PHYSICS 258 Lab Manual[1]

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[1]Updated: February 14, 2021

Lab 2

The Latent Heat of Vapourization of Water

Learning objectives

To determine the latent heat of vapourization of water (the amount of energy needed to convert a mole of liquid water into a mole of vapour at the same temperature) by measuring how the equilibrium vapour pressure of water varies as a function of temperature.

Introduction

In this experiment, we set out to demonstrate one of the most powerful features of thermodynamics: its ability to establish strong formal links between apparently unrelated quantities. In the specific example used here, you will determine the latent heat of vapourization of water.

Despite the ubiquity of liquid water on our planet, most materials are only rarely encountered as liquids. Solids and gases are far more common. This is the result of severe thermodynamic limits on the existence of liquids: too hot and you get a gas, too cold and you have a solid; pressure too low and you get a gas again, too high, and you have a solid. Thermodynamics shows that a liquid can only coexist in equilibrium with its vapour along a precisely defined Pressure–Temperature (P-T) line. In this experiment, you will determine a segment of this line.

Theory

At any definite temperature, a pure liquid can exist in equilibrium with its vapour at one and only one pressure. This pressure is the pressure of the saturated vapour.

If the external pressure is greater than the saturated vapour pressure at a given temperature, the temperature of the liquid can be varied until the pressure of its vapour is equal to the external pressure, at which point it will begin to boil. The pressure at which the liquid boils is the pressure of its saturated vapour at that given temperature. The determination of the boiling point of a liquid under different pressures is a direct method of finding the saturated vapour pressure at different temperatures.

The Clausius–Clapeyron equation, which expresses the first and second laws of thermodynamics as applied to a phase transformation such as vapourization, is written

$$\left(\frac{\partial P}{\partial T}\right)_{vapourization} = \frac{L}{TV_{vapour}}, \tag{8}$$

where T is the absolute temperature and L is the latent heat of vapourization. Assume that the specific volume of the liquid is much less than that of the vapour, V_{vapour} (the

level of approximation introduced by this assumption is readily checked and can be justified). Assuming further that L is independent of T (a much shakier approximation) and that the vapour can be approximated by an ideal gas, equation 8 can be integrated to give

$$P = P_\circ \cdot e^{\frac{-L}{RT}}, \tag{9}$$

where R is the universal gas constant. The saturated vapour pressure is clearly a nonlinear function of the absolute temperature.

Experiment

Thermodynamic relations such as the Clausius-Clapeyron equation only hold in equilibrium, so this experiment cannot be rushed. You must wait for equilibrium to be established at each pressure step. In order to help you with this, a PASCO Capstone program will be used to record temperature values and plot them over time. Equilibrium is achieved when the temperature graph levels off. In addition, a graph is provided in the appendix showing lnP as a function of $\frac{1}{T}$ at equilibrium. The triple point (0.458 cmHg, $0°C$) and the normal boiling point at 1 atm (76 cmHg, $100°C$) are marked on the graph, and joined by the simple linear interpolation expected if the latent heat of vapourization, L, is indeed independent of temperature.

As illustrated in figure 5, the apparatus consists of a water-flask (F) with direct-reading thermometer (T), a water-cooled condenser (C), and a ballast tube (B) connected to a mercury manometer (M). The pressure can be regulated by means of the air valve (V). A thermocouple inside the flask is connected to a converter. This converter has two pairs of cables coming out. Connect the red and black wire to the power supply on PASCO and the yellow and black wire to the multimeter. The latter outputs a voltage where $1\,\text{mV}$ equals $1\,\text{K}$. Make sure the cable is connected to the multimeter and to the analogue input A of PASCO interface. Make sure to check the PASCO readings with those on the multimeter. **Wire up the setup but have the TAs check it before turning on the power supply. To turn on the voltage supply, click on the tab of "signal generator" on the left-hand-side panel. Choose "Output 1" and click "On".**

In the PASCO interface program, the first page contains a graph showing lnP as a function of $\frac{1}{T}$ as a virtual semi-logarithmic graph, a table that records temperature values with user inputted manometer heights, and a plot of the time evolution of the temperature that is used to determine thermal equilibrium. The semi-logarithmic graph is populated with data points in real time as temperature and pressure values are taken. **Trouble Shoot: If the graph is not plotting the data during the experiment then click on the LnP axis and in the menu click LnP under Equations and Constants.**

The manometer M measures the pressure in the system relative to absolute pressure. The first step is to note the atmospheric pressure which can be found at www.weather.gc.ca. Make sure you extract the current, local pressure.

