Experiment 8

8/7/18

GAS LAWS

MATERIALS: Amontons' Law apparatus, Boyle's Law apparatus, Avogadro's Corollary apparatus, four beakers (2 L), warm-water bath, ice, barometer, digital thermometer, air compressor, tire gauge; 250 mL beaker, gas collection tube, 25 mL graduated cylinder, Mg ribbon, Cu wire, 3 M HCl.

PURPOSE: The purpose of this experiment is to determine the individual effects of temperature (T), volume (V), and mass (m) of a gas on the pressure (P) of the gas. The combined effects of these variables on the pressure of the gas can then be expressed in a single mathematical relationship known as the Ideal Gas Law.

LEARNING OBJECTIVES: By the end of this experiment, the student should be able to demonstrate these proficiencies:

1. Use a spreadsheet program for data manipulation, graphing and regression analysis.
2. Describe the effects of changes in temperature on the pressure of a gas at constant mass and volume.
3. Describe the effects of changes in volume on the pressure of a gas at constant mass and temperature.
4. Describe the effects of changes in mass (moles) on the pressure of a gas at constant volume and temperature.
5. Derive the Ideal Gas Law from experimental observations.

DISCUSSION: A scientific "law" is a concise verbal or mathematical statement of a relation that is always the same under the same conditions. Laws do not explain *why* a relation exist, but simply state *that* it exists. In physics, the law of gravity and the law of action/reaction are well-known. There are physical laws in Chemistry, too; you should be familiar with the law of conservation of mass as applied to reactions and, in this experiment, the gas laws. During the course of this experiment, the individual effects of gas volume (V), mass (m), and temperature (T) on the pressure (P) of a gas will be determined. Each of these effects will be studied in a separate procedure so that only one of the variables is changed at a time. This is the typical approach in what is often called the "scientific method", and also follows the path of discovery of the individual gas laws by Boyle, Charles, Avogadro and Amontons. For example, one procedure measures the effect of temperature on pressure. To make this as clear as possible, the mass and volume of the gas are kept constant. Once all of the individual effects have been studied, the combined effects of these three variables on the pressure of the gas can then be expressed in a single mathematical relationship known as the Ideal Gas Law. The combined proportionality constant is the universal gas constant, R.

PROCEDURE:

Note: Data collection for the four parts of this lab can be done in any order. Your instructor may assign a specific order or rotation to minimize delays in some parts. Follow the directions of your instructor. When not collecting data you should work on analysis of the data you already have.

Part A: Relationship between the pressure and temperature of a fixed amount of gas at constant volume (Amontons' Law)

1. Trap a fixed amount of gas in the Amontons' Law apparatus (Figure 1) by opening and then closing the brass stopcock. The stopcock is closed when it is oriented 90° to the barbed gas nozzle. The stopcock should remain closed for the duration of this part of the experiment. Make sure the outside of the bulb is dry. Using the gauge attached to the apparatus, measure the pressure of the trapped gas at room temperature. Record this value and the temperature of the room, using the proper number of significant figures and units, in the Data Section.

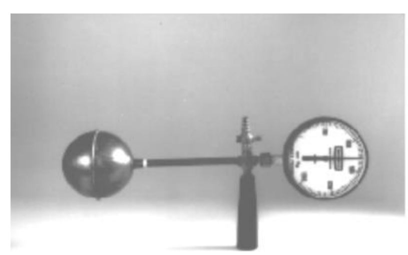

Figure 1: Amontons' Law Apparatus

2. The three remaining sets of pressure and temperature data will be measured at high temperature (boiling water bath), low temperature (ice bath), and an intermediate temperature (warm-water bath) and can be taken in any order. Class temperature baths may be used instead of individual setups.

   a. For the high temperature measurement, use the class setup or add approximately 1.1 L of water to a 2 L beaker on a large hotplate. Bring the water to its boiling point. Carefully immerse the bulb of the Amontons'

Law apparatus into the boiling water up to the joint where the ball and brass stem meet. **Care should be taken to hold the apparatus firmly while it is immersed because the buoyancy of the apparatus will cause it to twist**. *Hold the apparatus at an angle so that the steam does not come into contact with your hand* and keep the apparatus in this position until the needle on the pressure gauge stabilizes. In the Data Section, record the pressure (and units) of the gas at its peak. Remove the apparatus from the boiling-water bath. Measure the temperature of the water in the beaker using the thermometer provided and record this value in the Data Section.

b. For the low temperature measurement, repeat the procedure described above using the ice-water bath.

c. The final set of data will be obtained using the warm-water bath. Immerse the bulb of the Amontons' Law apparatus into the water up to the joint on the stem. *Hold the apparatus at an angle so that the steam does not come into contact with your hand***.** Once the needle on the pressure gauge has stabilized, record the pressure (and units) of the trapped gas at its peak. Remove the apparatus from the warm-water bath. Measure the temperature of the water bath using the thermometer provided and record this value in the Data Section.

