Molar Volume of Hydrogen Gas

Goals:

Apply Dalton's law of partial pressures to a mixture of gases.
Use the general gas law to calculate information about a gas.

Background:

In this experiment you will collect data that will allow you to calculate the **molar volume** (volume per mole) of hydrogen gas, H_2, at STP (P = 1 atm and T = 273.15 K). When the volume of a gas is measured at a certain temperature and pressure, its volume can be calculated at another temperature and pressure using the **general gas law**:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

In this equation P is the pressure of the gas, V is the volume of the gas, and T is the absolute (Kelvin) temperature. The subscript one refers to the initial state of the gas while the subscript two refers to the final state.

In a mixture of gases, each gas exerts pressure independently of the presence of the other gases. The total pressure of the mixture is the sum of the partial pressures of each gas: $\mathbf{P_{tot} = P_1 + P_2 + \ldots}$
The expression is known as **Dalton's law of partial pressures**.

In this experiment, hydrogen gas (H_2) will be produced by the reaction of an active metal (Mg) with excess hydrochloric acid. The number of moles of hydrogen gas produced in the reaction is equal to the number of moles of magnesium metal used, as seen from the balanced chemical equation:

$$Mg(s) + 2HCl(aq) \rightarrow H_2(g) + MgCl_2(aq)$$

The gas will be collected in a **eudiometer tube** (see the figure on the next page) that is initially filled with water and HCl. Since $H_2(g)$ is virtually insoluble in water, every 1 mL of gas that is produced will displace 1 mL of water. Also, since the gas is collected over water, there will be water vapor present. Dalton's law of partial pressures will be used to determine the pressure of the hydrogen gas alone.

Table of Water Vapor Pressure at Several Temperatures: (from CRC Handbook)

Temp (°C)	VP (mm Hg)	Temp (°C)	VP (mm Hg)
17°	14.5	22°	19.8
18°	15.5	23°	21.1
19°	16.5	24°	22.4
20°	17.5	25°	23.8
21°	18.6	26°	25.2

In this experiment: $P_{atm} = P_{H2} + P_{water\ vapor} + P_{column}$

where: P_{atm} is the barometric pressure
$P_{water\ vapor}$ is the vapor pressure of water (look up from the table above)
P_{column} is the pressure exerted by the column of liquid remaining in the eudiometer tube at the end of a trial

This equation is solved to find the partial pressure of hydrogen gas, P_{H2}.

Procedure: Work in pairs. Put on your goggles and lab coat.

Obtain a small piece of magnesium, about 0.03 g (about 2 - 2.5 cm). Clean the strip of magnesium with steel wool and wipe it clean. Weigh the magnesium and record the mass to the nearest 0.001 g.

Curl up the magnesium strip and tie a string around it, leaving one end of the string about 5 cm long.

Obtain a eudiometer tube and a one-hole stopper that fits the tube. You will also need a 250 mL beaker that is at least half filled with water.

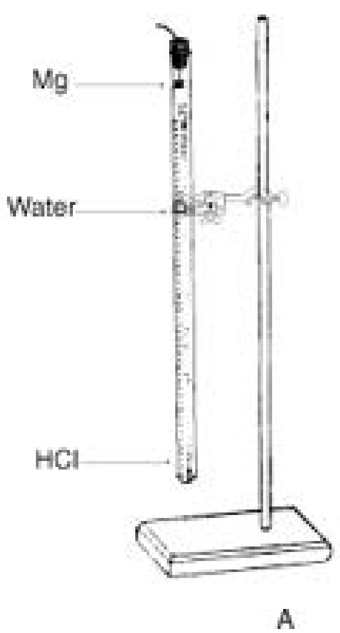
Hold the eudiometer tube so that the closed end is at the bottom and clamp it to a ring stand. Pour about 10 mL of 6 M HCl into the tube. Slowly pour deionized water down the side - you do not want the acid and water to mix yet! Fill the tube completely with water, past the markings to the top of the tube.

Put the string-wrapped magnesium at the top of the tube, leaving the long end of the string on the outside of the tube. Insert the rubber stopper into the tube, catching the string against the stopper. (Some water will be pushed out.) The tube should be full of water with the magnesium held close to the stopper by the string. Place the 250 mL beaker (partially filled with water) under the tube.