Enter the current atmospheric pressure in the variable P_0 found in the $\boxed{\text{Calculator}}$ tool. The absolute pressure of the system is calculated from the height difference of the liquid in

the manometer. The height of the liquid levels on the right hand side and the left hand side of the manometer are entered into the appropriate columns in the table. The program then subtracts the two values to get a relative pressure, and then subtracts the difference from atmospheric pressure to get the absolute pressure of the system. The program then calculates lnP and displays it once the temperature value is kept.
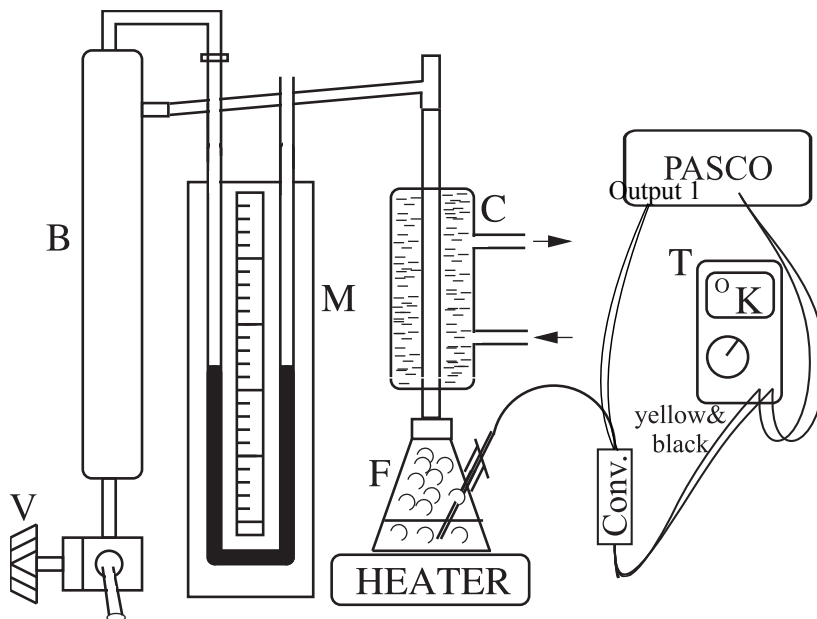

Figure 5: Vapour Pressure of Water Apparatus.

Procedure

- At the beginning of the experiment the heater should be off. Check that cooling water to the condenser is turned on. Start the experiment at the lowest pressure (highest vacuum), using a mechanical pump to evacuate the air from the system. The water will start boiling.

- Click preview, a temperature value should appear in the first row and column of the table. Once boiling is observed take readings of pressure (both sides of manometer) and enter them into the table, then click keep sample to record the temperature.

- The graph is being populated while you perform your experiment. If a point is very far off the interpolated graph then the system is probably not in equilibrium. Wait a few minutes and take another reading.

- Any bad data can be excluded by first highlighting its row, right click then click
  $\boxed{\text{Exclude Data}}$ **Remember: If no data appears on the semi logarithmic graph,
  then follow the trouble shoot step above.**

- We will now record the boiling point of water at higher pressures. Set the thermostat
  dial of the heater to approximately 60% of its maximum position and leave it there for
  the remainder of the experiment.

- Admit a small amount of air into the system by very gently opening and closing the
  valve. The manometer reading should change by 1-2 cm. It is helpful to increase the
  pressure in smaller steps at low pressure. Wait for equilibrium, i.e. boiling and the
  temperature graph flattening off, by looking at the graphs provided on the interface.
  Usually this takes 3-5 minutes.

- Once equilibrium is reached enter the manometer readings in the appropriate columns
  and press $\boxed{\text{Keep sample}}$ to automatically record the temperature in the column.

- Admit more air into the system and repeat the previous measurement until you reach
  atmospheric pressure (i.e. both sides of the manometer are at the same height). Keep
  the valve open at this point for your last measurement point. The water will be at a
  temperature close to $100°C$.

- You should try to measure 10-15 points between almost vacuum, i.e. the lowest pressure
  the pump can reach, and atmospheric pressure. Export your data as a csv file for
  analysis.

Analysis

- Estimate the systematic uncertainty that is introduced by reading the manometer and
  fit the extracted data.

- Perform a linear regression of LnP vs $\frac{1}{T}$ and calculate L from the slope:

$$slope = -\frac{L}{R},$$

  where R is the molar gas constant[2]: $8.314 \, \mathrm{J \, K^{-1} \, mole^{-1}}$

- Perform a non-linear fit on pressure as a function of temperature to find the heat of
  vapourization.

- Look up the accepted value in a textbook (don't forget to cite your source) and compare
  it with your results from both fits. Comment.

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[2]Note that 1 *mole* of water has a mass of 18 *g*.

- Compare your linear fit to the linear interpolation in the appendix. An equation of the interpolation is provided on the graph. Present both your fit and the fit from the appendix on the same graph.

- Estimate the triple point pressure. Is it consistent with the accepted value?

- At what temperature does water boil? Discuss.

References

[1] Sears and Salinger, Sections 2-5, 3-12, 7-6.

Appendix

LnP as a function of 1/T

$100^o C, 76 cmHg$

$y = -5205x + 18.3$

$0^o C, 0.458 cmHg$