Lab Report 2

PHY 2020: Physics Lab 3

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1 Aim

1. Calibrate an alcohol thermometer, thermistor, thermocouple and a Platinum Resistance (Pt100) thermometer using a pre-calibrated mercury thermometer.
2. Measure the melting point of an unknown liquid using any of the aforementioned thermometers.
3. To draw the cooling curves of water for beakers of different sizes and verify Newton's Law of cooling.
4. To find the heat transfer coefficients for beakers of different sizes.
5. To use Lee's Disc to find the thermal conductivity of a glass disc.

2 Theoretical Background

2.1 Thermometry

The science of measuring temperatures is known as thermometry. Any object that expands consistently upon heating or contracts upon cooling can be used to set up a standard to measure the temperature. For example, both mercury and alcohol change their volume on heating or cooling and both can be used to make thermometers. A liquid thermometer contains the liquid in a small bulb at the bottom surrounded by a thin glass surface. This bulb is connected to a column which is much thinner than the bulb that runs along the length of the thermometer. As the thermometer is heated the glass column being much thinner than the bulb, the liquid rises and this change in the length can be converted to a temperature change using certain calibration techniques.

Volume change on heating is how mercury and alcohol thermometers measure temperature. Another way of measuring the temperature is using electrical resistance. Two devices that measure the temperature using resistance are the **Platinum Resistance (Pt100)** thermometer and the **thermistor**. For a platinum resistance thermometer the property that is used is that the resistance of platinum increases linearly with temperature. Thus the relation between the resistance and the temperature for platinum is,

$$R_T = mT + R_0$$

Where m is the coefficient of the change in resistance with temperature and is assumed to be constant and R_0 is the resistance of platinum at 0° C. For the Pt100 value of R_0 is 100° C.

A thermistor is a solid state semiconducting device. The resistance of this device changes proportionately to small changes in temperature but this change is not linear. The relation between the temperature and the resistance for a thermistor is given by the Steinhart-Hart relation,

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

Another method of calculating the temperature is by measuring voltage. This can be done by using a **thermocouple**. Thermocouples work on the principle of the Seeback effect. This is a phenomenon where the difference in temperatures of two different conductors, connected at one or two points, sets up a voltage difference across the junction(s). This happens because the temperature difference is also an energy difference due to which more energetic electrons tend to follow the energy gradient effectively setting up a current which causes a voltage difference. These voltages are in the mV range and can be measured and a relation between the temperature and the voltage can be obtained.

2.2 Newton's Law of Cooling

Newton's law of cooling is a physical law that states that the rate of heat loss from an object is proportional to the difference between the temperature of the object and its surrounding temperature and also to the surface area of the object in consideration. In mathematical terms,

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

Solving this equation would give an exponential relation of the temperature in terms of the time. Thus it confirms what is seen on a daily basis where a hot cup of tea or coffee cools quicker on a cold day than on a hot day. This equation when solved for cooling from an initial temperature T_0 to a temperature T is,

$$T = T_s + e^{-\frac{hA}{mc}t}(T_0 - T_s)$$

Where T_s is the surrounding temperature, A is the surface area of the object that is cooling down, m is the mass of the object, c is the specific heat capacity and h is the heat transfer coefficient. Thus from this relation the cooling curves can be used to calculate the heat transfer coefficient for different sized containers.

2.3 Lee's Disc

Lee's disc is an experimental apparatus that is used to find the thermal conductivity of a bad conductor such as glass, teflon or plywood. This experiment is based on Fourier's law of heat transfer which in simple words states that heat transfer occurs in the direction of higher to lower temperature. Mathematically it relates the heat to the difference in temperature as,

$$Q = \frac{kA\Delta T}{x}$$

Where k is the thermal conductivity of the sample with cross-sectional area A and thickness x and ΔT (it is $T_2 - T_3$ for the Lee's Disc) is the difference in the temperature across the sample. This is assuming the loss of heat from the edges is minimal. Using this device the thermal conductivity of the material can be calculated. The heat radiated per second can be written as ,

$$Q = Mc\frac{\mathrm{d}T}{\mathrm{d}t} \times \frac{r + 2h}{2(r + h)}$$

Where M is the mass of the metallic disc, c is the specific heat capacity of the metallic disc, $\frac{\mathrm{d}T}{\mathrm{d}t}$ is the rate of cooling of the brass disc, r is the radius of the metallic disc and h is the height of the metallic disc.

