GAS BEHAVIOR: VOLUME, TEMPERATURE AND ABSOLUTE ZERO

OBJECTIVES

- To empirically derive a mathematical function that describes the relationship between the volume and the temperature of a gas.
- To become familiar with the Logger Pro software.
- To develop good graphing skills for effective data analysis.

PRE-LABORATORY READING

Review the use of the LabQuest 2. See documentation within the 1B Lab download folder.
Download and install the Logger Pro Graphing Program on your computer. Your instructor will give you download information.

BACKGROUND

Many scientific laws or principles were originally derived empirically, that is, they were derived based upon experiment or observation without regard to theory. The simple gas laws, such as Boyle's, Charles's, and Avogadro's, were derived during the mid-17th to early 19th centuries based solely upon carefully observed gas behavior. It was not until after these laws were proposed that the Kinetic-Molecular Theory was developed to explain these empirically derived gas laws. The basic postulates of the Kinetic-Molecular Theory, which provide a model for gases at the microscopic level that explains their behavior on the macroscopic level, are as follows:
1) a gas consist of particles in constant, rapid motion that act independently of one another.
2) the volume (V) of a gas is mostly empty space.
3) the average kinetic energy (KE) of the gas particles is proportional to the gas temperature, T in Kelvin.
4) the elastic collisions of the gas particles with the walls of the container create the Pressure (P) of the gas.
In this experiment, a relationship between the volume and temperature of a gas will be derived based solely upon experimental measurements. Additionally, analysis of the data in Logger Pro will demonstrate the basis for the definition of absolute zero

SAFETY

Be careful to avoid burns when using a Bunsen burner. Tie long hair back and do not wear clothing with long loose sleeves that dangle when you reach. The ring stand, ring and wire gauze will remain hot for a while after heating. Be careful when handling the hot water. **Safety glasses must be worn at all times.**

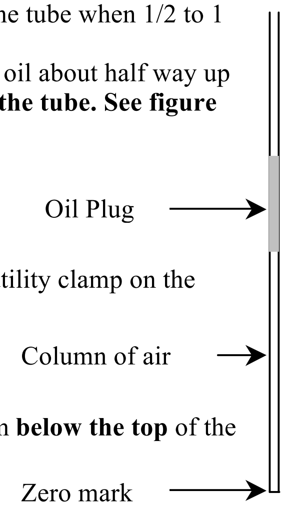
EQUIPMENT AND REAGENTS

A metal ruler
LabQuest
A capillary melting point tube
Mineral oil
Two small rubber bands
600-mL beaker
Bunsen burner, ring stand, ring, utility clamp and wire gauze

PROCEDURE: WORK IN PARTNERS.

RECORD ALL INFORMATION IN YOUR NOTEBOOK! CLEARLY LABEL ALL DATA!

1. **Preparation of sample tube:**
   a. **Record the inner diameter of the capillary tube you are using**. Most are 1.0 mm but you should check or ask your instructor.
   b. Grasp a capillary melting point tube near the closed end, with the tips of your crucible tongs.
   c. Heat the upper, closed-end 2/3 of the melting point tube over a Bunsen burner by passing it horizontally back and forth through the flame for about 10 to 15 seconds. Be careful not to melt the capillary tube.
   d. Quickly immerse the open end of the capillary tube in the oil provided. Remove the tube when 1/2 to 1 cm of oil has been drawn into it. Allow it to cool.
   e. After the tube has cooled, there should be a column of air confined by a "plug" of oil about half way up the tube. **The plug of oil needs to have moved at least 1/2 to 1/3 of the way into the tube. See figure at right.**



