Experiment 1B: CHARLES’S LAW OF GASES:
VOLUME vs. TEMPERATURE

Introduction

Gases expand when heated, and contract when cooled. At the end of the 18th century, this behaviour was investigated in detail by Jacques Charles, a French physicist with a passion for hot-air ballooning. Charles determined that the volume occupied by any sample of gas is directly proportional to its temperature, as long as the pressure is held constant. Charles’s law is summarized as:

\[ V_P = k T \quad \text{or} \quad \frac{V_P}{T} = k \]

where \( T \) is the absolute temperature (in Kelvin, K) \( V_P \) is the volume (at constant pressure) and \( k \) is a constant of proportionality.

If you think about it, Charles’s law implies that the volume a sample of gas occupies will approach zero as the temperature approaches zero on the absolute scale. Of course, this does not really happen, because the gas will liquefy and finally solidify if the temperature is low enough. Therefore, Charles's Law only applies to the gaseous state. However, if we ignore these phase changes, we can use the linear relationship between gas volume and temperature to estimate the temperature at which the gas’s volume would theoretically become zero. This is a crude way to estimate the lowest possible temperature, known as absolute zero. In this experiment, you will first confirm that real gases do obey Charles's Law and then you will use your linear data trend to estimate the value of absolute zero in degrees Celsius (°C).

Absolute zero is the temperature at which everything virtually stops moving, including molecules (although the atoms within the molecules still vibrate a tiny bit). Purposely cooling things to extremely low temperatures might therefore seem uninteresting, but in fact, as the temperature approaches absolute zero, the properties of some materials become very interesting indeed. For example, helium becomes "superfluid"; in other words, its viscosity becomes zero, and it also perfectly wets all the surfaces it touches, so it can appear to be able to flow uphill! Other substances, including certain metals, lose their resistance to electrical currents and become "superconducting".

Objective of the Experiment

Your goal is to answer the questions: “How well does a real gas obey Charles's law, and at what temperature would the volume of this real gas theoretically become zero?” To do this, you will trap a small quantity of air inside a capillary tube, and measure its volume as you change the sample's temperature.
**Prelaboratory Assignment**

Read the procedure and answer the prelaboratory questions before coming to the lab. Your demonstrator will inspect and collect in your prelab before you are permitted to begin the experiment - keep a copy of it for yourself, and have the TA sign your receipt record.

**Experiment Summary**

A fixed amount of air (*i.e.*, a mixture of gases, mainly nitrogen and oxygen) will be trapped in a capillary tube, which is sealed at one end and will be closed near the other end by a (moveable) drop of oil. The capillary will be attached to a thermometer, as shown in the diagram on the next page. The scale on the thermometer will be used both to measure the temperature in degrees Celsius and also to measure the length of the column of trapped air as the temperature is varied. Since the capillary has a uniform cross-section (or nearly so), the length of the column is proportional to its volume.

The trapped air's volume at various temperatures will be plotted graphically to confirm Charles’s Law, which predicts a straight line for a plot of gas volume vs. temperature. The graph will also be used to estimate absolute zero by determining the point where the extrapolated line crosses the temperature axis.

**Materials**

**Apparatus**

- thermometer
- melting-point capillary (sealed at one end)
- 2 small rubber bands
- deep water baths at about 0 °C (ice), 40 °C, 60 °C, 80 °C, 100 °C (boiling).

*NOTE: The bottom part of the thermometer’s scale (where the capillary is attached) will have to be immersed, not only the mercury bulb.*

**Reagents and Disposables**

- silicone oil in a syringe fitted with a blunt needle
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Procedure

**Warning:** Please handle your thermometer with great care. Firstly, it is quite expensive! Secondly, it contains mercury, which is very difficult to clean up completely and whose vapour is toxic. Although the vapour pressure of mercury is extremely low, prolonged exposure to even low concentrations is very dangerous. This will not affect you (and so there is *absolutely* no cause for panic if you do break one), but the laboratory staff could be at risk over an extended period. If you do break a thermometer, let your demonstrator and the technicians know at once. Do not try to pick up the mercury yourself - it will get everywhere, and you may make a bad situation worse.

