6—Evaluation of the Gas Law Constant

Name: ______________________________

Date: ______________________________

Section: ______________________________

Objectives

- Measure the value of the gas constant R
- Use Dalton's Law to calculate the partial pressure of hydrogen in a closed container
- Learn to collect a gas by displacing water from a closed container
- Additional experience with the uncertainty of physical measurements
- Additional experience with significant figures
- Additional experience with average, deviation, average deviation and relative average deviation

Pre-Laboratory Requirements

- Read chapter 5.1-5.4 in Silberberg
- Watch the instructional video titled "Eudiometer"
- Pre-lab questions (if required by your instructor)
- Laboratory notebook—prepared before lab (if required by your instructor)

Safety Notes

- Eye protection must be worn at all times.
- Hydrochloric acid is caustic and should not come in contact with your skin or clothing. Wear gloves when handling hydrochloric acid. A lab coat or lab apron is recommended.
- Hydrogen is highly flammable; there should be no open flames or electrical sparks in the area

Discussion

Gases, liquids, and solids constitute the three common forms of matter. This experiment gives you the opportunity to explore several properties of gases and to measure a value for the international gas constant R.

Gases expand to occupy the container in which they are placed and any gas is less dense than the liquid or solid form of a substance. In addition to expanding to completely fill containers, gases exert pressure on the walls of the container and the pressure increases with increasing temperature. The relationships between volume, pressure, and temperature are summarized in Charles' law in the Boyle's law. Avogadro's law demonstrated that the volume of a gas was proportional to the number of gas molecules.

These three empirical relationships were combined into one equation which is known as the ideal gas law, $PV = nRT$, where P represents pressure, V stands for volume, n is the amount of gas, and T is the absolute temperature. R is a proportionality constant that must be measured experimentally and the units for R will depend on the units used for each of the variables in the ideal gas law. Chemists measure pressure in atmospheres, volume in liters, quantity in moles and temperature in kelvins. The accepted value for the gas constant R is 0.0821 L·atm/mol·K.

In this experiment, hydrogen gas will be collected in a calibrated tube called a eudiometer. By measuring the volume, pressure, and temperature of the gas we are able to calculate a value for R if the quantity of the gas is known. We will generate hydrogen gas by treating a known mass of magnesium metal with HCl, providing a way to measure the amount of H_2 gas generated.

$$Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)} \qquad \text{(balanced equation)}$$

Volume: Hydrogen gas will be generated from a strip of magnesium placed at the opening of a water-filled to, the eudiometer. Water is displaced from the eudiometer by bubbles of hydrogen gas when magnesium reacts with HCl. Calibration on the side of the eudiometer gives us the volume of the collected gas. Figure 1, below, is a diagram of the apparatus we will use for this experiment.

Pressure: Because the hydrogen gas is collected in this manner, the eudiometer contains a mixture of H_2 and water vapor. In addition to water vapor, pressure can be applied to the hydrogen gas inside the eudiometer if the water level inside the tube is not exactly the same as the water level in the beaker outside the tube. The sum of these pressures must equal the atmospheric pressure in the room when the experiment is conducted, and we can use Dalton's law of partial pressures to calculate the pressure of H_2 inside the eudiometer.

$$P_{atm} = P_{H_2} + P_{H_2O} + P_{water\ level\ difference} \quad \text{equation 1}$$

$$P_{H_2} = P_{atm} - P_{H_2O} - P_{water\ level\ difference} \quad \text{equation 2}$$

Quantity: The number of moles of hydrogen gas generated is calculated from the mass of magnesium metal ribbon placed at the opening of the eudiometer.

Temperature: The reaction between magnesium and hydrochloric acid is exothermic. Heat generated from this reaction changes the temperature of hydrogen inside the eudiometer. Therefore the temperature must be measured by placing a thermometer in the water outside the eudiometer, where the reaction between magnesium and HCl takes place.

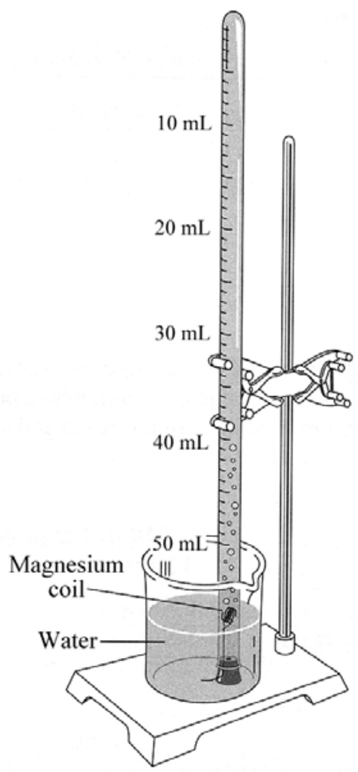

Figure 1. Collecting hydrogen gas with a eudiometer tube. (Courtesy of Xena's Chemistry Notebook. http://valenzuelachemistry.blogspot.com/2012/02/name-valenzuela-number-21-lab-partner.html)

Calculations

The quantity of hydrogen gas generated is calculated from the mass of magnesium, keeping in mind that one mole of magnesium generates one mole of hydrogen gas.

Temperature is recorded from a thermometer placed in the water outside the eudiometer. The temperature you read from the thermometer must be changed from Celsius to Kelvin which is accomplished by adding 273.15 to the Celsius temperature.

The volume of gas generated is read directly from the scale on the side of the eudiometer. Convert the volume of hydrogen gas from mL to L so your final answer will have correct units. If your eudiometer contained an air bubble at the start of the experiment, you should record the initial volume, then subtract this number from the final reading to obtain only the volume of hydrogen gas generated.