Part B: Relationship between the pressure and volume of a fixed amount of gas at constant temperature (Boyle's Law)

In this part of the experiment, a sample of gas will be trapped in a syringe attached to a pressure gauge (Figure 2). As the syringe plunger is moved, the volume of the system (syringe + gauge + tubing) available to the gas is changed, and corresponding changes in pressure are read from the gauge. Because the gauge and tubing themselves have volume, the system must first be calibrated by finding the volume of the gauge plus tubing.

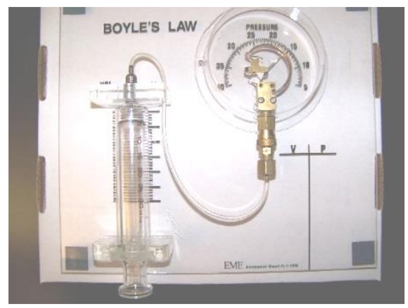

Figure 2: Boyle’s Law Apparatus

1. Calibrate the unit as follows:
   a. Disconnect the syringe from the gauge by gripping the knurled sleeve below the gauge and pushing it up towards the gauge housing, releasing the fitting.
   b. Set the syringe plunger at the 0 mL mark first, and *then* reconnect the fitting by lifting the knurled sleeve, inserting the fitting, and releasing the sleeve. Record the pressure reading (and units) at the 0 mL mark.
   c. Pull out the plunger until the ***pressure*** reading is ½ of the original value. Record the ***volume*** of the syringe at this point. (It will probably be about 4.0 mL; record to the nearest 0.1 mL) That is the volume of the gauge plus tubing.

2. Collect data as follow:
   a. Disconnect the fitting from the gauge, set the plunger at 20.0 mL, and reconnect the fitting. Record the pressure reading.
   b. Push in the plunger, stopping at three or four convenient values. Record the syringe volume and the pressure each time.
   c. Pull the plunger out beyond 20.0 mL, stopping at convenient values (**to a maximum of 30.0 mL**) until you have eight total data pairs. Record the volume and pressure readings each time.

Part C: Relationship between the pressure and mass of a gas at constant volume and temperature (Avogadro's Corollary)


Figure 3. Avogadro’s Corollary apparatus

1. **Wearing your goggles**, fill the aluminum pressure vessel (Figure 3) with air using the air compressor located in the hallway. Ensure that the pressure of the air in the aluminum vessel can be measured with the gauge provided before recording any measurements. Refill the can if necessary.

2. Using care not to transfer hand oil or dirt to the container, measure the pressure of the air inside the apparatus with a tire gauge. Use the *top-loading* balance to measure the total mass of the apparatus (aluminum vessel plus the air inside). Record these pressure and mass data in the Data Section. (Record pressures to 0.1 psi.)

3. Remove a small amount of air from the vessel by depressing the inner portion of the valve on the aluminum vessel ***for a small fraction of a second*** or by using the pressure gauge multiple times and until a reduction in pressure is observed. As before, measure the pressure of the air inside the apparatus and the total mass of the apparatus. Repeat this process until 6 pairs of pressure and total mass data have been recorded in the Data Section.

4. Remove the remaining compressed air from the container by depressing the valve stem until no more air escapes (a few seconds, usually). Weigh the "empty" vessel and record its mass in the Data Section.

Part D: Determination of the value of the universal gas constant R

1. On *the analytical balance* weigh a ~0.4 inch strip of Mg ribbon. It should weigh ~0.01 g or less. Record the mass (to four decimal places) in the Data Section.

2. Use a piece of thin copper wire ~7 inches long to wrap the Mg ribbon by first wrapping the Mg ribbon five or six turns along its length, and then folding the Mg and wrapping it several times perpendicular to the first wraps. End with a "tail" about 2 inches long, as shown in Figure 4. Put a bend in the wire about ~½ inch from the Mg bundle. The idea is to create a "cage" for the Mg sample to keep it from floating and a handle to allow you to adjust its position.

