Lab # 8: Gas Laws - Charles' Law
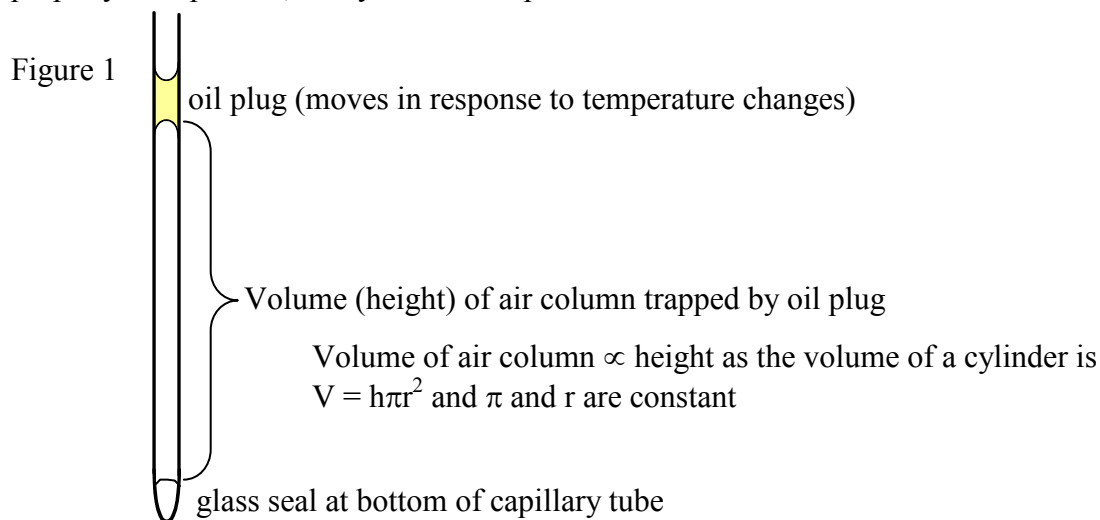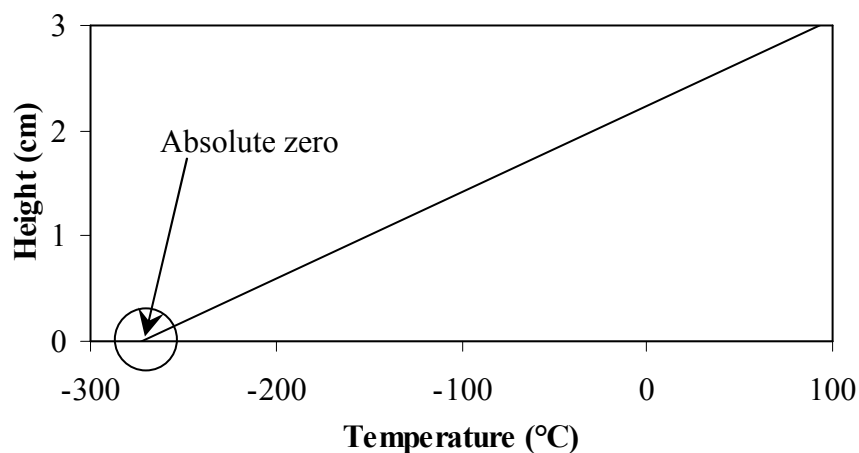
INTRODUCTION

In 1660, Robert Boyle, an English philosopher, performed an experiment in which he showed that the volume of a trapped amount of air varied inversely with the pressure applied to it. The relationship, however, between the volume of a trapped amount of air and its temperature was not noted at the same time since the accurate thermometers required to make this observation were not constructed until approximately 1750. It was some time after 1780 that the French scientist Jacques Charles made the observation that the volume and temperature of a gas are directly proportional; or "at a constant pressure, the volume of a fixed mass of gas is directly proportional to its temperature expressed in K." In this lab, you will investigate Charles' Law.

For the experiment, you will be given a piece of capillary tubing permanently sealed at one end and containing a moveable plug of oil at the other end. (Figure 1) This plug traps a fixed volume of air and moves up and down as the air expands or contracts with a change in temperature. A plot of the height of the gas versus the various temperatures (Figure 2), when properly extrapolated, will yield the temperature at which the air should have zero volume.

Figure 1

oil plug (moves in response to temperature changes)

Volume (height) of air column trapped by oil plug

Volume of air column $\propto$ height as the volume of a cylinder is $V = h\pi r^2$ and π and r are constant

glass seal at bottom of capillary tube

Figure 2: Charles' Law

Lab # 8: Gas Laws - Charles' Law

PROCEDURE

Obtain a capillary tube, thermometer and a ruler. The capillary will have a small plug of oil trapped in the upper end. Be sure to never turn the capillary upside-down since there is a possibility that the oil may fall out. The oil plug may decrease slightly in size throughout the experiment but it should not fall to the bottom of the tube. If it does so, you will have to restart the experiment.