Calculating the partial pressure of hydrogen gas is the most challenging part of these calculations, requiring several conversions of the raw data. Atmospheric pressure in the laboratory is available from a barometer on the wall of the lab. The units of the barometer are inHg which must be first converted to mmHg, and then to atm. For example:

Atmospheric pressure: 28.75 inHg X 25.4 mm/in ÷ 760 mmHg/atm = 0.961 atm

The vapor pressure of water is given in Table 1 at the end of this experiment. At a temperature of 23.0°C the vapor pressure of water is 21.1 mmHg. Vapor pressure of water in atmospheres then, is:

Partial pressure of water vapor: 21.2 mmHg ÷ 760 mmHg/atm = 0.028 atm

Pressure on the hydrogen gas due to differences in water heights must be calculated by measuring the difference between the water levels inside the eudiometer and outside the eudiometer, in the beaker. Measure this distance with a plastic ruler and record the level difference in millimeters. This number is the pressure due to water level difference, in mmH_2O, which must be converted to atmospheres. To convert mmH_2O to mmHg we must divide the value in mmH_2O by the density of mercury (13.5 g/cm^3). Since the density of water is 1.00g/cm^3, the units will cancel. If the water in the eudiometer is 227 mm above the surface of the water in the beaker, we can calculate the pressure from water level difference as follows:

Pressure from water level difference: 227 mmH_2O ÷ 13.5 H_2O/Hg ÷ 760 mmHg/atm = 0.022 atm

For this example, P_{H_2} would be calculated as follows:

$$P_{H_2} = P_{atm} - P_{H_2O} - P_{water\ level\ difference} = 0.961\ atm - 0.028\ atm - 0.022\ atm = 0.911\ atm$$

Solve the ideal gas law for R to calculate your final answer. Repeat the calculations for all three trials and calculate an average value for R, the deviation, average deviation and the relative average deviation.

R = PV/nT [rearranged]

Procedure

1. Measure 4 cm of magnesium ribbon and record the mass.
2. Bend a piece of copper wire into an S shape so that it fits snugly into the opening of the eudiometer. The purpose of the copper wire is to hold the magnesium in position when the eudiometer is inverted.
3. Coil the Mg ribbon around the copper.
4. Add 8 mL of 6 M HCl to the eudiometer tube, then carefully add deionized until the water level reaches the top.
5. Fit the copper wire and magnesium into the tube about 1 inch from the opening.
6. Invert the eudiometer tube into a large beaker filled about ¾ with water (*Note: Record the initial volume of the tube before any reaction takes place*) and clamp it into position.
7. The HCl will diffuse down and react with the magnesium to form hydrogen gas.
8. Record the volume of gas in the eudiometer after the magnesium dissolves (i.e., no bubbles are forming).
9. Record the temperature of the water.
10. Using a plastic ruler, measure the distance between the level of liquid in the eudiometer and the level of liquid in the beaker. Record this distance in mm.
11. Repeat this procedure two more times.

Data

	Trial 1	Trial 2	Trial 3
Mass of Mg ribbon (g)	________	________	________
Moles of Mg (mol)	________	________	________
Volume of gas in eudiometer (mL)	________	________	________
Volume of gas in eudiometer (L)	________	________	________
Temperature (°C)	________	________	________
Temperature (K)	________	________	________
Barometric pressure (inHg)	________	________	________
Barometric pressure (atm)	________	________	________
Vapor pressure of water (mmHg)	________	________	________
Vapor pressure of water (atm)	________	________	________
Difference in water levels (mm)	________	________	________
Difference in water levels (atm)	________	________	________
P_{H_2} (atm)	________	________	________
R (atm·L/mol·K)	________	________	________
Average value for R (atm·L/mol·K)		________	
Average deviation of R (atm·L/mol·K)		________	
Relative average deviation of R		________	

Reported valued for R: ________ ± ________ or ________ ± ________ %

Error for R		________	
Relative error for R		________	

Table 1. Vapor pressure (P) of water at various temperatures

T, (^{0}C)	P, mmHg	T, (^{0}C)	P, mmHg	T, (^{0}C)	P, mmHg	T, (^{0}C)	P, mmHg
13.0	11.2	19.0	16.5	25.0	23.8	31.0	33.7
14.0	12.0	20.0	17.5	26.0	25.2	32.0	35.7
15.0	12.8	21.0	18.7	27.0	26.7	33.0	37.7
16.0	13.6	22.0	19.8	28.0	28.3	34.0	39.9
17.0	14.5	23.0	21.1	29.0	30.0	35.0	42.2
18.0	15.5	24.0	22.4	30.0	31.8	36.0	44.6

Final Report

Your final report should include your reported value for R. Report your value to the correct number of significant figures with an estimate of the uncertainty of your value. You should include a discussion of the error with the accepted value for R. Include a sample calculation, demonstrating how R was calculated from the data you collected. The calculation does not need to be typed and may be hand written.

References

Cornely, K.; Moss, D. B.; Determination of the universal gas constant, R. A discovery laboratory. *J. Chem. Ed.*, **2001**, 78, 1260. doi:10.1021/ed078p1260

Lebman, T. A.; Harms, G.; Determination of the universal gas constant. *J. Chem. Ed.*, **1988**, 65, 811. doi:10.1021/ed065p811

Olsen, R. J.; Sattar, S.; Measuring the gas constant R: Propagation of uncertainty and statistics. *J. Chem. Ed.*, **2013**,90, 790-792. doi:10.1021/ed3005374

Calculations:

