Experiment

THE RELATIONSHIP BETWEEN VOLUME AND TEMPERATURE, i.e.,Charles' Law

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LEARNING OBJECTIVES

The objectives of this experiment are to . . .

- introduce the concepts and units of pressure, volume and temperature.
- experimentally determine the relationship between temperature and volume, using the ***MicroLAB*** interface system to collect and analyze the data.

BACKGROUND

One of the major differences between gases and solids or liquids are that the volume of a sample of gas varies when pressure or temperature is changed to a much greater extent than do the volumes of solids and liquids. Solids and liquids are also affected by temperature and pressure, but the magnitude of the volume change is very small. When the densities of solids and liquids are measured, there is little need to control temperature or pressure. Within normal limits of measurement precision, these densities are the same under somewhat different laboratory conditions. As you will observe in this experiment, the density of a sample of gas is much more sensitive to changes in temperature and pressure. The dependence of the density on these two factors is determined by varying the pressure and the temperature separately.

Pressure is defined as the force per unit area. A gas exerts pressure on any surface it touches. Thus, air, which is a mixture of gases, exerts pressure on the surface of the earth. This pressure is called atmospheric pressure. It depends on the mass of air above the surface and thus will be affected by wind conditions and by the relative elevation of the surface of the earth where the measurement is made. The ***standard atmosphere*** (1 atm) is defined as 101.325 kPa. A ***pascal*** (Pa) is the SI unit of pressure, which is the force of one newton exerted on an area of one square meter.

Atmospheric pressure can support a column of liquid, as shown in Fig. 1. Assume that all three tubes in the figure were originally filled with liquid, then were inverted into the dishes of liquid, as shown. The pressure of the atmosphere on the surface of liquid in each dish, at C and D, is just balanced by the pressure due to the mass of the column of liquid above the surface of the dish, at A, B, and E. If the liquid exerted a greater pressure than the atmosphere, then the level of the liquid would fall until the remaining mass of liquid produced the same pressure as the atmosphere. The same atmospheric pressure is able to support a higher column of liquid 2 than of liquid 1. Since the pressure exerted by the liquid depends on its mass, liquid 2 must be less dense than liquid 1.

Measurement of the height of a column of liquid, supported by a gas, in a tube of uniform diameter, is a convenient way of measuring pressure. The very dense liquid metal, mercury, is usually used to measure pressure. A column of mercury 760.0 mm high exerts a pressure of 1 atm or 101.3 kPa. Laboratory measurements are thus often expressed as mm Hg, or mm of Hg, which is also defined as a torr. The density of Hg is 13.6 g/cm^3 and that of the water is 1.00 g/cm^3. A column of mercury is therefore 13.6 times heavier than a column of water of the same height and diameter, so that the column of mercury will exert a pressure 13.6 times as great as the same column filled with water. A given atmospheric pressure can support a column of water which is 13.6 times as high as the column of mercury. This is one reason mercury is used in barometers and manometers for measuring pressure; a water barometer would have to be 34 feet high!

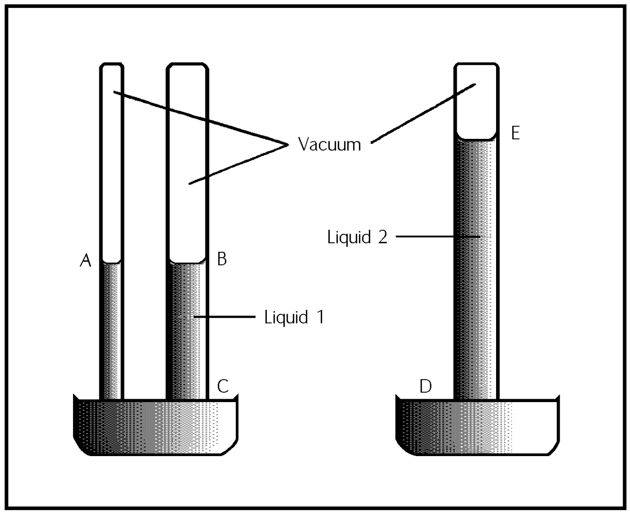

Figure 1. Column of liquid supported by atmospheric pressure.

Charles' Law

Around 1800, a French scientist and balloonist named Jacques Charles began studying the effect of increasing temperature on gases. He observed that the rate of expansion of gases with increasing temperature was constant and was the same for all gases as long as the pressure was constant.

In 1848, Lord Kelvin, a British physicist, noted that when studying gases at different initial but constant pressures, extending the temperature-volume lines back to zero volume always produced a common intercept. This common intercept on the temperature axis is −273.15 °C.
Kelvin named this temperature absolute zero. The Kelvin absolute temperature scale, in which K = °C + 273.15, is named in his honor. The volume-temperature relationship for gases using the absolute temperature scale becomes obvious and is known as Charles' Law: at a constant pressure, the volume of a definite amount (mass) of gas is directly proportional to the absolute temperature of the gas.

Mathematically, Charles' Law can be stated as follows using the absolute temperature scale:

$$V \propto T \qquad \text{or} \qquad V = kT$$

We will now explore this relationship.