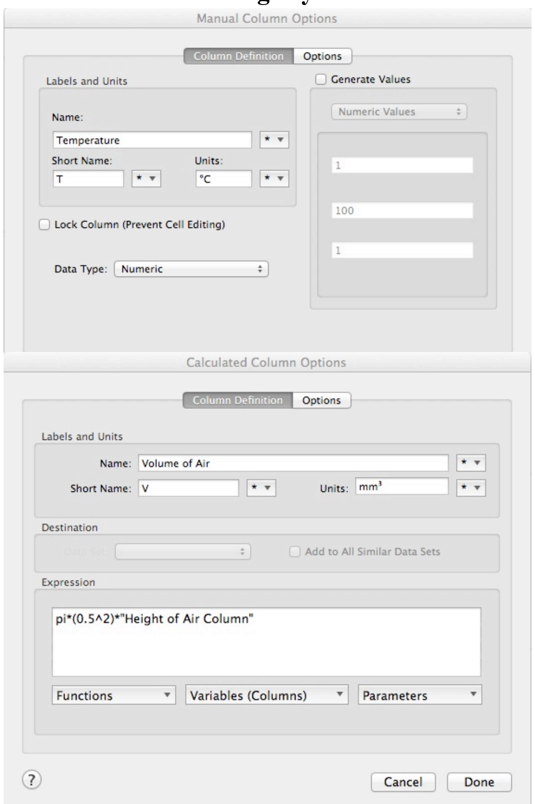
2. **Measurement of the height of the trapped air:**
   a. Attach the capillary tube, open-end up, to the metal ruler using two small rubber bands wrapped around the ruler, one at each end. **Align the bottom of the air column in the capillary tube with the zero mark of the ruler.**
   b. Place a 600-mL beaker on wire gauze supported by a ring on a ring stand. Use a utility clamp on the ring stand above the beaker to support the ruler with capillary tube attached in a vertical position, open end of the capillary tube up. The clamp will not close down tightly on the ruler; just rest the upper end of the ruler inside the clamp for support.
   c. Fill the 600-mL beaker with enough water so that the water reaches to about 5 mm **below the top** of the capillary tube.
   d. Place the digital thermometer into the hot water. **Be careful not to let the rubber cable of the thermometer touch the hot ring stand, doing so will melt it.** Heat the water to 90 °C. (**Watch to make sure that the oil plug is not completely forced out of the capillary tube as it warms up.** If some of the oil is forced out but some remains in the tube to provide a “plug” everything should still work. If all the oil is expelled you must start again with a new tube.) Turn off the Bunsen burner.
   e. As the water slowly cools to room temperature take readings of the temperature **when the top of the air column is precisely at each 1 mm scale division**. **Record the height of the air column as xx.0 mm** since you are recording the height precisely on each mm scale division**.** Stir the water regularly with the thermometer to avoid thermal gradients. As the water approaches 50°C, pieces of ice may be added, **one at a time**, to speed the cooling.
3. **Waste Disposal: Throw the used capillary tube into the broken glass receptacle. DO NOT throw it into the regular trashcan.**

GRAPHING THE DATA. TWO GRAPHS WILL BE MADE.

In chemistry we often make graphs to show the relationship between two variables. If the relationship can be modeled by a mathematical function, then we have a powerful tool for data analysis. You should be familiar with this type of analysis for linear data sets of the form y = mx + b. Here the **dependent variable, y**, is related to the **independent variable, x**, through the **slope, m**, of the line and the **y-intercept, b**. A linear regression fit (best fit) to the data yields a numeric value for the slope and the y-intercept.

Graph 1: Graphing of to find the x-intercept.

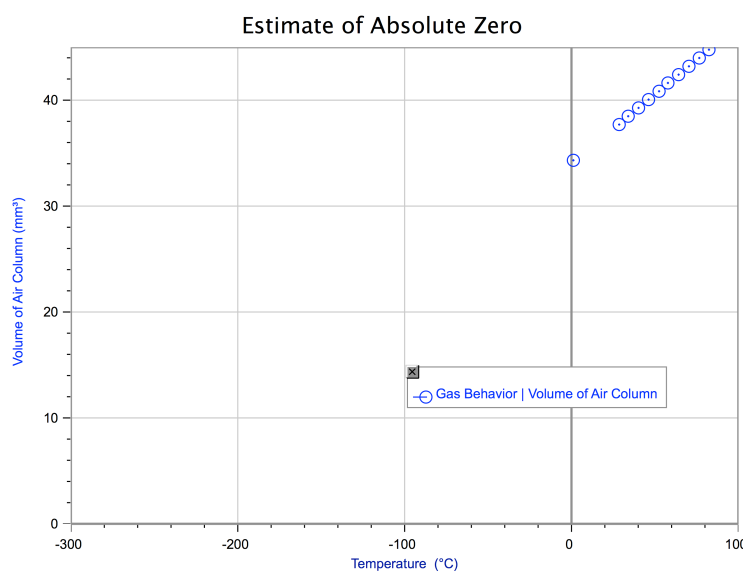
1) Convert height of the air column to volume of air.
We are going to prepare a graph of air volume (y-axis) versus temperature (x-axis). Since the diameter of the capillary tube is fairly uniform, the volume of the air sample is proportional to its height. This calculation and others will be done using the graphing software, Logger Pro. **In the following paragraphs, the screen shots are for the Mac version of Logger Pro. The PC version has slightly different menus but the same functionality.**



