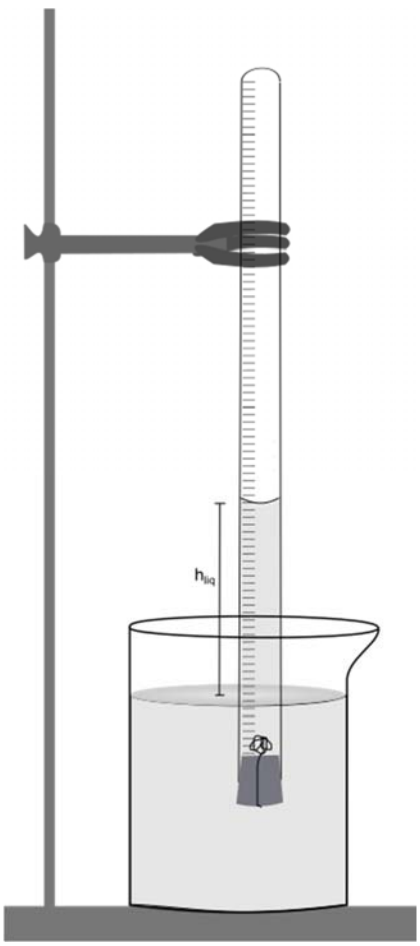
Experiment 14 - Calculation of the Ideal Gas Constant

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. It is more convenient to put this relationship in the form of an equation, adding a constant to ensure that units work out correctly. This constant, *R*, is called the **ideal gas constant**. The resulting equation is the familiar **ideal gas law**:

$$PV = nRT \qquad \text{Eq 1}$$

The object of the present experiment is to measure *R* using a sample of hydrogen gas, H_2. To do this, we must simultaneously measure *P*, *V*, *T*, and *n*. The value of *R* can then be calculated and compared with the accepted value of *R*. We will collect the gas in a graduated tube (eudiometer) over water, as shown. In this experiment *V* will be measured directly using the markings on the eudiometer, *T* will be inferred by assuming that the gas is at room temperature, and *n* will be calculated from the amount of magnesium used to produce the hydrogen gas according to the equation:



$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g) \qquad \text{Rxn 1}$$

To calculate the partial pressure of hydrogen in the tube, P_{H2}, which is the pressure we must use to find *R* (since this pressure matches the *n* we are using), there are two corrections to take into account. First, the gas is collected over water, so the vapor pressure of water must be subtracted from the total gas pressure. The second correction is due to the column of solution remaining in the tube at the end of the reaction. Because the level of solution inside the tube is higher than the water level in the beaker at the end of the reaction, the pressure of gas inside the tube is lower than the atmospheric pressure. You will need to convert the height of the liquid column to the corresponding height of mercury. Since **mm Hg** is the same as **torr**, a common unit of pressure, it may then be subtracted from the total pressure.

To convert the height of the column of solution to the corresponding height of mercury, the differing densities of mercury (d = 13.6 g/mL) and the acid solution (d = 1.05 g/mL) must be taken into account. You can relate the height of any liquid to the height of mercury that corresponds to the same pressure using

$$d_{liq}h_{liq} = d_{Hg}h_{Hg} \qquad \text{Eq 2}$$

where *d* is the density and *h* is the height of each liquid. In this case, you'll measure h_{liq}, and then find h_{Hg}. The height of a mercury column in millimeters is equal to the pressure in torr, so h_{Hg} (in mm) is gives the pressure of the liquid column in torr.

Finally, the atmospheric pressure on the surface of the water in the beaker is balanced by the partial pressure of hydrogen gas P_{H2}, the partial pressure of the water vapor P_{WV}, and the pressure of the water column ($P_{WC} = h_{Hg}$).

$$P_{atmosphere} = P_{H2} + P_{WV} + P_{WC} \qquad \text{Eq 3}$$

You can read the atmospheric pressure off the barometer in the lab and look up the vapor pressure of water at the room temperature online, allowing you to find the partial pressure of the hydrogen gas.

Safety Precautions:

- Wear your safety goggles.
- Use caution when handling 6 M HCl. It is corrosive and can burn your skin. If any HCl comes into contact with your skin, rinse it off immediately and thoroughly with lots of water.

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 2 cm long. Clean the ribbon with fine steel wool and weigh it to the nearest 0.0001 g (use the balances in the balance room). Make sure that it weighs less than 0.04 grams, and that your recorded mass has three significant figures. (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. Make sure that the ball is not too large to fit into the gas measuring tube.
3. Set up a ring stand with a buret 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. Add water to the tube until it overflows slightly. Holding the copper coil by the handle, insert the cage about 3 cm down into the tube. Hook the wire over the edge of the tube where it will be pinched by the rubber stopper and held in place. 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.

6. Add some more water to the hole in the stopper so that it is completely filled with water. 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.
7. Check if there is any bubble at the top of the tube (ideally, there won't be). Record if there is a bubble at the top of the tube, and how big it is.
8. 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 and record your observations.
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.
10. Tap the tube (gently) to dislodge the bubbles stuck to the sides. Try to get them all to join the main gas sample as the top.
11. Read and record the volume of the hydrogen gas in the eudiometer to the nearest 0.1 mL.
12. *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.
13. Measure and record the temperature of the gas.
14. Record the atmospheric pressure (the instructor will read the barometer and write today's atmospheric pressure on the board).
15. Repeat the entire procedure with a second sample of magnesium (you can probably use a second tube and other apparatus, and clean both up at once).
16. Perform your calculations before cleaning up your gas sample. This ensures that you can repeat any measurements if necessary.
17. Disassemble the apparatus (remove the stopper carefully from the tube, and collect all the liquid in the beaker). 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.
18. Write your name and your two results for *R* on the board in the classroom.

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. Use Eq 2 to find the pressure correction for the height of the water column, in mm Hg (torr). Make sure to convert the height of the liquid column to units of millimeters before using the equation. Do this for each trial.
3. For each trial, find the partial pressure of hydrogen using Eq 3. All the units should be mm Hg (torr).
4. Using the Ideal Gas Law (Eq 1), calculate the experimental value for *R* for each trial.

5. Find your average value of *R*. Calculate the percent error using the accepted value of *R* (62.36 L torr K^{-1} mol^{-1}) and your average experimental value of *R*.
6. Write your results for *R* on the board with your name. The instructor will post the class results so you can use them for your post-lab.

Name: Section:

Experiment 14 Pre-Lab Sheet

1. (1 pt) Why don't we need to measure the acid volume precisely?

2. (2 pts) How many moles of hydrogen gas are produced when 0.2145 g of Mg are reacted completely with HCl?

3. (1 pt) Why should you measure the mass of the Mg ribbon to 0.0001 g, not 0.001 g?

4. (2 pt) Before you clean up your experiment, what do you need to measure? In addition measurements of your apparatus, what other information do you need for your calculations?

5. (4 pts) A sample of nitrogen gas is collected over water, like in this lab. The atmospheric pressure is 745 torr, the vapor pressure of water is 17.5 torr, and the height of the column of water is 22.4 cm. Find the partial pressure of the nitrogen gas.