Equation the two the thermal conductivity of the material is,

$$k = \frac{Mc\frac{\mathrm{d}T}{\mathrm{d}t}}{\pi r^2 (T_2 - T_3)} \times \frac{(r + 2h)x}{2(r + h)}$$

3 Equipment

1. Hot plate
2. Thermometers: Mercury, alcohol, Pt100, thermistor, thermocouple
3. Ice
4. Multimeters
5. Beakers of capacity 2000, 1000, 500 and 250 ml.
6. Lee's Disc
7. Vernier Callipers

4 Procedure

4.1 Part A: Calibration

Using a pre-calibrated thermometer (the mercury thermometer) the other thermometers were calibrated by measuring the parameter that changes on change in temperature.

1. The 2000 ml beaker was filled with ice and placed on the heating plate. The mercury thermometer was placed using a retort stand with the bulb completely surrounded by the ice.
2. The alcohol thermometer was calibrated first. It was placed as the mercury thermometer was and the hot plate was turned on. At regular intervals of temperature increment on the mercury thermometer the change in the length of the alcohol was noted down and a graph of the length change versus the temperature change was plotted.

3. The same procedure was followed for the remaining- Pt100, thermistor and thermocouple. For each plots of resistance versus temperature, inverse of temperature versus resistance and voltage versus temperature were made to calibrate the thermometers.

4.2 Part B: Melting point of unknown solid

1. The unknown solid was taken in a test tube and this test tube was immersed in a beaker of water using a retort stand. The Pt100 thermometer and a mercury thermometer was also placed inside the beaker to note the temperature changes of the solid.
2. The beaker was kept on the heating plate and the heat was switched on. The values of the resistance as measured by the Pt100 were noted down at 20 second intervals till the resistance stabilized. The resistance was plotted against time to get the heating curve of the unknown solid.
3. The beaker was removed from the heating plate and kept aside. While the solid cooled down the resistance measured by the Pt100 was noted down at 30 second intervals till the resistance stabilized. Following this the resistance was plotted against the time to get the cooling curve of the solid.
4. The two plots were compared to get the melting point of the unknown solid.

4.3 Part C: Newton's Law of cooling

1. 100 ml of water was first taken in the 2000 ml beaker and kept on the heating plate. The hot plate was switched on.
2. As soon as steam was observed the beaker was removed from the hot plate and kept aside. The mercury thermometer and the calibrated Pt100 were kept inside the water.
3. At regular intervals of time, 15 seconds for this experiment, the resistance readings were noted. Following this the resistance versus the time were plotted to check the trend.
4. The same procedure was followed for the 1000, 500 and 250 ml beakers and the corresponding cooling curves were plotted.

4.4 Part D: Heat transfer coefficient

The relation given in the *Theoretical Background* above can be re-written as,

$$\ln\left(\frac{T - T_s}{T_0 - T_s}\right) = -\frac{hA}{mc}t$$

Thus the slope of the plot for this relation can give the heat transfer coefficient since the area, the mass and the specific heat capacity are known quantities.

4.5 Thermal conductivity of glass disc

For this section the Lee's disc was used.

1. The material of unknown thermal conductivity was placed in between T_2 and T_3 and the power switch and the heater switch were turned on. Then the manual mode was selected.

2. Following this the maximum temperature was set at 50° C and then the setup was left to heat up to that temperature.
3. The setup was allowed to heat up till the temperatures T_2 and T_3 more or less became constant.
4. Following this the maximum temperature setting was increased to 60° C. The setup was allowed to heat up till the temperature increased by 7° C. After that the brass disc T_3 was removed and kept on the slot on the side and allowed to cool.
5. The brass disc was allowed to cool and at each decrease in temperature by 0.5° C the time was noted. This was done for a 5° drop in temperature.
6. This data was used to plot the temperature versus the time plot to get the rate of cooling of the brass disc.
7. The dimensions of the brass disc were measured using the Vernier calipers and used to calculate the thermal conductivity of the glass disc.

4.6 Precautions

1. Take care while using the hot plate since after heating for a while it becomes really hot and can cause serious burns. The same goes for handling boiling water.
2. While taking readings for the thermocouple, thermistor or the Pt100 care should be taken to not touch the connecting wires while taking readings since doing that causes an abrupt change in the values shown by the multimeter which can disrupt the process of taking readings.
3. The thermometes should not be screwed on too tight in the retort stand since they are very fragile items.

