# Experiment 13 – Calculation of the Molar Volume of a Gas at STP and the Ideal Gas Constant, R

According to both theory and experiment, the pressure (P) of any sample of an ideal gas is inversely proportional to its volume (V) and directly proportional to its absolute temperature (T) and to the number of moles (n) of the gas present in the sample. This proportionality may be written: $P \propto \frac{nRT}{V}$ which $\propto$ is read "is proportional to." It is more convenient to put this relationship in the form of an equation: $P = \frac{nRT}{V}$ $in$ which R, the "proportionality constant" is usually called the "ideal gas constant." This equation is more familiar in the rearranged form PV = nRT, and this equation is called the "ideal gas equation" or the "ideal gas law."

The purpose of this lab is to determine the molar volume of hydrogen gas, $H_{2\,(g)}$ at STP. To do this, we must measure P, V, T, and n. We will use several gas laws to help us achieve the final goal of the molar volume of hydrogen at STP: Avogadro's law (the volume of one mole of gas at STP is 22.41 L at 273.15K, the Combined gas law, which we derive from the ideal gas law, and Dalton's Law of Partial Pressures.

The value of molar volume ($V_{STP}$ experimental) can then be calculated and compared with the accepted value of $V_{STP}$. In this experiment, P, V, and T will be measured directly, while n will be calculated from the amount of magnesium used to produce the hydrogen gas.

## INTRODUCTION

In the text and lecture, we have learned that metals above hydrogen on the activity series will react with strong acids such as hydrochloric acid, and reduce the hydrogen ions to form hydrogen gas. Magnesium is one such metal, while copper which is below hydrogen in the series, is not. This makes copper an ideal container for the magnesium metal during the reaction. We will use copper wire to make a cage to contain the magnesium metal as the reaction occurs.

In this lab, we will generate hydrogen gas by the oxidation of magnesium metal with excess hydrochloric acid and collect the gas in a device called a **eudiometer.** Eudiometers are used to collect and measure gas volumes.

Let's take a closer look at the setup of the experiment. We begin the experiment by adding concentrated hydrochloric acid to the eudiometer, followed by the careful addition of distilled water. Magnesium wire is wrapped in a copper cage and attached to the stopper of the eudiometer. The reactants are on opposite ends of the eudiometer and are separated by water. The eudiometer is inverted into a beaker filled with water. The denser hydrochloric acid slowly makes its way to the magnesium metal, where it reacts to form hydrogen gas. The reaction continues until all the magnesium is consumed. The hydrogen gas mixes with the ever-present water vapor. We measure the height of the column of water in the eudiometer, the volume of gas, and the temperature of the reaction.

## Determining pressure of the gases

**Dalton's Law of Partial Pressure** states that the total pressure of a mixture of gases is equal o the individual gases pressures, as long as those gases are not reacting. The two gases that are trapped in the eudiometer are hydrogen gas, from the reaction, and water vapor. Water is always in equilibrium with its vapor. The total pressure will equal the pressure due to the hydrogen gas and the vapor pressure of water at the temperature measured during the experiment.

$P_{T\ of\ gases\ in\ eudiometer} = P_{hydrogen} + P_{water.}$ *Equation 1: Dalton's Law-No internal column*

If the level of the liquid inside the eudiometer is equal to the level of the fluid in the beaker, the internal and external pressures are the same and the equation above would suffice. For our experiment, the level of the liquid will be higher than the external level of liquid in the beaker. We must account for the pressure due to the height of the column. The density of the solution in the eudiometer is about 1.05g/mL.

$h_{col}d_{col} = h_{Hg}d_{Hg}$ *Equation 2: The Barometer equation*

Using the barometer equation, we can calculate the height of the column of the liquid in terms of mmHg. (h stands for the height of the column, whether acid solution or mercury, and d stands for the density of the two materials.)

$P_{atmosphere} = P_{T\ of\ gases\ in\ eudiometer} = P_{hydrogen} + P_{water} + P_{column\ of\ diluted\ acid}$ *Equation 3: Dalton's Law- Internal column*

Rearranging equation 2, we can solve for the vapor pressure of hydrogen at STP

$P_{hydrogen} = P_{atmopherie} — (P_{water} + P_{column\ of\ diluted\ acid})$ Equation 4: Dalton's Law Rearranged

Once the pressure of the hydrogen gas is known at $T_{exp,}$ the molar volume can be calculated at STP using the other experimental data for volume and temperature.

## Determining volume at STP

Once the pressure of the hydrogen is determined at STP, the **Combined Gas Law** can be used to determine the volume of the hydrogen sample at STP. We can then compare this value to the **Avogadro's Law** value of 22.4L/mol using the stoichiometry of the reaction to solve for moles of gas sample..

$\frac{P_{STP}V_{STP}}{T_{STP}} = \frac{P_{EXP}V_{EXP}}{T_{EXP}}$ *Equation 5: Combined Gas Law*

## PRE-LAB QUESTIONS

See the prelab for the pre-lab questions.