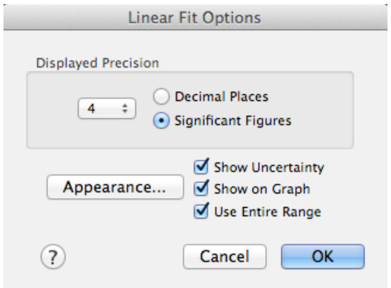
Manually enter the temperature (x-axis) and height (y-axis) data into Logger Pro. Double click on the X column to set the **name, short name and units** for the data in the column. See figure. Repeat for the Y-column. Use **h for the short name of the height data.**
Mathematically, convert the height of air data into volume of air.
Use the **Data>New Calculated Column…** from the menu bar. The program will create a new data column and convert all the heights to a volume of air based on a mathematical formula that you enter symbolically. You enter the required conversion formula using the pull-down menus at the bottom of the Options box. The formula to convert height to volume is entered as:

pi*(0.5^2)*"Height of Air Column"

This formula uses 0.5 mm as the radius of the capillary tube. (your radius may be different, check your notebook) **Also enter a column name (Volume), short name (V), and units (mm^3).**
Plot the volume of the air column as the ordinate (y-axis) against the temperature in °C as the abscissa (x-axis). Double-click on the graph to bring up the Graph Options box. Put a title on your graph. **Change the scaling on your graph to have the x-axis start at –300 °C**. Select "Axes Options" and chose Scaling: "Manual" for the x-axis. Enter the left and right scale values. **Change the scaling on your y-axis to Autoscale from 0.** This will set the y-axis minimum to zero. Your graph should look something like the one below.

