Lab 8. Determination of the Gas Law Constant

Prelab Assignment

Before coming to lab:

- Complete the following sections of your report for this lab exercise *before* attending lab: Title and Date of Lab, Introduction, Materials/Methods and Data Tables. An outline or flow chart of the procedure is appropriate for the Materials/Methods section. Ensure that the table of contents of your lab notebook is current.
- Read the lab thoroughly and answer the pre-lab questions on the last two pages of this lab.

Introduction

The ***gas law constant***, *R*, provides a relationship between the pressure, volume, temperature and number of moles of a gas. Interestingly, the value for R is the same for all gases. Thus we can use any gas to determine a value for R.

In today's experiment you will determine a value for *R*, by collecting a sample of hydrogen gas. From the ideal gas law, **PV = nRT**, we see that we can determine a value for R if we can isolate a sample of gas for which P, V, T and *n* are all known.

You will collect hydrogen gas by reacting magnesium metal with hydrochloric acid. Note that this is redox reaction. What is the oxidizing agent?

$$\mathbf{Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2\,(aq)} + H_{2\,(g)}}$$

The gas will be collected over water in a gas collection tube. Once the experiment has finished, your set-up will look something like figure 1, below. (*Your set-up will not include the piece of tubing*). Note that the water in the tube is higher than the water in the beaker. Why is that? What does that tell you about the pressure of the gas inside the tube as compared to the pressure of the gas (air) outside the tube?

If you think about it, you should realize that the pressure of the gas inside the tube is *less than* the pressure outside. Part of the challenge of this lab will be figuring out how to account for this pressure difference.

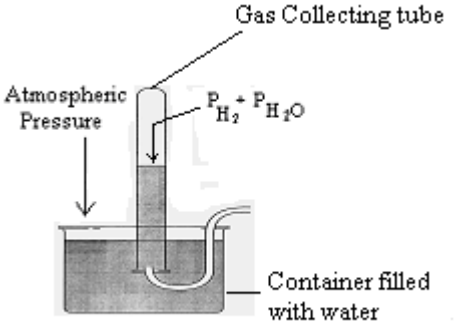

Figure 1. Collection of a gas (e.g. H_2) over water. Note that since the water level inside the gas collecting tube is higher than that in the container, the pressure of the gases within the tube is lower than atmospheric pressure. Also note that the gas collected will be wet since water within the tube evaporates. Hence the pressure within the tube is due to the pressure exerted to the gas collected (e.g. H_2) and the water vapor.

Another factor that will need to be considered is the pressure exerted by evaporated water. Anytime a gas is collected over water, it is saturated with water vapor. Thus, the total pressure of the gas inside the tube is due to *both* the hydrogen and the water vapor. You will need to subtract of the portion of the pressure that is due to the water vapor in order to find the pressure of the hydrogen.

Remember, to find *R* you will need to know the pressure, volume, temperature and number of moles for your sample of hydrogen gas. The section below reviews how to find this information from the data you will collect in lab.

- **Number of moles of gas, n**: In this experiment the magnesium metal will be the limiting reactant. Thus, you can determine the number of moles of hydrogen gas produced from the mass of magnesium that reacted.

- **Temperature of gas**: It is not possible to place a thermometer directly in the gas collection tube, so you will have to assume that the temperature of the water in the beaker approximates the temperature of the gas.

Determination of the Pressure and Volume of the Hydrogen

You will need to adjust the pressure of the hydrogen collected so that it is equal to the atmospheric pressure. Once this is done you can read the volume of the gas from the gas collecting tube. The gas pressure is adjusted by "dunking" the gas collecting tube in a large bucket of water. As the tube is submerged in the bucket of water, the pressure increases. The volume also changes in proportion to the pressure change.

Rationale: The pressure of the gas inside the tube is *less than* the pressure outside the tube, because the liquid in the tube is higher than the liquid in the beaker. The pressures are *equal* when the liquid levels are equal.

- **Pressure of gas:** Once the tube has been "dunked" (figure 2) and the liquid levels are equal, $p_{atmosphere} = p_{gas}$. However, this gas pressure includes the pressure of *both* the hydrogen *and* the pressure due to water that has evaporated. This pressure is called the ***vapor pressure of water***, and its value *depends only on the temperature of the water*.

$$P_{atmosphere} = p_{gas} = p_{hydrogen} + p_{water\ vapor}$$

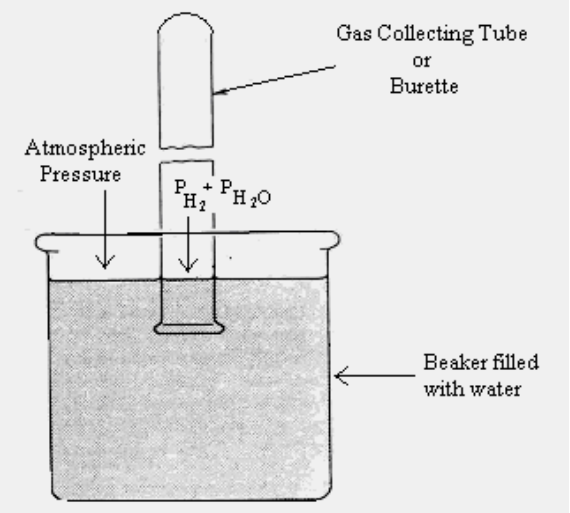

Figure 2. If the level of water within the collection tube is the same as that in the beaker, then the pressure of the gases within the tube is equal to that of the atmosphere.

