.169}{0.200} = 0.845\text{ mol}$$

Homework Problems

1. A 5 L container contains 0.125 mol of O_2 and 1.000 mol of He at 65 °C. What is the partial pressure of each gas? What is the total pressure?

   Answer: 6.24 atm

Use this space for summary and/or additional notes:

2. A 50 L gas cylinder contains 186 mol of N_2 and 140 mol of O_2. If the temperature is 24 °C, what is the total pressure in the cylinder?

   Answer: 159 atm

3. A sample of O_2 gas is collected by water displacement at 25 °C. If the atmospheric pressure in the laboratory is 100.7 kPa and the vapor pressure of water is 3.17 kPa at 25 °C, what is the partial pressure of the O_2 gas in the sample?

   Answer: 97.5 kPa

4. Two flasks are connected with a stopcock. The first flask has a volume of 5 liters and contains nitrogen gas at a pressure of 0.75 atm. The second flask has a volume of 8 ℓ and contains oxygen gas at a pressure of 1.25 atm. When the stopcock between the flasks is opened and the gases are free to mix, what will the (total) pressure be in the resulting mixture?

   Answer: 1.058 atm

Use this space for summary and/or additional notes: