Chapter 4

Thermometry

Objectives

1. Calibrate (i) Alcohol Thermometer (ii) Thermocouple (iii) Thermistor and (iv) Platinum Resistance Thermometer (Pt100) using the melting and boiling point of water and pre-calibrated Mercury thermometer
2. To measure the melting point of a given unknown solid, using the above thermometers.
3. To draw the cooling curves for water, using containers of different surface areas and verify Newton's Law of Cooling

Introduction/Theory/Background

Thermometry

Thermometry is the science of measuring temperature. Any physical property that depends consistently on temperature and is reproducible can be used as the basis of a thermometer, and is called thermometric property. For example, in the case of **mercury and alcohol**, their volume increases with temperature. Mercury, on one hand, expands quite uniformly over a significant range of temperatures, on the other hand, alcohol expands non-linearly over different range of temperatures.

The liquid in a **liquid-thermometer** is contained in a thin-walled glass bulb. The bulb is made relatively larger than its bore to contain more of the liquid to improve sensitivity. Thin glass surrounds the bulb to allow the heat flow to be quick. Small expansion of the liquid in the bulb will cause a big change in the length of the liquid thread in the capillary tube as it is made narrow. The narrower the bore, the higher the sensitivity. The round glass stem around the capillary tube is made thick and acts as a magnifying glass.

(Estimate the length change that corresponds to a change in 1 degree Celsius in a standard thermometer)

Another property used to measure temperature is electrical resistance. You will be provided Pt-100 Platinum resistance thermometer (Pt100) and thermistor. In each case the resistance of the device depends on temperature.

The working of **Platinum resistance thermometer** is based on the fact that the electrical resistance of Platinum increases linearly with temperature, and that the coefficient of change of resistance with temperature is large. Platinum also has a high melting point, making it useful in thermometry. The 100 suffix in Pt100 is due to the fact that the resistance at $0°C$ is 100Ω. The value of the electrical resistance at a temperature above $0°C$, R_T can be expressed as

$$R_T = m \times T + R_{0^\circ\mathrm{C}} \tag{4.1}$$

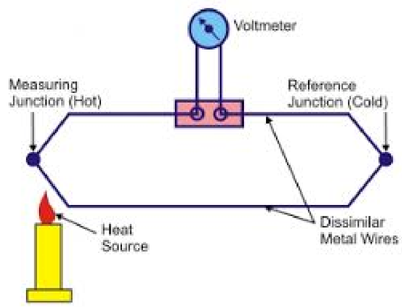
where m is the coefficient of change of resistance with temperature (this is assumed to a constant over the range of temperature we are interested in) and $R_{0^\circ\mathrm{C}}$ is the value of the resistance at 0°C which as stated earlier is 100Ω for the Pt100 thermometer.

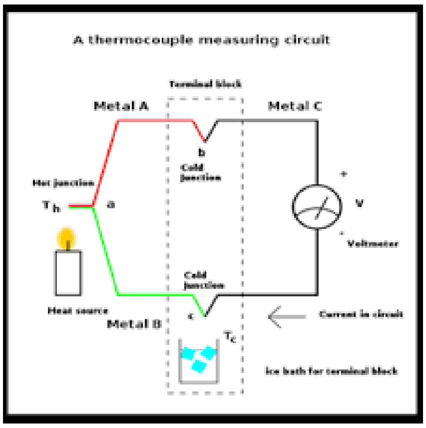
A **thermistor** is a solid state temperature sensing device that is an electrical resistor but is temperature sensitive as it changes its resistivity value in proportion to small changes in temperature. It is a type of semiconductor and has a greater resistance than conducting materials, but lower resistance than insulating materials. In contrast to PRTs that change resistance in a nearly linear way, thermistors have a nonlinear change in resistance and actually reduce their resistance with increases in temperature.

The resistance-temperature relationship for a thermistor is given by the Steinhart-Hart equation:

$$\frac{1}{T} = a + b\ln R + c(\ln R)^3$$

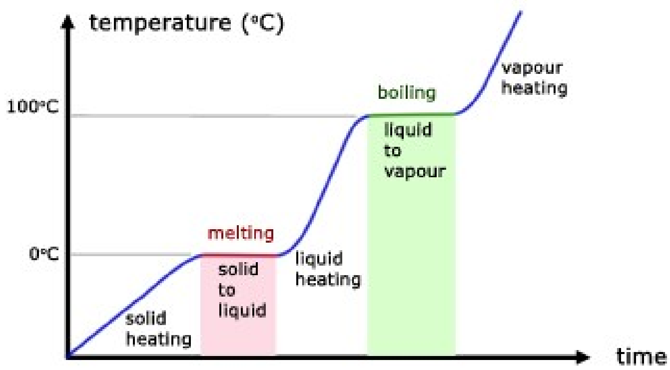
You have also been provided a standard low temperature copper-constantan (constantan is a copper - nickel alloy) **thermocouple**. Thermocouples work on a principle called the Seebeck Effect. When two different metal wires are twisted together at a junction, an EMF (electromotive force) is generated across the loose ends. The hotter and more energetic electrons tend to diffuse towards to colder regions, as a result of which in the steady state there is a charge gradient in the conductor, and hence a voltage. The magnitude of this EMF (in mV range) relates to the temperature at the junction. A more convenient and efficient setup is to have two junctions (hot and cold) instead of one, but still have just two metals. The reference cold temperature is usually melting ice.





Melting Point

Melting point is defined as the temperature at which a solid converts to liquid.
At the melting point, the solid and liquid phase exist in equilibrium, and it is observed that the temperature of the system does not rise till the whole solid mass has melted, the temperature-time curves shown below illustrates the point. The curve also shows that a similar behaviour occurs at the boiling point where liquid and vapour coexist.



Newton's Law of Cooling

Newton's law of cooling states that the temperature of a cooling body falls exponentially towards the temperature of its surroundings with a rate that is proportional to the area of contact between the body and the environment. The cooling rate can be expressed as

$$\frac{\mathrm{d}T}{\mathrm{d}t} \propto (T - T_{surrounding})$$

where T is the temperature of the body.

So we see that as the temperature of the body falls, it takes more time for a unit change in temperature.

Question : Show that the Temperature-time curve follows an exponential graph.

This is an intuitive result, we have obviously noticed that a cup of hot coffee cools faster on a cold winter morning than on a hot summer's afternoon.

Experimental Setup

Apparatus

1. Hot Plate
2. Available Thermometers
3. Ice
4. Multimeters
5. Beakers of different volumes
6. Test Tubes
7. Retort stands and clamps

Description

Warnings

- Use proper gloves and lab coats during this experiment.
- Be cautious while handling hot beakers.
- Water in proximity to electronics always requires caution.
- Make sure the openings for inserting thermometers are air tight, to avoid any heat loss through these.
- Don't screw the thermometers too tight, as they are fragile items.

Procedure

Part A: Calibration

If you measure a few known temperatures (in this laboratory, the known temperatures we use correspond to the melting and the boiling point of water) with a given device, you can figure out the mathematical relationship that links the changing property (say, X) and the temperature, i.e. the form $X(T)$. This is referred to as calibration, just like marking the scale on a mercury thermometer. In this experimental session, you'll have one of each : mercury thermometer, alcohol thermometer, thermistor or Pt100 and thermocouple. The following steps are generic, and you are expected to adapt to the thermometer at hand.

1. Place the beaker containing ice-water mixture on top of the hot-plate but do not switch it on.
2. Clamp the thermometers properly on top of the retort stand and make sure you do not tighten the glass tubes (Mercury and Alcohol) too much.

3. The thermometers should be completely immersed (the bulb which contains the fluid, in case of glass thermometers) in the mixture
4. Find the voltage/resistance output for Ice-Water Mixture (0°C).
5. By now switching on the hot plate, start heating the mixture and record the corresponding readings in different thermometers, including the pre-calibrated Mercury thermometer.
6. Plot calibration curves for the different thermometers given to you.

Part B:Melting point of the unknown solid

You are provided with an unknown material in its solid phase which will make it difficult to get its temperature by heating as immersion of a thermometer is no longer feasible. You will need to choose an appropriate thermometer for this experiment. To accurately get the melting point of the substance, you should take both the heating and cooling data.

1. Put the unknown material in a test tube, place the thermometers inside the test tube and secure the open end with cotton plug.
2. Dip the test tube in water contained in a beaker.
3. Start heating the water and wait for the solid to melt. Ensure that thermometers are immersed in the liquid.
4. Switch off heating, and as the liquid cools keep measuring the temperature, this will give you the cooling data.
5. You will notice that the temperature will stabilise at a point
6. Now, by heating you can heat the system, as thermometers are surrounded by the solid and take a heating curve

Part C:Newton's Law of cooling

1. Take 100 ml of distilled water and boil it. As soon as the water starts steaming, measure the appropriate resistance or voltage.
2. Let it cool and as it reaches 90^oC, at equal drops of voltage/resistance or equal intervals of time measure time or voltage/resistance.
3. Plot the curve and do appropriate characterisation.

Part D:Varying Surface Area

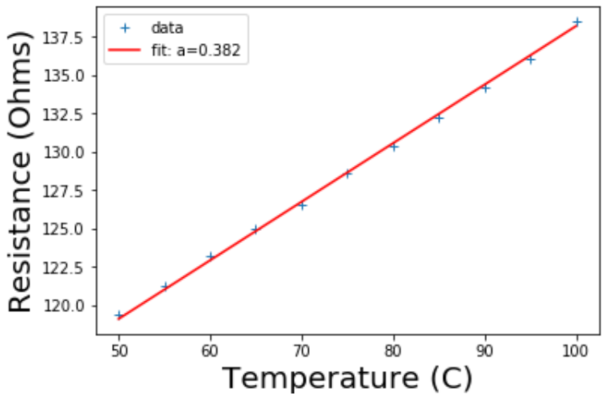
We saw that the Newton's law of cooling states that the rate of cooling is proportional to the area of contact between the body and its surroundings. In this part, we will verify this.

1. Do the above experiment with same volume but with different surface areas (difference sizes of beakers).
2. Use Fourier's law of conduction to calculate heat transfer coefficient. (what can you infer?)

4.1 Expected Outcomes

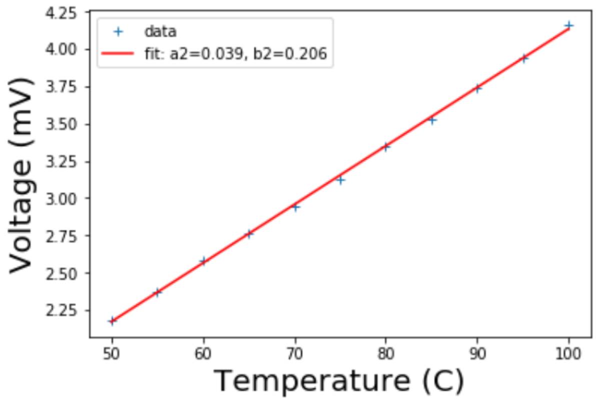
4.1.1 Pt100

First you have to check that the curve best fits a linear polynomial as compared to higher degree polynomials. Then after you have fitted the linear curve, check if at 0°C, the resistance is, within experimental error, what you observed, if this is not the case, force it to go through the melting point temperature.

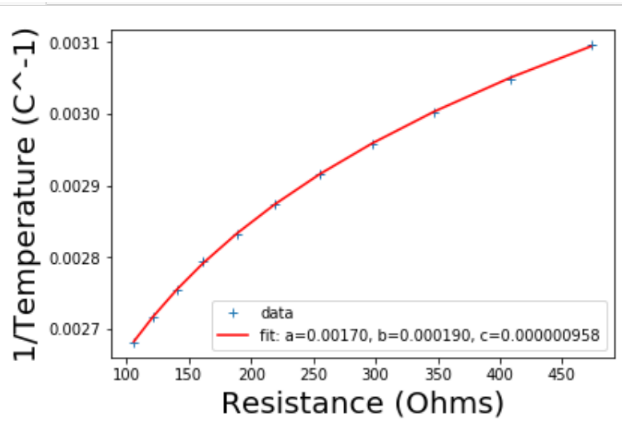


4.1.2 Thermocouple

Here also you can try to force fit the curve to appropriate intercept at 0°C.



4.1.3 Thermistor



4.1.4 Melting point of Unknown Solid

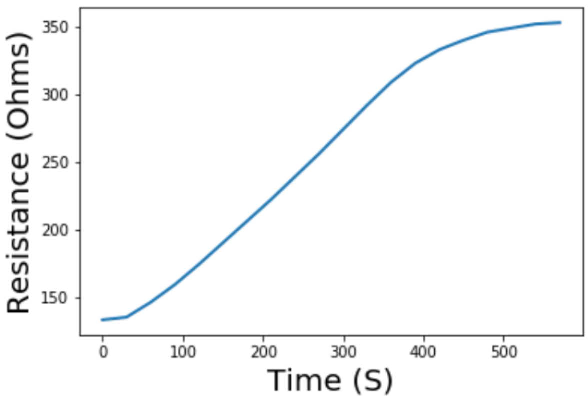


Figure 4.1: Using Thermister

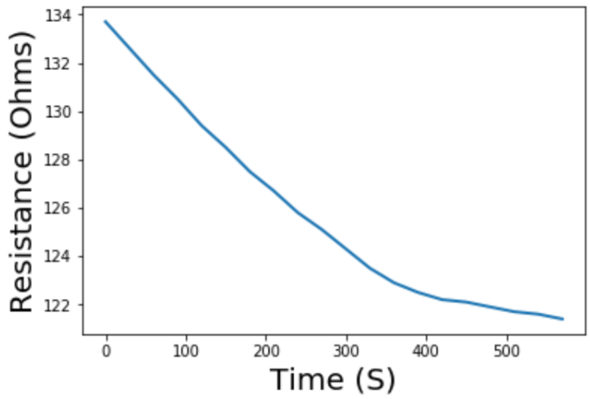


Figure 4.2: Using Pt100

4.1.5 Newton's Law of Cooling