Determining the Universal Gas Constant

From the ideal gas law, PV = nRT, it is possible to determine a value for R if you can isolate a sample of gas for which P, V, T and n are all known. In this experiment you will accomplish this by collecting hydrogen gas formed in the reaction of magnesium metal with hydrochloric acid, according to the equation

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

Based on the reaction stoichiometry, if the HCl(aq) is in excess, the moles of H_2 produced can be calculated from the mass of Mg used, its formula mass and the mole ratio from the balanced equation. If the volume, pressure and temperature of the known number of moles of H_2 produced are measured, then the ideal gas law can be used to calculate *R*. The H_2 will be generated in the Erlenmeyer flask shown in Figure 1 by adding the HCl solution in the syringe to the flask containing the Mg ribbon.

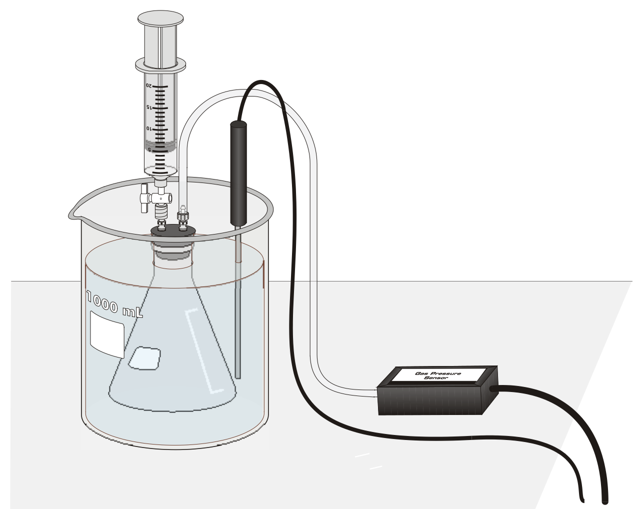

Figure 1

According to Dalton's Law, the total pressure of the gas mixture is the sum of the partial pressure of H_2 plus the partial pressure of the water vapor. The partial pressure of the water vapor can be looked up in tables in the *CRC Handbook*, and subtracted from the total pressure to find the pressure of the H_2. The volume of the gas will be determined by finding the actual available volume of the flask. In this experiment you will calculate the gas law constant, R, by collecting a known quantity of hydrogen gas and measuring the temperature, pressure and volume of the gas collected.

OBJECTIVES

- Collect a known quantity of hydrogen gas from a chemical reaction
- Measure the temperature, pressure and volume of the gas collected.
- Determine the partial pressure of the dry gas.
- Calculate the universal gas constant, R

MATERIALS

LabQuest interface	3.0 M hydrochloric acid, HCl, solution
Computer with Loggerpro (optional)	small beaker for HCl solution
Vernier Gas Pressure Sensor	Analytical balance
Temperature Probe	125 mL Erlenmeyer flask
600 mL or one liter beaker	20 mL gas syringe
10 mL graduated cylinder	plastic tubing with two Luer-lock connectors
Magnesium ribbon, pre-cut	rubber stopper assembly with two-way valve

SAFETY PRECAUTIONS

Hydrochloric acid is corrosive to skin, eyes, and clothing. When handling hydrochloric acid, wear safety goggles and a lab apron. Wash spills and splashes off your skin and clothing immediately using plenty of water. Inform your teacher immediately.

Hydrogen is highly flammable, so don't keep any open flames or electrical sparks close to your experiment. The amount of gas evolved is relatively small and causes no danger once released in the laboratory.

PROCEDURE

1. Obtain and wear goggles.

2. Obtain a piece of magnesium ribbon. Precisely determine the mass of the magnesium ribbon using a sensitive balance. Place the piece of magnesium ribbon in a clean and dry 125 mL Erlenmeyer flask.

3. Prepare a room temperature water bath in a large beaker. The bath should be deep enough to completely cover the gas level in the Erlenmeyer flask.

4. Connect a Gas Pressure Sensor to Channel 1 of the LabQuest interface. Connect a Temperature Probe to Channel 2 of the interface. Set up data collection: you need to collect data for 5 minutes (150 samples, 2 seconds/sample).

5. Use the clear tubing to connect the white rubber stopper to the Gas Pressure Sensor. (About one-half turn of the fittings will secure the tubing tightly.) Twist the white stopper snugly into the neck of the Erlenmeyer flask to avoid losing any of the hydrogen gas that will be produced in the reaction (see Figure 1). **Important**: Close the valve on the white stopper by turning the white handle so it is perpendicular with the valve stem.

6. Obtain a small amount of 3.0 M hydrochloric acid. **CAUTION:** *Handle the hydrochloric acid with care. It can cause painful burns if it comes in contact with the skin*. Draw 5 mL of HCl solution into the 20 mL syringe. Thread the syringe onto the two-way valve on the white stopper (see Figure 1). Submerge the Erlenmeyer flask into the water bath. Position the Temperature Probe in the water bath so that the tip of the probe is not touching the beaker.

7. With the flask still submerged in the water bath, select START to begin data collection. After about 20 seconds, open the two-way valve directly below the syringe, press the plunger to add all of the 5 mL of HCl solution to the flask, and then close the two-way valve.

8. Gently swirl the flask, while keeping it immersed in the water bath, as the reaction proceeds. Data collection will stop after 5 minutes. During the experiment, only the pressure readings will be plotted on the graph. You may end data collection *before* 5 minutes have elapsed, if the pressure readings are no longer changing. (Note: If the stopper pops off before all the magnesium has reacted, you will need to repeat the trial.)

9. Carefully remove the white stopper from the flask to relieve the pressure in the flask. **Important**: Do not open the two-way valve to release the pressure in the flask.

10. Analyze the data. Temperature and pressure will be plotted on separate graphs.
    a. Examine the graph of pressure *vs.* time. Examine the graph and record the initial and maximum gas pressures. Calculate the maximum pressure change. Record the pressure change, ΔP, in your data table..
    b. Examine the graph of temperature *vs.* time. Determine the average temperature of the water bath during the reaction (considered to be the temperature of the reaction) and record this value in your data table.

11. Save your data from the first trial. If you brought a USB drive, save the data on your drive.
12. Rinse, clean, and dry the flask for a second trial. Obtain a new piece of magnesium ribbon and place it in the flask. Repeat the necessary steps to conduct the second trial.
13. Follow the same procedure to conduct a third trial, if time allows. Share your data with your classmates.

14\. With the 125 mL Erlenmeyer flask used for the experiment, determine and record the available volume of the flask that the hydrogen gas will occupy as it is produced from the reaction of the solid magnesium and the hydrochloric acid solution. Account for the following items when you determine the volume of your flask:

- A 125 mL flask does not have a volume of precisely 125 mL.
- During the experiment, you sealed the flask with a rubber stopper and the stopper occupied some of the volume of the flask.
- You added 5 mL of solution (3.0 M HCl solution) to the flask.

14\. Use your text, or another appropriate reference, to find and record the water vapor pressure for the temperature of each trial.

DATA TABLE

	Trial 1	Trial 2	Trial 3
mass of Mg (g)			
Volume of flask (mL)			
Maximum pressure (kPa)			
Initial pressure (kPa)			
Pressure change, ΔP (kPa)			
Temperature (K)			
Vapor pressure of water (kPa)			

DATA AND CALCULATIONS

1. Calculate the number of moles of each piece of magnesium that you used. As part of your calculations, confirm that the magnesium was the limiting reagent.
2. Calculate the number of moles of $H_2(g)$ produced.
3. Determine the partial pressure of the dry hydrogen for each trial.
4. Using the experimental values for pressure, temperature, volume, and moles of the dry hydrogen, calculate a value for R. Repeat the calculations for your second and third trials.
5. Use class data to determine an average.
6. Calculate the average deviation for your trials (compared to the class data).
7. Calculate your percent error from the literature value for R. (Be sure to state your source for the literature value of R.)

ANALYZE AND APPLY

1. Which measurement limits the number of sig figs in your calculated value of *R*?
2. Discuss experimental sources of error. Be specific.
3. Explain how each of the following would affect your experiment value for the universal gas constant. In each case, justify your answer.
   a) You forgot to subtract the vapor pressure of water.
   b) Not all of the magnesium reacted.
   c) Hydrogen gas is soluble in water.
4. Do your results indicate that, under the conditions of the experiment, hydrogen behaves as an ideal gas? Justify your answer.
5. Which gas would you expect to deviate more from ideal behavior: H_2 or HBr? Explain your answer.