Experiment 8

FV 8/8/02

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, Meeker burner, air compressor, tire gauge.

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 the following 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:

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. For example, the first procedure measures the effect of temperature on pressure. To make this as easy as possible, the mass and volume of the gas is kept constant. Once all 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.

PROCEDURE:

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 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. 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.

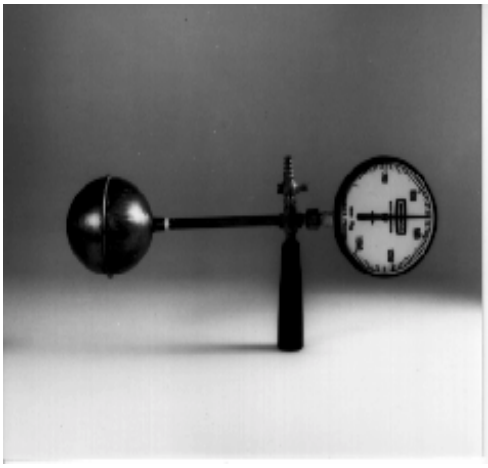

Figure 1: Amontons' Law Apparatus

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.

   a. For the high temperature measurement, add approximately 1.1 L of water to a 2 L beaker that has been secured on a tripod. With a Bunsen burner, heat the water in the beaker 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 of the gas in the bulb. 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 located in the fume hood. Use tongs to remove the stainless steel rings covering one of the wells of the apparatus. 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 of the trapped gas. 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, an open-end mercury manometer with an adjustable arm (Figure 2) will be used to measure the pressure and volume of a fixed amount of gas. A manometer is a device for measuring the relative pressure of a gas or a liquid in a sealed vessel. One end of the manometer is open to the atmosphere and a sample of gas is trapped in the closed end. Adjusting the height of the open end of the manometer varies the pressure, and thus the volume, of the gas trapped in the closed end. The volume ($V = \pi r^2 l$) of the trapped gas is equal to the cross-sectional area ($A = \pi r^2$) of the glass tubing times the length (l) of tube that contains the gas. If the cross-sectional area of the tubing is approximately the same at all points in the tubing, then the volume of the trapped gas is proportional to the length of glass tubing in which the gas is trapped. Therefore, the pressure of the gas will vary with its length in the same way that it does with its volume. The length of the column containing the trapped gas is equal to the difference in heights between the top of the closed end of the manometer and the position of the mercury level in the closed end (see Figure 4).

Figure 2: Boyle's Law Apparatus

1. Using the meter stick fastened to the apparatus, record the position of the top of the closed end of the manometer.

2. While making certain the *mercury-gas interface always remains in the glass portion of the tubing*, slowly lower the open end of the manometer as far as possible. Record the levels of the mercury in the open and closed ends of the manometer.

3. To complete this portion of the experiment, a total of five sets of data should be recorded in the Data Section. The mercury levels in the open end of the manometer should differ by approximately 10 cm between readings and the pressure of the trapped gas should be above atmospheric pressure in at least two of the readings.

4. Because the pressure of the trapped gas is related to atmospheric pressure, the barometer should be used to determine ambient atmosphere pressure. Record this value in the Data Section.

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

1. Fill the aluminum pressure vessel (Figure 3) with air using the air compressor. Ensure that the pressure of the air in the aluminum vessel can be measured with the gauge provided before recording any measurements.

Figure 3: Avogadro's Corollary Apparatus

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.

3. Remove a small amount of air from the vessel by depressing the inner portion of the valve on the aluminum vessel. As before, measure the pressure of the air inside the apparatus and the total mass of the apparatus. Repeat this process until 6 or 7 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. Weigh the “empty” vessel and record its pressure and mass in the Data Section.

Name _____ Section _____

Partner _____ Date _____

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

Using the proper number of significant figures and units, record the pressure and temperature values in the spaces provided.

	Pressure	Temperature
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)

Using the proper number of significant figures and units, record the levels of mercury in the open and closed ends of the manometer in the spaces provided. Also record the barometric pressure in the laboratory and the position of the top of the closed end of the manometer.

Open End	Closed End
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

Barometric Pressure _____

Position of the top of the closed end of the manometer _____

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

Using the proper number of significant figures and units, record the pressure of the gas and the total mass of the apparatus in the spaces provided.

	Pressure	Total Mass	Mass Air
	_____	_____	_____
	_____	_____	_____
	_____	_____	_____
	_____	_____	_____
	_____	_____	_____
	_____	_____	_____
"Empty"	_____	_____	_____

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 this experiment will be analyzed using a spreadsheet program. **Note**: only include the experimental data points and the best-fit line, not the points used to generate the best-fit line, on the graphs. Go to http://www.chemistry.usna.edu/plebechem/excel_tutor/homepage.html for information on using a spreadsheet program. Include your spreadsheet and all graphs with your lab report.

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. Plot a graph of P versus T. The graph should be constructed so that the pressure and temperature scales include the points 0.0 mm Hg (or Torr) and -300.0 °C, respectively. 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? To unambiguously determine if there is a linear relationship between these variables, perform a linear regression analysis (or trendline) on the data. The closer the value of R^2 is to 1.00, the more linear the data.

(A.2) Show the best-fit line (or trendline) on your graph of P versus T. Plot the equation of the line on the graph.

(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 = _____

(A.4) Calculate the percent error between this experimentally determined value of absolute zero and the theoretical value.