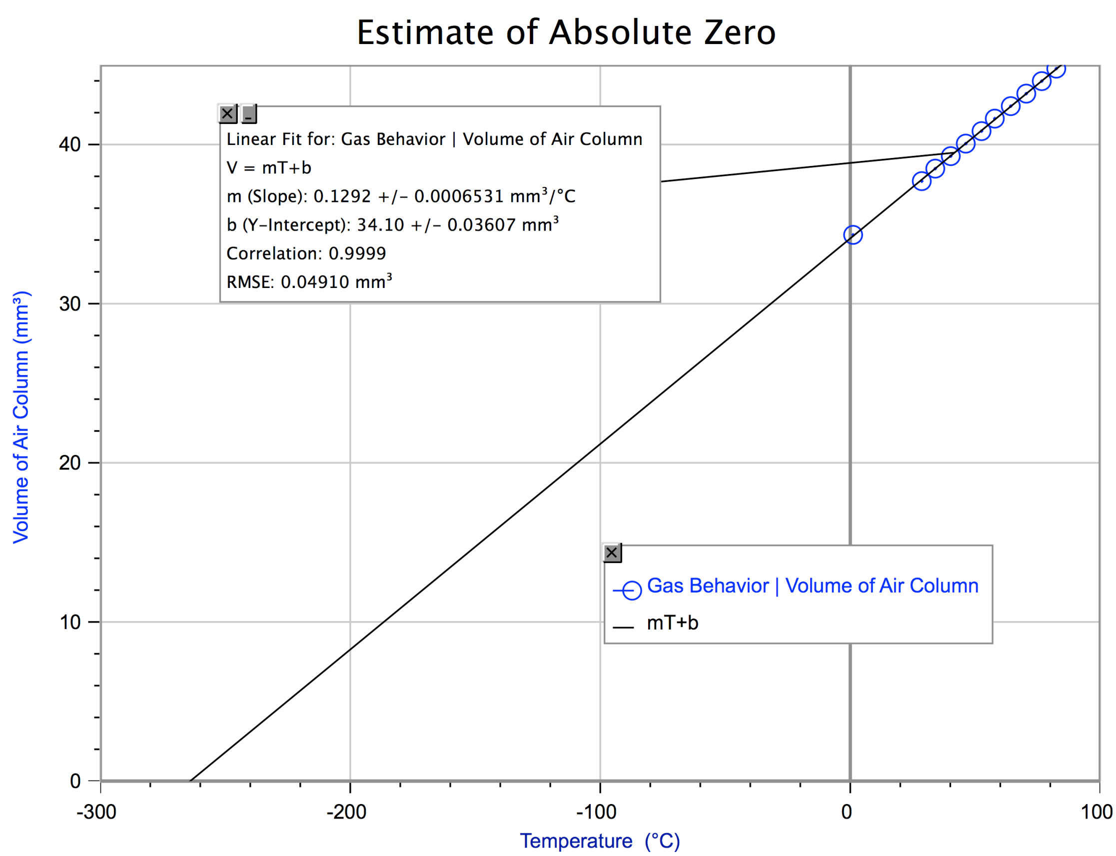


Have the program perform a linear regression analysis to the data. Under the Analyze… menu choose Linear Fit or click on the menu bar icon for a linear fit. The graph should now show the linear fit with a dialog box giving the slope and y-intercept values.
IMPORTANT! To show the uncertainty in the slope and y-intercept values **double-click the dialog box** containing the slope and y-intercept results to bring up the Linear Fit Options menu. **Make sure the Show Uncertainty checkbox is selected** to give the error values for the slope and y-intercept. See figures at left. Select the Appearance… menu to change the font size and color.



The completed graph will look similar to the one below.

PRINT A COPY of THIS GRAPH for GRADING



Graph 2: Graphing to find the moles of trapped air in the capillary tube.

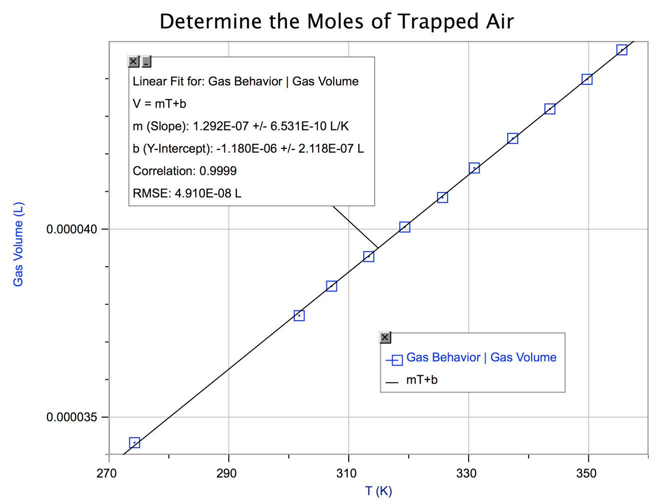
Using the ideal gas law, PV = nRT, the following relationship between volume (L) and temperature (K) is derived:

$$V(T) = \left(\frac{nR}{P}\right)T$$

V(T) means V is a function of temperature, T with n and P constant.

Where n is the moles of gas, R is the gas constant (0.08206 L-atm/mol-K) and P is the gas pressure (atm). From a graphical fit of volume (L) versus temperature (K) the slope of the line must equal the ratio of the constants $\frac{nR}{P}$. The y-intercept should be zero (in theory).

Make two new calculated columns in your data set. The first is temperature in Kelvin. Use the **Data>New Calculated Column…** to add 273.15 to your column of °C temperatures to make Kelvin temperatures.
The second is volume in Liters. To do this, mm^3 units must be converted to liters. What is this conversion factor? You should be able to derive the following conversion factor: **1 L = 10^6 mm^3.** Use this conversion factor to obtain an air volume in liters using **Data>New Calculated Column…**
To make the second graph, **add a second page to your file** by selecting: **Page>Add Page…** from the top menu. **Select Blank Page.**
Insert a new graph on the page by selecting: **Inset>Graph** from the top menu. Change the axis to temperature (K) and the y-axis to Volume (L). . Resize the graph as needed. **You can auto scale this graph.**
Use Linear Regression to obtain a slope and y-intercept with uncertainty values. Your finished graph will look like the one below.