5 Data

5.1 Least Count of Instruments

1. Stopwatch: 0.01 s
2. Lee's Disc: 0.1°C
3. Mercury Thermometer: 0.1°C
4. Vernier Callipers: 0.02 mm.

5.2 Part A: Calibration

The data for the calibration of all thermometers is provided in the *Appendix*

5.3 Part B: Melting Point of Unknown Solid

The data table is attached in the *Appendix*.

5.4 Part C: Newton's Law of Cooling

The data table is attached in the *Appendix* below since there are too many data points and would take up space that can be used to present results in a more space-efficient manner.

5.5 Part D: Heat Transfer Coefficient

The data for this part is the same as in *Part C*.

The mass of water used for each beaker is 0.1 kg and the specific heat capacity of water is 4181 $JK^{-1}kg^{-1}$.

5.6 Thermal Conductivity of glass disc

The different dimensions that are used in calculating the thermal conductivity are,

- Mass of glass disk: 0.885 kg
- Radius of Metal disc: 0.0382 m
- Height of metal disc: 0.0022 m
- Thickness of glass sample: 0.00445 m
- Specific heat capacity of metal disc: 375 $J/kg^{-1}K^{-1}$
- Temperature of disc 2 (T_2): 48.6°C
- Temperature of disc 3 (T_3): 46.8°C

The data for the temperature and the time for cooling for the brass disc is,

Time (s)	Temperature (°C)
53.58	52.0
86.83	51.5
152.96	51.0
196.93	50.5
252.5	50.0
297.36	49.5
364.53	49.0
418.74	48.5
488.59	48.0
540.71	47.5

Table 1: The time taken by the brass disc to cool from 52° to 47.5° C.