The capillary and the thermometer should be attached to the metric ruler by means of rubber bands. Before making any measurements, and several times during the course of the experiment, check to see that the top of the glass seal at the bottom of the capillary is exactly on the "zero line" of the ruler. The same capillary must be used for the entire experiment in order to get consistent results.

Make a mixture of ice and water in a 600 mL beaker. Place the capillary and ruler into the water bath so that the capillary is immersed at least up to the top of the oil plug. Be careful not to get water into the top of the capillary. Wait several minutes for the tube to reach the temperature of the bath. Record the height of the air column to the nearest 0.1 mm or 0.01 cm and the temperature of the bath to the nearest 0.1°C. (If you are unsure about whether you are reading mm or cm, see the instructor.) Save the ice water. Put the capillary, ruler and thermometer in a 400 mL beaker about three-fourths full of room temperature water. Record the temperature of the water (it should be near 20°C) and the height of the oil plug. Put the beaker and a flask of water on a hot plate. Slowly heat the water. When the temperature of the water reaches 30°C (between 28 and 32°C), record the temperature and height. Continue heating the water and make temperature and height readings every approximate 10°C intervals until the water is boiling. If you overshoot the desired temperature, add a bit of ice water to the 400 mL beaker.

There will be a bath of dry ice and ethanol in the hood which will have a temperature well below 0°C. Repeat the same procedure using this bath. **This must be your last reading.** Be sure that the oil plug has stopped moving before you record the height of the air column. Also, be very careful when using this bath because its low temperature can cause severe burns to the skin if the skin should be in contact with it for a long period of time. At the end of these determinations put the capillary and ruler in the hood.

Lab # 8: Gas Laws - Charles' Law

DATA

Approx. Temp.	Temperature (°C)	Air Column Height (____m)
0		
20		
30		
40		
50		
60		
70		
80		
90		
100		
-70		

Instructor's Initials_____

GRAPH

Using Excel, Graphical Analysis or a similar computer graphing program, plot your data on a graph, with temperature in °C on the x-axis and height in cm or mm on the y-axis. (Start your axes at -300°C and 0.0 mm/0.00 cm. If your line does not hit the x-axis before -300°C, adjust the minimum value on the x-axis until it does. For example, you may have to start your x-axis at -320°C instead of -300°C.) Have the computer put the best straight (linear) line through the data and include the equation of this line on the graph.

Lab # 8: Gas Laws - Charles' Law

FROM YOUR GRAPH

1. (1) Estimate (to the tens place) the temperature in °C at which the column height is zero (from the **x**-intercept, like Figure 2).

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2. For the line on the graph, the equation is h = mT + b, where h = height, T = temperature in °C, m = slope, and b = y-intercept.

a. (1) What is the slope (m) of your line, (including units)? _____

b. (1) What is the y-intercept (b) of your line, (including units) _____

c. (2) Absolute zero, 0K, in °C, can be calculated by dividing the negative y-intercept by the slope (-b/m). Calculate your experimental value for absolute zero in °C using this equation. Your value is essentially good to 0.1°C.

3. (1) What advantage is there in using the absolute temperature, in K, rather than the Celsius temperature, in °C, when doing calculations involving gases?

4. (2) What is the percent error for your value of absolute zero? The accepted value for absolute zero is -273.15°C. $\left(\% \text{ error} = \dfrac{|\text{theoretical value} - \text{experimental value}|}{\text{theoretical value}} \times 100 \right)$

Lab # 8: Gas Laws - Charles' Law

5. Using the equation of your line, answer the following questions.

a. (2) If you had measured the temperature at 125.0°C, what would you have expected for the height of the air column?

b. (2) If you had been able to get the temperature down to 4K, what would you have expected for the height of the air column? (Use your experimental value of absolute zero to convert 4K to °C.)

c. (2) At what temperature in K would the air column height be 50% of the height at your lowest experimental temperature? (Use your experimental value of absolute zero to convert °C to K.)

Lab # 8: Gas Laws - Charles' Law

PRESTUDY

1. (2) Convert the following temperatures and express the answers with the proper number of significant figures:

a) -248°C to K

b) 149.1 K to °C

2. (8) Construct a graph of the following data either using a computer graphing program such as Excel or Graphical Analysis or by hand (using GOOD graph paper and following proper graphing procedure, see WebCT for help).

Temperature (°C)	Air Column Height (cm)
100.9	8.14
77.5	7.62
56.1	7.03
39.4	6.59
20.0	6.14
0.6	5.69
-71.9	4.37

Plot air column height (y-axis) vs temperature (x-axis) and attach the graph to this sheet. Start your axes at 0.00 cm. and -300°C. (-300° and 0.00 cm will NOT be a point though.) Include the best straight line and extrapolate it to 0.00 cm.

a. What is the slope (m) of your line, (including units)? _____

b. What is the y-intercept (b) of your line, (including units) _____

c. Absolute 0 in °C is equal to -b/m. Determine the value of absolute 0 from your graph.

d. Use the equation of your line to determine what the air column height would be at a temperature of 121.0°C.