THE MOLAR VOLUME OF A GAS

OBJECTIVE:
To calculate the standard molar volume of a gas from accumulated data

INTRODUCTION

Solids, liquids and gases are called the three states of matter. In this experiment, we will examine the gaseous state.

The "condition" or state of a gaseous substance is determined by four properties: volume (V), pressure (P), temperature (T), and the number of moles of the substance present (n). A change in one variable causes a change in one or more of the other variables. If any 3 of the variables are known, the fourth can be calculated using the ideal gas law:

$$PV = nRT \qquad (1)$$

where R is a constant determined from experiment. It is called the universal gas constant.

One mole of <u>any</u> gas at 0.00EC (273 K) and 1.00 atm (760 torr) occupies a volume of 22.4 L. These conditions are called **standard temperature and pressure**, or **STP**, and 22.4 L is called the **standard molar volume**. Using this data, R can be calculated:

$$R = \frac{PV}{nT} = \frac{(1.00\ \text{atm})(22.4\ \text{L})}{(1.00\ \text{mol})\ (273\ \text{K})} = 0.0821\ \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}} \qquad (2)$$

If the number of moles of gas is constant, another useful relationship is the **combined gas law**:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \qquad (3)$$

If P, V and T are known under an initial set of conditions and 2 of the conditions change, the change in the third can be calculated.
For example, if a sample of 0.0500 moles of a gas occupies a 1.42 L container at 298 K and 654 torr, the volume it will occupy at 323 K and 985 torr is:

$$\frac{(654\ \text{torr})(1.42\ \text{L})}{298\ \text{K}} = \frac{(985\ \text{torr})(V_2)}{323\ \text{K}} \qquad (4)$$

$$V_2 = \frac{(654\ \text{torr})(1.42\ \text{L})(323\ \text{K})}{(985\ \text{torr})(298\ \text{K})} = 1.02 \qquad (5)$$

The volume occupied by 1 mole of gas under these nonstandard conditions would be:

$$\frac{(1.02\ \text{L})}{(0.050\ \text{mol})} = 20.4\ \text{L/mol} \qquad (6)$$

Note: Pressure units do not have to be changed to atm, as long as the units cancel out. However, when using the gas laws, temperatures must <u>always</u> be in Kelvin!

In this experiment, the volume, pressure, temperature, and mass of a gas will be determined. From these measurements, the volume occupied by 1 mole of the gas, or its **molar volume,** can be calculated. Finally, the volume occupied by 1 mole of the gas at STP can be calculated, using the combined gas law.

In the actual experiment, a mixture of $KClO_3$ and MnO_2, a catalyst, is heated to produce O_2. The balanced equation is:

$$2\ KClO_3\ (s) \longrightarrow 2\ KCl\ (s) + 3\ O_2\ (g) \qquad (7)$$

The mass of oxygen produced is determined from the difference in the mass of $KClO_3$ and KCl. The oxygen gas is collected in a Mohr buret by displacing water (see Figure 7.1). This allows its volume to be measured. The temperature of the gas and the water it displaces will be the same, if allowed to reach thermal equilibrium. Also, if the water levels are equalized in the bulb and buret, the total pressure in the bottle will be the same as atmospheric pressure. The total pressure in the buret, however, is the sum of the partial pressures of both the oxygen and the water vapor (Dalton's Law). The vapor pressure of water is a function of temperature and can be found in a chemical handbook. The partial pressure due to the oxygen alone is then obtained from the equation:

$$P_{total} = P_{water} + P_{oxygen} \qquad (8)$$

PROCEDURE

This experiment will be a demonstration. You are responsible for collecting the necessary data and completing all calculations.

Set up the buret and leveling bulb without the pyrex tube and contents as shown in Figure 7.1. Fill the leveling bulb with water, so that the water will rise into the buret within 1 mL of the top graduated marking. Allow to come to room temperature (reach thermal equilibrium). Place into the pyrex tube approximately 0.10 g of the $KClO_3$-MnO_2 mixture. Weigh the tube and contents to the nearest mg. With a rubber connector, attach the tube with contents to the buret; equalize the water levels in the buret and leveling bulb by lowering or raising the bulb. Hold an asbestos board to keep the tube at the proper angle and provide a heat shield between the burner flame and the water in the buret. Gently heat the $KClO_3$, until about 40 mL of water is displaced from the buret by the oxygen gas evolved. Stop heating and let the entire apparatus cool to room temperature. After cooling, record the temperature and the barometric pressure. Equalize the levels of water in the buret and bulb and record the volume of oxygen evolved. Detach the pyrex tube and weigh. The difference in the weight before and after heating is the weight of the oxygen evolved.

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LABORATORY REPORT

NAME ______________________

DATE_______________________

Data:

Initial mass of pyrex tube and contents: ____________

Final mass of pyrex tube and contents: ____________

Volume of oxygen evolved: ____________

Temperature: ____________

Atmospheric Pressure: ____________

Vapor pressure of H_2O at today's temperature ____________

Results: SHOW YOUR WORK

Mass of oxygen evolved: ____________

Moles of oxygen evolved: ____________

Pressure of dry oxygen: ____________

Molar volume of oxygen under experimental conditions ____________
(Use the volume and moles of oxygen from your experimental data to find the molar volume of O_2 (L/mol) under experimental conditions)

QUESTIONS

1. Using the combined gas law and your experimental data, calculate the molar volume of oxygen at STP.

2. How does your value compare with the standard molar volume?

3. Using your experimental data, calculate a value for R. Be sure to report your answer in $L \cdot atm/mol \cdot K$.

4. How does your value compare with the accepted value? In your opinion, what is the greatest source of error in this experiment? Justify your choice.