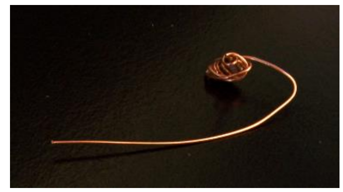

Figure 4. Mg ribbon wrapped in copper wire

3. Fill a 250 mL beaker with deionized water. Fill a gas collection tube to the brim with deionized water. Use your finger or thumb to cover the opening and place the tube upside down in the beaker *without admitting air bubbles* to the tube. Now drain off all but about 50 mL of water from the beaker, *taking care not to let any air into the tube*.

4. Keeping its mouth under water, lift the gas collection tube slightly and place the Mg sample bundle into the tube. Lower the tube onto the bend, so that the Mg stays inside the tube.

5. Using a graduated cylinder, add 25.0 mL of 3 M HCl to the beaker. Stir the liquid with a glass stirring rod. The Mg should begin to react with the acid solution, evolving H_2 gas.

6. Continue to stir while the Mg reacts. You can tilt the tube while stirring to allow fresh acid solution to reach the sample, but don't lose any of the gas bubbles. Allow the reaction to continue until gas evolution ceases, which should be ~5 minutes or less.

7. With the reaction completed, adjust the gas collection tube until the liquid level inside the tube is the same as the liquid level in the beaker surrounding the tube. (You can add extra water to the beaker if necessary.) When the levels are equal, read the volume of gas trapped in the tube and record it in the Data Section.

8. Read the temperature of the water in the beaker and record it in the Data Section.

9. Read the barometer and record the value in the Data Section. Your Instructor will demonstrate the use of the barometer, and directions are also posted next to the instrument. Also, identify and record the value of the equilibrium vapor pressure of water at your measured temperature. Tables will be available; be sure to interpolate if necessary.

10. When you have all necessary data, remove the gas collection tube from the beaker and rinse all of your glassware with distilled water. Place the used copper wire in the trash, NOT the sink!

Name ______________________________________ Section _______________________

Partner _____________________________________ Date _________________________

DATA SECTION
Experiment 8

Part A: Relationship between the pressure and temperature of a fixed amount of gas at constant volume (Amontons' Law)

	Pressure (units: ______)	Temperature (ºC)
Ice Bath		
Room Temperature		
Warm-Water Bath		
Boiling-Water Bath		

Part B: Relationship between the pressure and volume of a fixed amount of gas at constant temperature (Boyle's Law)

Calibration data:

Pressure reading with syringe at 0.0 mL mark: _____________ psi

Syringe volume reading with pressure at ½ initial value: _____________ mL
(this is the calibration volume)

Measurements:

Syringe Volume (mL)	Pressure (psi)
20.0	

Syringe Volume (mL)	Pressure (psi)

Part C: Relationship between the pressure and mass of a gas at constant volume and temperature (Avogadro's Corollary)

Pressure (psi)	Total Mass (g)

Pressure (psi)	Total Mass (g)
"empty"	

Part D: Determination of the value of the universal gas constant R

Mass Mg (g)	
Vol. gas collected (mL)	
Temperature (°C)	

Barometric pressure (torr)	
Vapor pressure of H_2O (torr)	

DATA TREATMENT
Experiment 8

For all calculations, include the proper number of significant figures and the appropriate units. Unless otherwise indicated by your instructor, all data in Parts A-C of this experiment will be analyzed using a spreadsheet program.

Part A: Relationship between P and T of a fixed amount of gas at constant volume (Amontons' Law)

(A.1) Enter the experimental data into a spreadsheet. Depending on which device you used, it may be necessary to convert pressure units; the conversion is 1 psi = 51.7 torr. Plot a graph of pressure in torr vs. temperature (°C). *Note: Pressure is on the y-axis.* The graph should be constructed so that the pressure and temperature scales include the points 0.0 mm Hg (or torr) and minus 300 (–300.0) °C, respectively.