SAFETY PRECAUTIONS

No chemicals are used in this experiment, so there is no concern for chemical hazards. Eye protection should be worn in case there is a rupture of the apparatus under pressure. In the Charles' Law investigation, care must be taken to avoid being scalded or burned.

BEFORE PERFORMING THIS EXPERIMENT . . .

...you will need a ***MicroLAB*** program capable of

- Measuring temperature from the temperature probe and inputting the corresponding volume from the keyboard. Choose the ***Charles' Law*** from the **Gas Laws** tab on the opening window.

Equipment set-up

1. Calibrate the apparatus as follows:
   a. Connect the temperature probe leads to the CAT-5A input on the ***MicroLAB***.
   b. Open the **MicroLAB** program ***Charles Law*** from the **Gas Laws** tab on the opening window and **recalibrate**, the temperature probe at a minimum of three temperatures covering the range from 0 to 50 °C. If you are not familiar with this process, check the **Measurement Manual** for instructions.
   c. The temperature probe should now be calibrated to read in °C.

2. Assemble the apparatus as follows on top of a magnetic stirrer:
   a. A 1 ml pipet which has been cut off just above the top calibration mark is mounted vertically from a utility clamp. A rubber bulb is used to suck up about 0.5 ml of a non-volatile, non-hygroscopic liquid (e.g. Antifreeze) such that there is about a two ml volume from the beginning calibration mark and insert a short stopper into the end.
   b. The pipet is then suspended with the beginning calibration end down, into an 800 ml beaker with an ice slurry such that the temperature is about 2 to 3 °C.

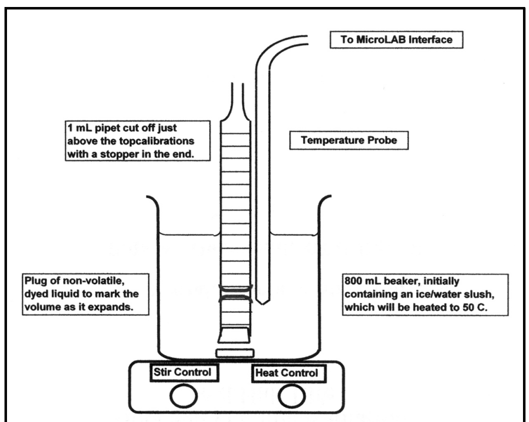

Figure 2. Diagram of the Charles' Law apparatus.

   c. Reconnect the temperature probe leads to the **CAT-5A** input, if necessary and solidly mount the probe alongside the pipet in the beaker.
   d. Add the stirring bar and begin stirring at a moderate rate.

Collect the data

1. If necessary, reselect the ***Charles' Law*** from the **Gas Laws** tab on the opening window.
2. Start the program so that the temperature can be recorded.
3. When the temperature reaches 5 °C, take your first *volume* measurement. (Read the bottom of the liquid plug in the tube. It may be necessary to wipe condensation from the outside of the beaker.)
4. Turn the plate heater on **High** and monitor the temperature so that it is increasing at about 1 °C per minute by adjusting the control. **Caution**: If you heat the water too rapidly, you will not get good results. As you heat the beaker, be sure the water level *does not rise above the top* of the beaker and overflow. To avoid this, remove water with a 60 ml syringe.
5. Continue step 5, taking measurements about every 5°C until the water has been heated to about 50 °C, or until the liquid plug in the pipet approaches the liquid level in the beaker.

VOLUME VS TEMPERATURE DATA WORK UP:

The volume-temperature data are stored on your disc under the file names you gave it.

Data Manipulations for Charles' Law

1. For each experiment run, graph the dependent variable on Y and the independent variable on X . If the points of the scatter graph appear linear, then do a regression line through the data. If the points are **clearly not** linear, then perform the proper transform to make the data linear. Print this graph with the appropriate title as described above. **(Graph 1.1 to 1.3).**
2. Plot a linear regression graph of temperature on Y and volume on X. Print this graph with the appropriate title as described above. **(Graph 4.**)
3. Using the **Predict** function under **Analysis**, for **Graph 4**, predict the temperature value for zero (0) volume from the above graph. Enter the predicted value and the Y intercept value in Table 1.2 and calculate their percent difference.
4. Using the **Add Formula** function, calculate the corresponding Kelvin temperature and drag to **column C**.
5. Using the **Add Formula** function, divide the temperature in Kelvin by the volume (This is the reverse of the normal procedure, but for a purpose.), drag this to **column D**, then determine the mean, standard deviation and percent error on the standard deviation of the data in **Column D** and enter it in **Table T1.2**.
6. Plot a linear regression graph of Kelvin on Y and volume on X. Print this graph with the appropriate title as described above. **Graph 5**
7. Calculate the percentage difference between the mean and slope values in the above question and add this value to **T1.2**.

(**T2** Include an expanded table like this in your Results and Conclusions section.)

Y intercept value	Predicted intercept	K/V Mean	Std. Dev.	% error on Std. Dev.	L.R. slope	% Diff. (K/V vs. Slope