Name ___________________________________**Chem 161, Section**: _______**Group Number:** ______

ALE 23. Mixtures of Gases

(Reference: Chapter 5 in *Silberberg* 5th *edition*)

How is pressure handled when we have a mixture of gases?

The Model: Collecting Gas Over Water

When gas is collected in a container, it is often collected using a technique called, "water displacement," the method you used to collect oxygen gas in the hydrogen peroxide – bleach lab. In water displacement, a container is filled with water and then gas is bubbled into the container. In this way, the container can be filled with relatively pure gas without air in it.

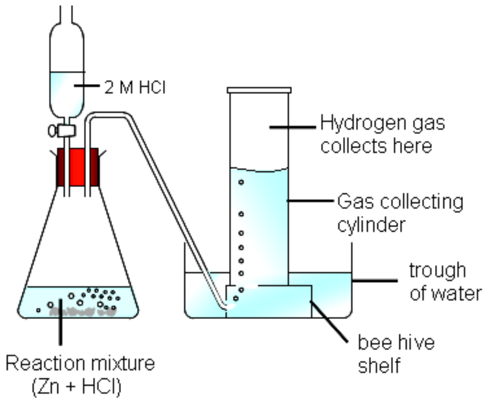


Figure 1. Collection of hydrogen gas by the displacement of water.

Key Question

1. In Figure 1, is the hydrogen gas collected in the cylinder pure? *Explain why or why not.*

The Model: Vapor Pressure

The gas that is collected is not "dry" because there is some water vapor mixed with it. If you attempt to collect pure hydrogen, you will actually get mostly pure hydrogen with a little water vapor. You can get an idea of how much water vapor is present by examining the water vapor pressure at various temperatures.

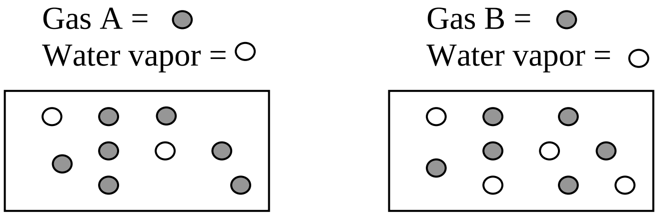
Table 1. Vapor pressure of water at various temperatures.

Temperature (^oC)	**Vapor Pressure (kPa)**
0	0.6
5.0	0.9
10.0	1.2
15.0	1.6
20.0	2.3
25.0	3.2
30.0	4.2
35.0	5.6
40.0	7.4

Key Questions

2. Why is it logical to expect that the vapor pressure of water would increase as the temperature increases?

3. Examine the two containers below. Both contain gases that were collected over water. Which one was collected at the higher temperature—gas A or gas B? *Explain your answer*.



4. Consider Gas A from question 3, above. The total pressure in the container is 104.0 kPa. If the temperature of the container is 20.0 ^{o}C, calculate the pressure of Gas A when it is “dry”. Hint: you will need data from table 1, above! *Show your work using correct significant figures*—circle your answer.

5. Consider Gas B from question 3, above. The total pressure in the container is 110.0 kPa. If the temperature of the container is 35^{o}C, calculate the pressure of Gas B when it is “dry”. *Show your work using correct significant figures*—circle your answer

The Model: Dalton's Law of Partial Pressures

The pressure of a gas is understood to be the cumulative tiny pushes of the gas molecules as they collide with the walls of the container. Suppose we have a mixture of three ideally-behaving gases, here labeled simply as A, B, and C. According to the ideal gas law, the partial pressure of each gas is:

$$P_A = \frac{R\,T_A}{V_A} n_A \qquad P_B = \frac{R\,T_B}{V_B} n_B \qquad P_C = \frac{R\,T_C}{V_C} n_C$$

Key Questions

6a. There are only the three gases in a container. That being the case, the total number of moles of ideally-behaving gas in the container is simply a sum of the numbers of moles of each gas (*i.e.*, $n_{total} = n_A + n_B + n_C$). Complete the following equation, using the Ideal Gas Equation to algebraically substitute each n (n_A and n_B and n_C) for appropriate expressions in terms of the volumes (V_A and V_B and V_C), temperatures (T_A and T_B and T_C), and partial pressures (P_A and P_B and P_C):

$$n_{total} = \qquad + \qquad +$$

b. Now recognize that all three gases have the same temperature and the same volume (they are in the same container). Complete the following equation in which what is common of the three gases is factored out:

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

c. Now we multiply both sides by ${}^{RT}/_{V}$, keeping the appropriate subscript:

$$P_A + P_B + P_C =$$

d. Now we use the ideal gas law to rewrite ${}^{nRT}/_{V}$, keeping the appropriate subscript:

$$P_A + P_B + P_C =$$

This is **Dalton's Law of Partial Pressures**, which says that the total pressure of a gas mixture is equal to a sum of the ____.