(A.2) Due to scatter in the data, it is often difficult to ascertain visually whether or not there is a linear relationship between the plotted variables. That is, do the data have the form

$$y = m\,x + b$$

where y is the dependent variable (P), x is the independent variable (T), m is the slope of the line, and b is the y-intercept of the line? The goodness of fit is indicated by the value of R^2. The closer the value of R^2 is to 1.00, the more linear the data. To unambiguously determine if there is a linear relationship between these variables, perform a linear regression analysis (or trendline) on the data. Show the best-fit line (or trendline) on your graph of P versus T. Also, include the equation of the line and R^2 on the graph. *(Note that the goodness of fit R^2, is not the square of the universal gas constant.)*

Trendline equation ___________________________________ R^2 ____________________

units of slope _____________________ units of y-intercept _____________________

(A.3) Use the equation for the best-fit line to calculate the temperature at which the pressure equals zero. This temperature is known as absolute zero. In theory, the gas occupies no volume and exerts no pressure at this temperature. Include the absolute zero point on the P versus T graph and extrapolate the best-fit line to include this point.

Experimental absolute zero value = ______________ °C

(A.4) Calculate the percent error between this experimentally determined value of absolute zero (expressed in °C) and the theoretical value (in °C). Percent error (also called relative error or percent deviation) is calculated as

$$\%\ \text{error} = \frac{(\text{measured} - \text{true})}{\text{true}} * 100$$

____

(A.5) Using the values of slope and y-intercept obtained from the trendline of the P versus T data, write the mathematical equation which expresses the relationship between the pressure and temperature of the gas. *(Note: this expression should have the form of a straight line, i.e., y = m x + b.)*

P (torr) = ______________(torr/°C) × T(°C) + ______________(torr)
y m x b

(A.6) Factor the slope from the right side of this equation so that the equation takes the form y = m *[x + b/m].

(A.7) The part in **[**brackets**]** on the right side of the equation in A.6 defines the relationship between the Celsius and Kelvin temperature scales. (Note that Kelvin and the °C are the same size, so the slope of the line is the same in torr/°C as in torr/K.) Based on this, what is your value of the conversion factor between the Kelvin and Celsius temperature scales?

T (K) = T (°C) + ____________________

(A.8) Write a detailed description of the relationship between the pressure of a gas and its temperature. Indicate the experimental conditions necessary for this relationship to hold.

Part B: Relationship between P and V of a fixed amount of gas at constant temperature (Boyle's Law)

(B.1) Enter the experimental pressure reading and syringe volume reading data into a spreadsheet. To be consistent, convert pressure units from psi to torr; the conversion is 1 psi = 51.7 torr. Create a new column for total volume, where

total volume = syringe volume reading + calibration volume

Use your calibration volume determined in Procedure step B1 and recorded on the data sheet. (NOTE: this value depends on the apparatus you used, and may differ from that of classmates.) Create new columns for the inverse of the total volume, and for the product pressure*total volume.

(B.2) Make plots of pressure (torr) vs. total volume (mL), and of pressure (torr) vs. 1/(total volume) (mL^{-1}).

(B.3) The pressure of the gas P_{gas} varies linearly with *either* the volume of the gas or the inverse of the volume of the gas. The output of the R^2 variable from the trendline analysis for both sets of data will be used to determine the relationship between pressure and volume. Perform a linear regression on the P versus V data *and* on the P versus 1/V data. Show the regression equations and R^2 values on the plots. Identify the plot which gives the best straight line and show the trendline equation and R^2 values here as well.

Plot ______________ Trendline equation ___________________________________ R^2 __________

(B.4) Use the spreadsheet program to calculate the mean (average) of the PV products. The Excel function to calculate averages is

= AVERAGE(range)

where (range) is the set of cells that you want to average. (In this case it is the column of pressure*volume values.)

(B.5) Create a new column to calculate the percent deviation of the *individual* PV products from the average deviation. Percent deviation is how far each value differs from the average:

$$\%\ \text{deviation} = \frac{(\text{measured} - \text{average})}{\text{average}} * 100$$

(B.6) Calculate the average of the percent deviations. Absolute cell references (e.g. $F$38) may again be helpful since all deviations are measured from one specific value.

(B.7) Write a detailed description of the relationship between the pressure of a gas and its volume. Indicate the experimental conditions necessary for this relationship to hold.

Part C: Relationship between P and m of a gas at constant volume and temperature (Avogadro's Corollary)

(C.1) Enter the experimental data into a spreadsheet.