Since the calculation for moles of gas includes just the hydrogen, the calculated pressure should be the pressure of just the hydrogen. Thus you will need to subtract off the partial pressure of the water vapor. This value can be looked up in a table that will be posted in the lab. Remember the vapor pressure of water depends only on the temperature. Once the vapor pressure of water has been determined, it can be subtracted from the total pressure to give the pressure of the hydrogen gas.

$$p_{hydrogen} = P_{atmosphere} - p_{water\ vapor}$$

- **Volume of gas**: The volume of the gas is recorded *after* the pressures have been equalized. Because you will pressurize the gas by dunking it in the bucket, this volume should be *less than* the volume before equalizing pressures.

Procedure

1. Obtain a gas collection tube, a length of Cu wire (about 12 in) and a one-hole stopper. You will also need a clamp for mounting the tube on a ringstand.

2. Record today's barometric pressure in your notebook.

3. Weigh out an amount of Magnesium that will produce between 25 and 40 mL of hydrogen gas.

4. Fold the Mg to produce a small wad and wrap the Mg with the Cu wire to form a copper cage around the magnesium. Leave about a 3 cm length of Cu wire coming off of the cage.

5. Obtain about 50 mL of 6 M HCl. Add approximately 20 mL to the gas collection tube. Then *carefully* add water to completely fill the tube. The idea is to not disturb the HCl as the water is added. Try pouring the water down the side of the tube.

6. Run the loose end of the copper cage through the one-hole stopper and insert the stopper into the gas collection tube. Make sure that the tube is completely filled with water and that no air bubbles remain.

7. With one finger covering the hole in the stopper, invert the tube into a beaker of water. Mount the tube to a ringstand, but do not let the end of the tube come out of the water. As the HCl flows down the tube it will react with the Mg, generating H_2 gas which will rise to the top of the tube and displace water out of the bottom.

8. When the reaction has finished, record the temperature of the water in the gas collection tube.

9. Carefully remove the gas collection tube from the beaker, placing a finger over the stopper so that no liquid escapes. Carry the tube over to the large bucket of water at the front of the room and submerge the tube in the water. Raise the tube up and down and note how the volume of the gas changes as the gas collection tube is raised or lowered in the bucket. The *volume* of the gas changes because the *pressure* changes as it is raised and lowered. When the tube is lowered in the bucket, the pressure *increases* because there is a greater mass of water pushing on the gas. It's the same reason your ears hurt when you dive to the bottom of a swimming pool.

10. When the liquid level inside the tube equals the level in the bucket, the pressure inside the tube must equal the pressure outside the tube (atmospheric pressure). Record the volume of the gas at this point.

11. ***Use the data collected to calculate a value for the gas constant R. Compute a percent error for and discuss the results in a thoughtfully written analysis section.***

Error Analysis Questions

Consider the following questions when analyzing the results of this lab for sources of experimental error, but record your answers to these questions after the conclusion section of your report. Title this section of your report "Error Analysis Questions" and number your responses as the questions are numbered below.

1. If air enters the gas collecting buret before hydrogen gas is generated and is *not* removed, will the reported value for the gas law constant be too high, too low, or unaffected? Explain your reasoning.

2. If all the connections in the apparatus are *not* airtight and some hydrogen gas escapes during the reaction, will the reported value for the gas law constant be too high, too low, or unaffected? Explain your reasoning.

3. Suppose the water in the gas collecting tube is assumed to be 25 ^{o}C, but it is actually 15^{o}C. Will this error cause the reported value for the gas law constant be too high, too low, or unaffected? Explain your reasoning.

4. Assume the leveling tank is not available and the water level in the gas collecting tube is *higher than the water level in the beaker*. If the pressure of the "wet" hydrogen is assumed to equal atmospheric pressure and the volume is recorded, will the calculated moles of hydrogen gas be too high, too low, or unaffected? Explain your reasoning.

Lab 8 Prelab Questions
Gas Law Constant Lab

Name _____

Team No. ___ **Date** _____ **Section** ____

Instructions: Complete all parts of the following three questions and hand in at the start of your lab period. Show your work with units and correct significant figures for all questions that involve a calculation.

1. Using the fact that one mole of gas occupies *approximately* 24 L, calculate the amount of Mg metal that will produce between 25 and 40 mL of H_2 gas. *Note that this is only an approximation that allows you to calculate an appropriate amount of Mg to use. Circle your answer.*

2. You will use about 20 mL of 6 M HCl to react with the magnesium. Confirm that the magnesium will be the limiting reactant this experiment.

3. A 30.0 mg sample of impure aluminum reacts with excess 6 M HCl. A 40.2 mL volume of hydrogen gas is collected over water at 20.0 ^{o}C. The pressure of the "wet" hydrogen gas is adjusted to atmospheric pressure, a pressure of 747.5 mmHg. The vapor pressure of water at 20.0 ^{o}C is 17.5 mmHg.
   a. Write the balanced chemical equation for the reaction between aluminum and hydrochloric acid, HCl.

   b. Calculate the number of moles of hydrogen gas produced. *Circle your answer.*

   c. Calculate the number of *milligrams* of aluminum that reacted. *Circle your answer.*

   d. Calculate the percent aluminum in the 30.0 mg sample. *Circle your answer.*