(Fill in the blank with the rest of what Dalton's Law of Partial Pressures is.)

The Model: Mole Fraction

When we have a mixture of gases in the same container (*i.e.*, they share the same volume and temperature), we have a direct relationship between the partial pressure of a component and the number of moles of that component:

$$\frac{P_A}{P_{total}} = \frac{n_A}{n_{total}} \quad \textbf{(Eqn 1)} \quad \Rightarrow \quad P_A = X_A P_{total} \quad \textbf{(Eqn 2)}$$

where: X_A **= mole fraction of A**

Key Questions

7a. Compare equations **1** and **2** in the Model to mathematically define what the mole fraction of component A is in terms of the number of moles of A in the mixture.

$\boldsymbol{X}_{\mathbf{A}} =$

b. In a like manner, define what the mole fraction of component B is.

$\boldsymbol{X}_{\mathbf{B}} =$

8a. Suppose you have a two-component mixture (A and B). Substitute your answers to Questions 7a & 7b to the following:

$\boldsymbol{X}_{\mathbf{A}} + \boldsymbol{X}_{\mathbf{B}} =$

b. Since the two terms on the right-hand side of the equation have the same denominator, you can easily combine the two terms. What numerical value must the sum of all mole fractions for a mixture be equal to? (*Hint*: How does the sum in the numerator compare with the denominator?)

Exercises

A. A gas mixture contains 0.25 mol of CH_4, 0.87 mol of Ar, and 0.65 mol of O_2. The total pressure is 1.50 atm.

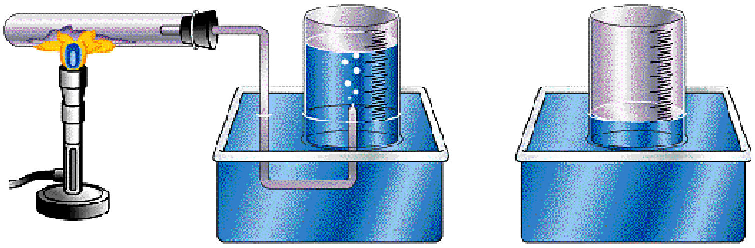
① Calculate the mole fraction of each gas in the mixture. *Show your work and circle the answer.*

② What is the partial pressure (in atm) of each gas in the mixture? *Show your work and circle the answer.*

B. Potassium chlorate decomposes upon heating to yield oxygen according to the following chemical equation:

$$\mathbf{2\ KClO_3(\mathit{s}) \rightarrow 2\ KCl(\mathit{s}) + 3\ O_2(\mathit{g})}$$

8.000 g of $KClO_3$ (122.55 g/mol) are placed in a test tube. A stopper fitted with glass tubing and a rubber hose is placed at the end of the test tube. The hose is led to the bottom of an inverted beaker, initially filled with water, as shown in the following figure.



while filling **once filled**

The potassium chlorate is heated and the oxygen gas bubbles into the beaker, displacing the water. The temperature of the water and the collected oxygen above the water is 21.9 °C. At 21.9 °C, water has a vapor pressure of 19.8 mmHg. (The collected O_2 is accompanied by H_2O vapor and is called “wet”.) When all of the oxygen has been bubbled into the beaker, the beaker is positioned so that the water level inside the beaker is the same as that outside the beaker. A barometer informs us that the atmospheric pressure is 761.2 mmHg.

① What was the purpose of positioning the beaker to make the level of water outside of the beaker the same as that inside of the beaker?

② What is the partial pressure of O_2 in the beaker? (*Hint*: the oxygen gas is wet!) *Circle your answer*.

③ What is the mole fraction of O_2 in the beaker? (*Hint*: Use eqn **2** in the Model.) *Circle your answer.*

④ How many milliliters of *wet* O_2 will we have at 21.9 °C and 761.2 mmHg? (*Hints*: How many moles of O_2 are produced when 8.0 g of $KClO_3$ are decomposed? How can the definition of mole fraction (See Question 3) be used to calculate the *total number of moles of gas* that is collected above the water in the beaker? What is the absolute temperature? What is the value of *R*?) *Circle your answer.*