(C.2) Note that the pressure gauges used in parts A and B are "absolute" gauges, which means they read the actual pressure directly. By contrast, the tire gauge used in part C is a "relative" pressure gauge, and only reports how much the pressure *differs from* room pressure. (i.e., pressure relative to 1 atm.) The standard atmospheric pressure is ~14.7 psi. Create a new column for true pressure (in psi), and obtain those values by adding 14.7 to your pressure readings. Make a new column to convert those true pressures in psi to true pressures in torr; 1 psi = 51.7 torr.

(C.3) Use the spreadsheet program to construct a graph of true pressure (in torr) vs. mass (in g). Perform a linear regression. Show the regression equation and R^2 on the plot. Also, report the equation and R^2 value here.

Trendline equation ________________________________ R^2 ______________

(C.4) Write a detailed description of the relationship between the pressure of a gas and its mass. Indicate the experimental conditions necessary for this relationship to hold.

Part D: Determination of the value of the universal gas constant R

(D.1) Write out the balanced overall chemical and net ionic equations for the reaction between Mg metal and HCl solution, producing H_2 gas and an aqueous solution of $MgCl_2$.

overall chemical equation:

net ionic equation:

(D.2) Use the mass of Mg and known stoichiometry of the reaction to calculate the number of moles of H_2 that was produced in your reaction. Show your work.

________________ mol H_2

(D.3) Since it was collected over water, the gas sample that was trapped included both H_2 gas and H_2O vapor, with a total pressure equal to the barometric pressure. Use Dalton's Law and your data to calculate the pressure of the H_2 alone, and convert that value to atmospheres. Show your work.

_________________ atm H_2

(D.4) Use your results from above and the temperature of the sample to calculate an experimental value of the gas constant R, in units of L-atm/mol-K. Show your work.

_________________ L-atm/mol-K

(D.5) Calculate your percent error from the accepted value of 0.08206 L-atm/mol-K. Show your work.

_________________ % error

QUESTIONS
Experiment 8

1. Explain why the sphere containing the gas sample in Part A (Amontons' Law) must remain sealed (stopcock closed) throughout the duration of that part of the experiment.

2. The “universal gas constant” has the value R = 0.08206 L-atm/(K-mol). What is the value of R in mL-torr/(K-mol)? Show your work.

3. In Part D, Procedure step 7, what was the purpose of adjusting the liquid level inside the gas collection tube to match that of the water in the beaker?

4. In Part B you first calibrated the apparatus by finding the volume of the gauge and tubing, and then used the total volume in all calculations. How would the results be affected if only the syringe volume, rather than total volume, were used in calculations? Would the slope of the line in your plot of P vs 1/V be larger, smaller, or unchanged? EXPLAIN YOUR ANSWER.
If you are not sure how to reason this out, try using a few data pairs to calculate the slope in both cases.

Name ____ Section ____________________

PRE-LABORATORY QUESTIONS
Experiment 8

1. Some pressure gauges measure relative pressure; i.e., they measure pressures relative to *room* pressure. For example, the pressure gauge on a flat tire may read "zero", but the actual pressure of the tire is that of the surrounding atmosphere (1 atm under normal conditions). Given that 1 atm = 14.70 psi and 1 psi = 51.7 mmHg, calculate the actual pressure (in atm) in an apparatus that has a relative pressure gauge reading of 10.0 psi. Assume normal atmospheric conditions.

2. The table below is an *excerpt* from a spreadsheet on the length of certain objects identified by their color.

	A	B	C
1	**object**	**length (cm)**	**% deviation**
2	Red	5.02	
3	Blue	6.99	
4	Green	6.55	
5	Orange	6.19	
6			
7	average	6.19	
8			
9			

The percent deviation for each measurement will be computed in column C, using the formula

$$\%\ \text{deviation} = \frac{(\text{measured} - \text{average})}{\text{average}} * 100$$

Of the following, what is the correct formula for this computation in cell C4?

a. =(C4-$B$7)/$B$4*100
b. =(C4-$B$7)/$C$4*100
c. =(C4-$C$7)/$C$7*100
d. =(C4-$B$1)/$C$4*100
e. =(B7-$B$4)/$B$7*100
f. =(B5-$B$5)/$B$5*100
g. =(B4-$B$7)/$B$7*100
h. =(B6-$B$6)/$B$6*100
i. =(B3-$B$7)/$B$7*100

3. Metals such as Mg react with HCl(aq) to produce a gas and an aqueous solution of a salt. Write the chemical formulas of the gas and the salt.

gas: __________

salt: __________