SAFETY PRECAUTIONS: Wear your safety goggles. Use caution when handling 6 M HCl. It is corrosive and can burn your skin. If any HCl encounters your skin, rinse it off immediately and thoroughly with lots of water.

EQUIPMENT: Eudiometer, large beaker (400 mL), copper wire, strip of Mg metal, single hole stopper, burette clamp and ring stand, thermometer.

WASTE DISPOSAL: At the end of the experiment, the HCl solution will be much more dilute. The water/HCl/$MgCl_2$ mixture may be rinsed down the sink with plenty of water.

# PROCEDURE

1. Obtain a piece of magnesium ribbon approximately 5 cm long. Clean the ribbon with fine steel wool and weigh it accurately (to the nearest 0.0001 g). Make sure that it weighs less than 0.04 grams. (If it weighs more, cut off a small piece and re-weigh.)
2. Roll the ribbon loosely and then wrap it in a little ball of fine copper wire (see the display in the laboratory), leaving a "handle" of copper wire. The wrapping is designed to prevent small pieces of magnesium from breaking off and escaping during the experiment. Make sure that the ball is not too large to fit into the gas measuring tube.
3. Set up a ring stand with a burette clamp in position to hold a 50-mL gas-measuring tube (eudiometer). Fill a 400-mL beaker about 2/3 full of tap water and place it near the ring stand.
4. Tilt the gas-measuring tube slightly and pour in about 10 mL of 6 M HCl. (Estimate volume using the marks on the tube, and don't worry about getting exactly 10 mL.) Then, with the tube still in the same tilted position, gently add some water from a wash bottle, being careful not to mix the water too much with the acid. Then, gently fill the tube to the top with water (pour from a beaker or wash bottle). While pouring, rinse down any acid that may have wet the sides of the tube. The object is to have acid at the bottom of the tube and water at the top. Try to avoid stirring up the acid layer at the bottom of the tube. Air bubbles that may cling to the insides of the tube can be dislodged by gentle tapping of the tube.
5. Fill the top of the eudiometer such that you create a 'bead' of water at the top. It will look like it is over flowing, but surface tension will keep the water in place.
6. Holding the copper coil by the handle, insert the cage about 3 cm down into the tube.. When you insert the stopper, don't put your finger over the hole in the stopper. Let the water overflow as you insert the stopper so that there are absolutely no air bubbles trapped in the tube.
7. Add some more water to the hole in the stopper so that it is filled with water.
8. Cover the hole in the stopper with your finger and invert the tube in the beaker of water, so that the stoppered end is under water. Once the hole is under water, you can remove your finger; the water cannot now run out. Clamp the tube in place. The acid, being denser than the water, will diffuse down through the water and soon reach the metal sample. When the reaction begins, you will see bubbles of hydrogen gas form. Check to see if there is a temperature change associated with this reaction.
9. After the bubbles stop forming, you know that the reaction is completed, but you should wait for a few minutes for the tube to come to room temperature and for bubbles that may be clinging to the sides of the tube to be dislodged. (Tap, if necessary.)

10. Read and record the volume of the hydrogen gas in the eudiometer to the nearest 0.1 mL. Without changing the position of the eudiometer, hold a ruler at the top surface of the water level inside the beaker, and measure the distance from the water level in the beaker to the water level inside the eudiometer. Record this height (in centimeters). This will be the "height of the liquid column" referred to in the calculations. Measure and record the temperature of the gas by holding a thermometer against the eudiometer where it contains gas. Record the barometric pressure (the instructor will read the barometer and write today's atmospheric pressure on the board).
11. Disassemble the apparatus. If your instructor so directs, slowly add some sodium carbonate ($Na_2CO_3$)) or sodium bicarbonate ($NaHCO_3$) to the HCl solution in the beaker until there is no further fizzing (this step neutralizes the remaining acid). Dump the neutralized solution down the drain. If there is no sodium carbonate or bicarbonate available, dump the solution down the sink followed by lots of water. Rinse the eudiometer with water.
12. Repeat the entire procedure with a second sample of magnesium.

# CALCULATIONS

1. From the mass of magnesium used and the balanced equation, calculate the number of moles of hydrogen gas expected for each trial.
2. Using the Barometer equation (Equation 2) calculate the height of the column of acid solution remaining in the eudiometer in terms of mmHg. Remember the density of the acid solution is approximately 1.05g/mL.
3. Look up the vapor pressure of water at $T_{rxn}$ (see chart on website)
4. The values from steps 1-3 will be used to calculate the pressure of the hydrogen gas using Dalton's Law (Equation 3).
5. Once you have the volume of the gas (in L the temperature of the experiment (in kelvin) use the Combined Gas Law to determine the volume of the sample at STP.
6. Calculate the molar volume of the gas using the moles of gas
7. Calculate the % error and the % difference for your trials.
8. Use the experimental values of P, V, and T solve for the ideal gas constant (R).
9. Calculate the % error and the % difference for your trials.

# QUESTIONS

Post lab questions are found in the Pre-lab.