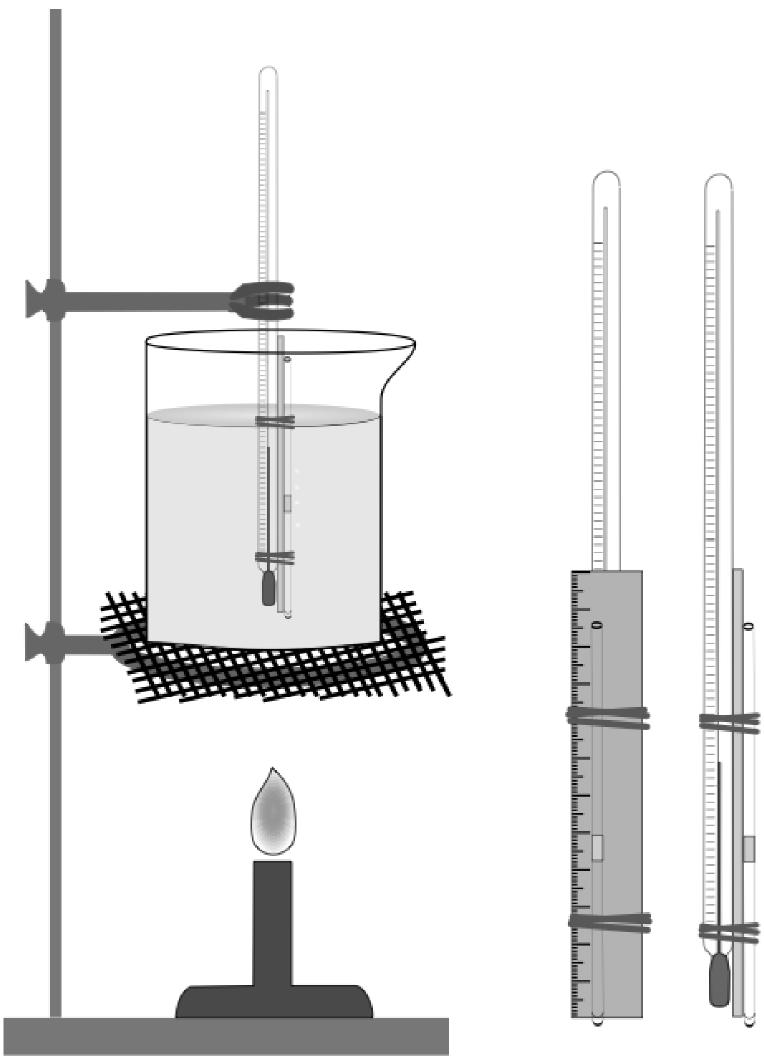
Experiment 3 - Relationship between Temperature and Volume of Gases

Introduction

Gases are distinguished from liquids and solids by their **compressibility**, the ability to change volume depending on circumstances. In this experiment, you will study the relationship between the temperature and the volume of a gas, which will lead to a new temperature scale, the absolute or Kelvin scale.

In your experiment, the gas sample will be a small amount of air that is trapped beneath a tiny plug of oil in a very narrow glass tube called a **capillary tube**. When the air sample is heated, it will expand and the oil plug will move upward in the tube. The opposite will occur when the air sample is cooled. You will measure the volume of the air by measuring and recording how far the plug moves, using a ruler to which the capillary tube is fastened along with a thermometer. (See below.)



The sample capillary tube (attached to thermometer and ruler) is then immersed in a water bath. The temperature of the bath is read off the thermometer in Celsius degrees. The volume of the sample is read off the ruler in millimeters. We are assuming that the capillary tube has a constant diameter, so that the volume of the tube is proportional to its length ($V = \pi r^2 h$, so if r is constant, V is proportional to h). You will thus measure the <u>length</u> of the air column in the tube at each temperature. We don't need to know the *actual* volume in the capillary tube; knowing a quantity proportional to volume is sufficient.

You will finish the lab by analyzing a graph of the data, in which the *x*- and *y*-intercepts in the graph are of particular interest (although we don't care about the slope). For this reason, although it doesn't matter what unit the volume is in for this lab, it is important to measure the absolute volume, not just the change in volume when the temperature changes. To get a meaningful value of the intercept, you should make sure that 0 mm on the ruler matches up with zero volume in the capillary tube, as shown in the diagram. This means the bottom of the capillary tube should be a little below the bottom of the ruler.