(A.5) Using the values of slope and y-intercept obtained from the linear regression output 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., $y = m\,x + b$.)*

(A.6) Factor the slope from the right side of this equation so that the equation takes the form,

$$y = m \cdot \left[x + \frac{b}{m} \right]$$

The right hand side of this equation defines the relationship between the Celsius and Kelvin temperature scales. The Kelvin temperature scale is used in all calculations involving gases.

(A.7) 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.

(A.8) Express this relationship as a mathematical equation. (The symbol $\propto$ means "is proportional to".)

$P \propto$ _____

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

(B.1) Enter the levels of the mercury in the open and the closed ends of the manometer into a spreadsheet program. Also enter the values of atmospheric pressure and the position of the top of the closed end of the manometer into the spreadsheet.

(B.2) Use the program to calculate the following:

(a) the difference in height between the closed and open ends of the manometer, Δh;

(b) the pressure of the trapped gas, P_{gas};

(c) the length of the column of air, l, of the trapped gas (since $V \propto l$, as described in the discussion, this value will be treated as the volume of the gas in subsequent calculations);

(d) the inverse of the volume of trapped gas, 1/V;

(e) the product of the pressure and volume of the gas, PV.

Note, the pressure of the trapped gas (P_{gas}) is given by

$$P_{gas} = P_{atm} \pm \Delta h$$

where P_{atm} is atmospheric pressure measured with the barometer and Δh is defined above. When the pressure of the trapped gas is above or below atmospheric pressure, Δh should be added to or subtracted from atmospheric pressure (P_{atm}), respectively. *(Use common sense and Figure 4 to determine when the pressure of the trapped gas is above or below atmospheric pressure.)*

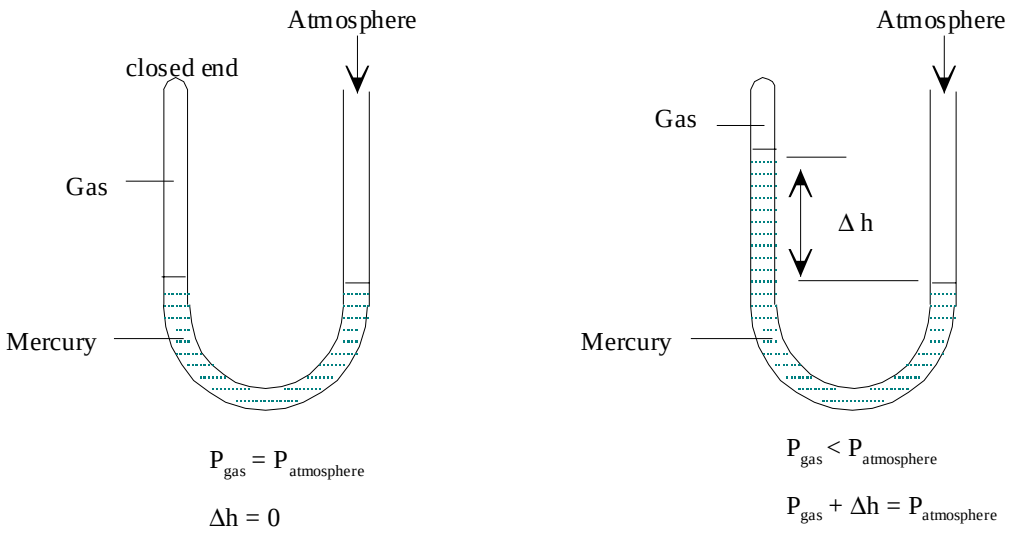

Figure 4: Illustration of an open-ended manometer

(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 linear regression for both sets of data will be used to determine the relationship between pressure and volume. On separate graphs, plot P versus V and P versus 1/V. Perform a linear regression on the P versus V data *and* on the P versus 1/V data. For the set of data that is linear, include the best-fit line on the appropriate graph.

(B.4) Use the spreadsheet program to calculate the mean (average) of the PV products and the percent deviation of the *individual* PV products from the mean. Percent deviation of each datum is given by

$$\text{Percent Deviation} = \left[\frac{|\text{mean PV - experimental PV}|}{\text{mean PV}} \right] \text{x } 100$$

(B.5) Calculate the average of the percent deviation.

(B.6) 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.

(B.7) Express this relationship as a mathematical equation.

$P \propto$ _____

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

(C.1) Use the spreadsheet program to construct a graph of P versus m. Perform a linear regression on these data. Again, show the best-fit line and its equation on the graph.

(C.2) 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.

(C.3) Express this relationship as a mathematical equation.

$P \propto$ _____

(C.4) Use Amontons' Law (A.8), Boyle's Law (B.7) and Avogadro's Corollary (C.3) to derive the Ideal Gas Law.

QUESTIONS
Experiment 8

1. Explain why the stopcock of the Amontons' Law apparatus must remain closed throughout the duration of the experiment.

2. Explain why the mercury-gas interface must be located in the glass tubing portion of the manometer when the pressure and volume measurements are taken.

3. Assume the calculations for obtaining the PV products were done correctly by all midshipmen in the class and that *human error obtaining the measurements was negligible*. Also assume the temperature and the pressure in the lab during the course of the experiment was approximately constant. Explain why the PV products obtained by one midshipman might differ significantly from the PV products obtained by another midshipman.