1. Introduce a small droplet of silicon oil into a melting-point capillary, using the syringe of oil. The droplet should be placed at least ¼ of the way down the tube from the open end. This will trap a suitably small volume of air in the tube.

2. Attach the capillary to the thermometer with two rubber bands so that it lies along the part of the thermometer where the scale is found. *Remember, the scale will be used as a ruler to measure the length of the air column in the capillary as well as the temperature.* The sealed end should be positioned nearest the bulb by the beginning of the scale. Record the length of the air column and the temperature reading on the thermometer.

3. Now place the thermometer in an ice bath so that the air column in the capillary is completely immersed, but so that the open end of the capillary remains above the surface. After a couple of minutes, when the temperature reading on the thermometer has stabilized, again note the length of the column of air and the temperature.

4. Repeat these measurements at room temperature and in the water baths at about 40, 60, 80 and 100 °C.

5. Return the capillary to the stockroom.

When this experiment is complete, proceed with Experiment 1C. Remember to clean all glassware, other apparatus, and your work space when finished.
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Prelaboratory Questions

1. (2 marks) Provide a half-page (maximum) summary of the experimental procedure. This can take the form of a flow-chart or a list of the main steps in the procedure.

2. (1 mark) What is the accepted value of absolute zero in degrees Celsius? What is its value in degrees Kelvin?

3. (2 marks) The melting-point capillaries can vary quite a bit in diameter since their real purpose does not require a careful control of this parameter in their manufacture. Read the procedure and the method of using the results. Does the value you will obtain for absolute zero depend on the diameter of the capillary you use? Explain.
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Laboratory Report

(5 marks) Observations and Data

<table>
<thead>
<tr>
<th>Reading</th>
<th>Temperature (°C)</th>
<th>Length of the air column (in degree marks)</th>
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(3 marks) Graphical Analysis of Data

NOTE: Please draw your graph by hand so you learn how to properly handle graphical data. There are a few sheets of graph paper at the end of your lab manual. For later reports, you may be permitted to use a computer to graph your data, but NOT for this one.

The data tabulated above should be plotted on a piece of graph paper. The vertical axis (ordinate or "y-axis") should represent the length of the air column, which is proportional to the volume. The horizontal axis (mantissa or "x-axis") should represent the temperature in degrees Celsius.

The axes should be labeled to include zero (on both the axes) and go up to the maximum values of column length and temperature that you measured. To make your measurements on the graph...
as accurate as possible, the scales should be such that the graph comes as close as convenient to filling the graph paper. You may need to do a trial plot to see how best to achieve this.

The points should be marked as small dots (you can circle them to avoid losing them) on the graph. Draw the best straight line that you can through the points: if your data points do not all lie along a line, which is not unusual, draw the line so it lies with the points scattered evenly above it and below it. Extrapolate the best-fit line (i.e., extend the line beyond the range of your actual data) down to zero on the column length/volume axis. In the space below, note the position of the intercept on the temperature axis; this is your estimation of absolute zero.

Temperature at which the volume of the gas would apparently become zero: ____________ °C

Interpretation of Data

1. (1 mark) Was the behaviour of your gas sample in close agreement with Charles' law? Explain your answer by discussing relevant features of your graph.

2. (2 marks) Use your graph to determine a value for the constant of proportionality k in Charles's law: \( V_P = k T \). Show your calculation, and remember to include units.
3. **(2 marks)** How well does your experimental estimation of absolute zero agree with the accepted value? Express the experimental error as a percent difference. Provide a reasonable explanation for this difference (other than the possibilities presented below in the additional questions!).

**Additional Questions**

There are several factors in the experimental procedure and calculations that might lead to the differences between your value and the accepted value for absolute zero. Qualitatively, in what way have the following two limitations of our experiment affected your result? Explain.

1. **(1 mark)** Ignoring the fact that the ends of the air column are actually rounded; that is, the column is not a perfect cylinder.

2. **(1 mark)** Using a relatively restricted range of temperatures for the volume measurements.