Unclamp the eudiometer tube and turn it so that the stoppered end is down. Make sure this end is in the 250 mL beaker. Hold the tube in place with the clamp. Watch as the more dense acid falls down through the water, reacting with the magnesium when the acid reaches the bottom of the tube. Hydrogen gas will bubble up toward the top of the tube and water will run out of the hole in the stopper into the beaker.

Allow the apparatus to cool when reaction is complete. Measure and record the volume of hydrogen gas collected. Record the temperature of the room (since the apparatus has cooled, this will also be the temperature of the gas). Measure the height in mm of the water remaining in the eudiometer tube.

<u>Waste Disposal</u>: The liquid in the beaker is acidic. Neutralize the acid with baking soda and wash down the drain with water.



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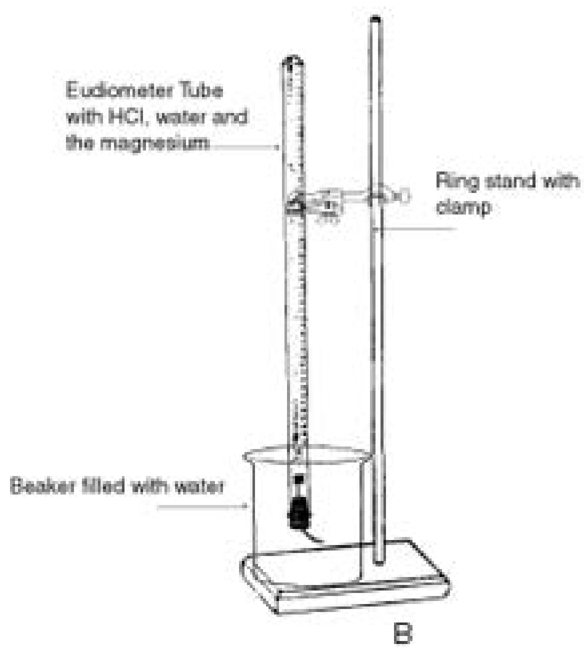

Molar Volume of Hydrogen Gas
Data and Calculations

Name ______________________________ Partner______________________________ Sec _____

	Trial 1	Trial 2
Mass of magnesium metal	.031g	.035g
Moles of Mg		
Moles of H_2		
Volume of H_2 gas	31.8mL	37.4mL
Temperature (°C)	21.8C	21.8C
Temperature (K)		
Height of water column (mm H_2O)	253.6 mmH2O	203.6 mmH2O
P_{column} (mm Hg)*		
Total pressure, P_{atm} (mm Hg)	740. mmHg	740. mmHg
$P_{water\ vapor}$ (mm Hg)		
Partial pressure of H_2 (mm Hg)		
Volume of H_2 at STP		
Molar volume of H_2 at STP		

*__Calculation for P_{column} in mm Hg:__ $P_{column}\text{ (mm Hg)} = \dfrac{\text{height (mm } H_2O)}{13.6\text{ (mm } H_2O/\text{ mm Hg)}}$

⇨ **Show calculations for one trial.**

Gas Law Questions

1. What type of chemical reaction occurs when magnesium react with hydrochloric acid? Briefly explain your answer:

2. For the following errors, indicate whether the calculated value for the molar volume of H_2 will be too high, too low, or not affected. Explain your choice.
   a. Some of the magnesium metal did not react with the acid.
   Explain:

   b. You forgot to subtract the vapor pressure of water from the total pressure of hydrogen gas.
   Explain:

3. Standard temperature and pressure (STP) for gases is a reference set of conditions where the temperature is 0ºC and the pressure is 1 atm.
   a. Use the ideal gas law to calculate the molar volume of an ideal gas at STP to five significant figures (R = 0.082057 L•atm/mol•K).

   b. Calculate the percent error of your experimental molar volume of H_2 at STP from the value for an ideal gas.

4. All gases deviate to some extent from the behavior of perfect gases. At STP, the density of $O_2(g)$ is 0.0014290 g/mL, that of $H_2(g)$ is 0.00008988 g/mL, and that of $CO_2(g)$ is 0.0019769 g/mL. Using these values and the precise atomic weights (H = 1.00794, C = 12.011, O = 15.9994), calculate the molar volume of each of these gases (in units of L/mole) to the correct number of significant figures.