Safety Precautions:

- Wear your safety goggles at all times.

Waste Disposal:

- Place the used capillary tubes in the glass waste containers. The water from the water baths can be poured down the drain.

Procedure

First you will prepare the gas sample in a capillary tube, then collect data, then graph the data.

Part 1 - Capillary Tube Preparation

1. Assemble the following materials: a Bunsen burner, a pair of crucible tongs (NOT a test tube clamp), an empty capillary tube, and a small dish of oil. Light the Bunsen burner.
2. Pick up the capillary tube with the crucible tongs so that you have a firm grip on it and so that the open end of the tube is pointing down.
3. Turn your hand so that the tube is horizontal, and wave the tube back and forth through the flame while you count to 20. (The purpose of this step is to heat up the air inside the tube without actually melting the tube itself. Make sure to keep it moving, or it will melt. Keep it mostly in the flame.)
4. When you have counted to about 20, quickly dip the end of the tube into the oil (have the oil within easy reach so it won't cool before you get it in the oil). When 4-8 mm of oil has been drawn into the tube, remove it from the oil.
5. After it cools, you should have a sample of air trapped under a small bubble of oil about halfway up the tube. You now have a trapped sample of air in a "flexible" container: the volume adjusts itself to keep the pressure constant.
6. Make sure that your tube is properly set up: there should be a single bubble of oil, 4-8 mm long, and it should be at least one third of the way down the tube.

Part 2 - Measurement of Volume at Varying Temperatures

1. Attach your capillary sample tube to a metal ruler and thermometer using rubber bands. Make sure that the bottom of your air sample is lined up with the zero mark of the ruler so you can easily read the height of the air column. The bulb of the thermometer should be level with the air sample.
2. Set up a ring stand with a water bath: attach a ring to the ring stand, put a piece of wire gauze on top of it, and then place a 400 ml beaker of water on the wire gauze.

3. Put your sample tube with ruler and thermometer in the beaker, and clamp it in place using a "3-finger" clamp coated with rubber. The air sample should be under the water, but the top of the capillary tube should be above the water. Make sure you can easily read the length of the air sample and the temperature.

4. Heat the water bath until it boils using a Bunsen burner. If necessary to keep the air sample under water, add more water.

5. When the water boils, turn off the Bunsen burner. As the water bath cools, take readings of the temperature and the height of the bottom of the oil bubble every 5 °C, starting close to 100 °C and stopping at about 30 °C. Record the data in a table in your notebook. Record your measurements with 3 significant figures! (It's ok that the last sig fig is uncertain.)

6. You can speed up the cooling by stirring the water bath with a test tube of ice.

7. If time allows, repeat the experiment with a new sample tube.

Data Analysis

1. Plot the length of the gas sample (which is proportional to its volume) against the temperature in °C. (This means length on the *y*-axis and T on the *x*-axis.) You can do it by hand in your lab notebook or in a spreadsheet program like Excel. Show data points clearly as dots or markers. Scale the graph so that the **data** (not just the axes) take up at least half a page.

2. Find the equation of the "best-fit" straight line through the data points. You can do this by hand or with the program. Show the best-fit line on the graph.

3. Find the *x*-intercept of the line. This is the temperature where (in theory) the volume of the gas sample would be zero. Write your value of the *x*-intercept on the board, along with your length at 100 °C, before you leave. If you don't find the x-intercept before you leave, email it and your length at 100 °C to your instructor within 48 hours. The instructor will collect everyone's results and send the list to the class for analysis in the post-lab.

Name: Section:

Experiment 3 Pre-Lab Sheet

1. (1 pts) What is inside the capillary tube, under the oil bubble?

2. (1 pt) What happens to the position of the oil bubble as the tube is heated?

3. (2 pt) Draw the precise position of the ruler relative to the capillary tube shown. Assume it is drawn actual size; number the first several lines of your ruler.

4. (2 pts) Why is the ruler position important? ("To make it accurate" is ***not*** a useful answer—be specific.)

5. (2 pts) What is a reasonable unit to record the position of the oil bubble? How many decimal places should you include, for this unit?

6. (1 pt) What will the label on the *x*-axis of your graph be? (Include units)

7. (1 pt) What will the label on the *y*-axis of your graph be? (Include units)