PRINT A COPY of THIS GRAPH for GRADING

GOOD GRAPHING CHECKLIST

- Use single letters for axis short names. This will make fitting the data much easier.
- ALWAYS include the Show Uncertainty Option for the fitted curves. This will set your significant figures for the fitting constants.
- Always include a label and units on your data columns/axis.
- Add a suitable, informative title to the graph (the Y-label versus X-label is NOT be a suitable title for any graph). Usually the experiment name will be acceptable for a title.
- Display the data points with the options Point Protectors on. This gives a larger symbol for the data point.
- Use open symbols for your points, not solid symbols.
- Include the fitted regression curve when needed.
- Expand your scales when needed to make the axis as "readable" as possible.
- Determine the units of the fitting constants from your axis units. Remember, when plotting a ln(x) term, the values of ln(x) have no units. However the units of x should be stated. The axis units should be “x in units of …”.
- Add a legend to the graph if there is more than one data set plotted.

ANALYSIS OF THE DATA: GRAPHS 1 AND 2.

INCLUDE Copies OF YOUR GRAPHS with THIS REPORT. ***For mathematical problems show your work with units and report answers to the correct number of significant figures.***

Graph 1 Significant Figures Analysis

1) **Your instructor will guide you through an analysis of your data to determine the proper number of significant figures for your slope and y-intercept values.**

   Record the rounded slope and y-intercept to the correct number of significant figures **with units**.

   slope = ___________________________ y-int = _______________________

Graph 1 Analysis of Data

2) Write out the empirically derived mathematical function for the volume of air, V in mm^3, given the temperature, T in °C. (i.e., y = mx+b). Use your slope and y-intercept values in the function. Include units in your equation!

   V(T) =

   a) Using the equation above, calculate the x-intercept. This is the temperature where the volume of the air sample is zero. Use proper significant figures!

   b) What theoretical temperature should have been obtained from your data? That is, in theory, at what temperature should the volume become zero?

   c) Does your answer seem reasonable based upon the experimental procedure? Determine a percent error in your determination. % error = (exp value – theor. value)/ theor. Value x 100%

3) Using your slope and y-intercept values, calculate the volume of air in mm^3 at temperatures of

   –20 **°C**:

   100 **°C**:

   20 **K**:

Graph 2 Analysis

4) **Record the slope to the correct # of significant digits. (Same significant figures as the previous slope.)**

   Rounded value of slope with units: ______________________

5) Using this value of the slope, estimate the moles of gas present in the capillary tube by solving for n using the mathematical relationship between the slope and the ideal gas law constants:

   Plotted $V(T) = \left(\frac{nR}{P}\right)T$, so the slope = $m = \frac{nR}{P}$; Rearranging for n: $n = \frac{mP}{R}$

   We will assume a lab pressure, P, of 1.00 atm when the data was collected in lab. Calculate n below using your slope value. Convert you moles to μmol units.

6) Assuming the air is a 20.0% mixture of oxygen gas and 80.0% nitrogen gas, the average molar mass of air would be 28.8 g/mol. Use this to determine the mass in ug of air trapped in your capillary tube.

COMPLETE THE FOLLOWING PROBLEMS.

1) Consider the following reaction: $2\ CO(g) + O_2(g) \longrightarrow 2\ CO_2(g)$
   Imagine that this reaction occurs in a container that can expand or contract to allow constant pressure to be maintained within the container when the reaction occurs at constant temperature. What happens to the volume of the container as a result of the reaction? Hint: how does volume at constant pressure depend on the number of gas particles in the system? Explain.

   a) Now, if the container had a fixed volume, what happens to the pressure as a result of the reaction?

2) Consider a mixture of two ideal gases, A and B, confined to a closed vessel. A quantity of a third ideal gas, C, is added to the same vessel at the same temperature. How does the addition of gas C affect the following:

   a) The partial pressure of gas A: Increase, decrease or no effect?

   b) The total pressure in the vessel: Increase, decrease or no effect?

   c) The mole fraction of gas B: Increase, decrease or no effect?

Name: ____

Circle lab section: MW or TTh

Partner: ____

3) Magnesium can be used as a "getter" in evacuated enclosures, to react with the last traces of oxygen molecules:

$$2\ Mg(s) + O_2(g) \rightarrow 2\ MgO(s)$$

(The magnesium is usually heated by passing an electric current through a wire or ribbon of the metal to promote a fast reaction with the oxygen.) If an enclosure of 87.4 L contains 3.58×10^{-7} torr of oxygen at 27 °C, then what mass of magnesium is needed to remove all this oxygen by chemical reaction?