6 Graphs and Analysis

6.1 Part A: Calibration

6.1.1 Pt100

The graph of the resistance versus the temperature for the Pt100 thermometer is,

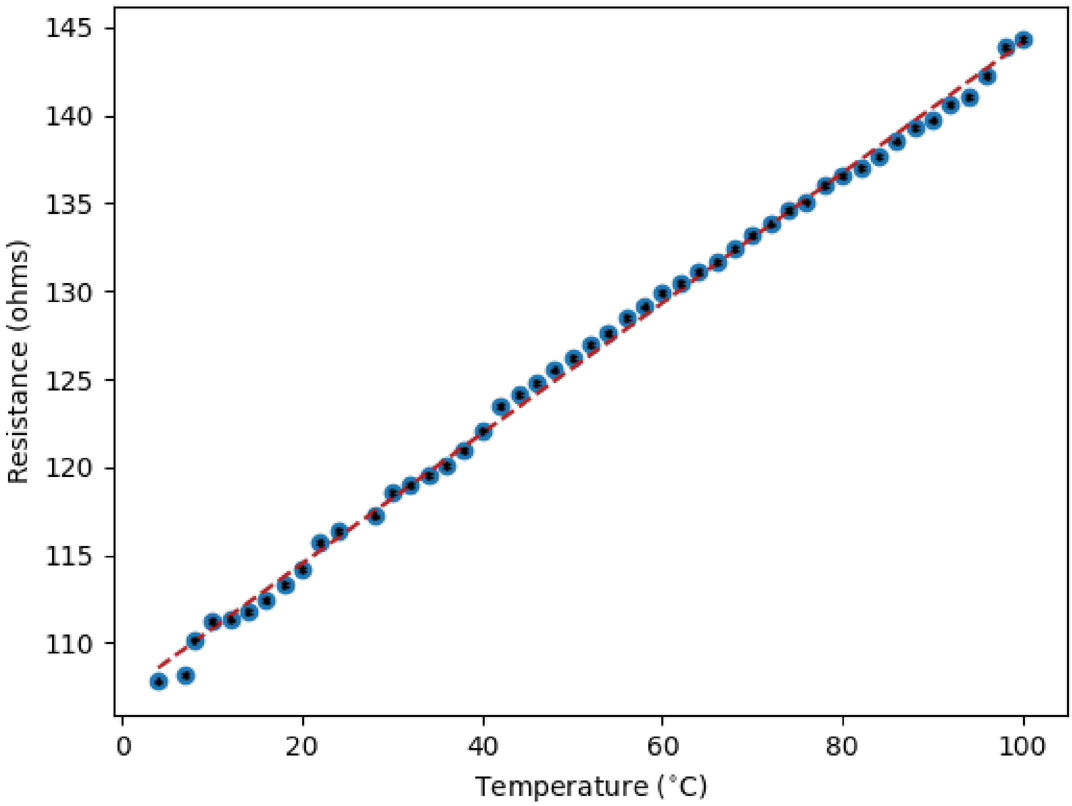

Figure 1: Resistance versus temperature plot for the Pt100 thermometer

The equation of the fit here is

$$R_{Pt100} = 0.37T_{mercury} + 107.09$$

Where $T_{mercury}$ is the temperature shown by the mercury thermometer and R_{Pt100} is the resistance of the Pt100 thermometer at a certain temperature.

The plot agrees with the theoretical prediction of the relation between the resistance of platinum and the temperature being a linear one.

6.1.2 Thermocouple

The graph of the voltage recorded by the thermocouple versus the temperature is,

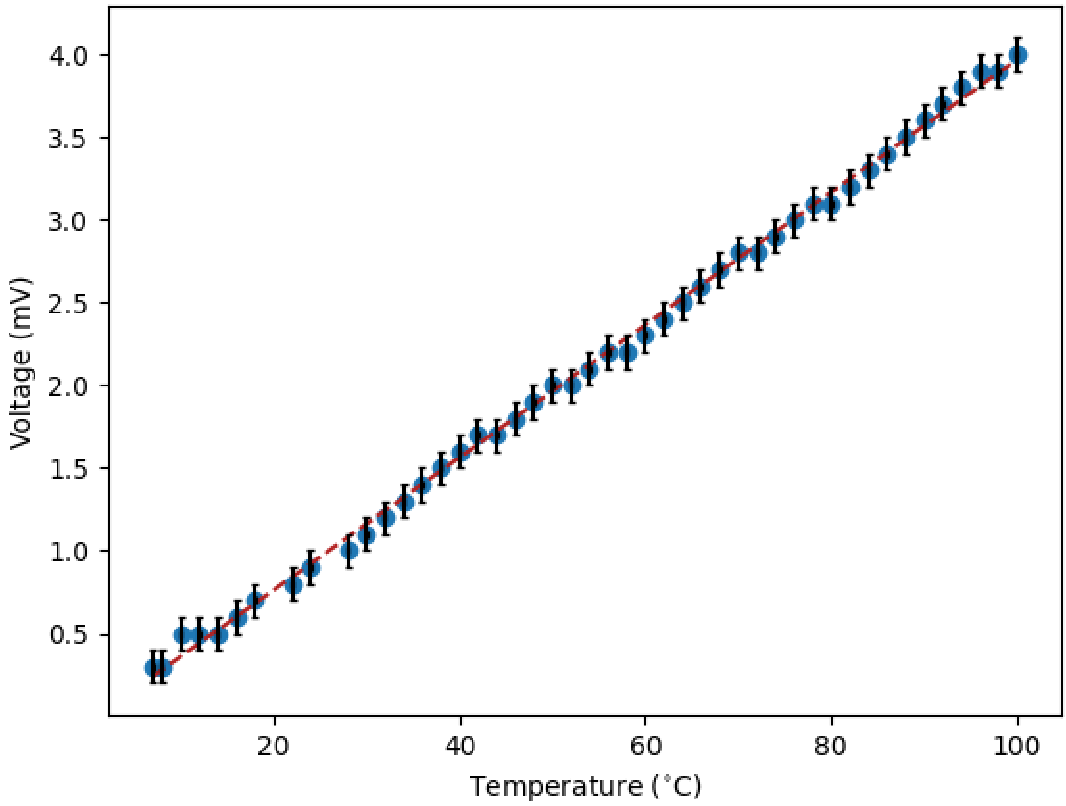

Figure 2: Voltage versus temperature plot for the thermocouple.

The equation of the fit is

$$V_{thermocouple} = 0.04T_{mercury} - 0.04$$

Where $V_{thermocouple}$ is the voltage measured by the thermocouple in the mV range.

Once again the plot agrees with theory, i.e., the relation between the voltage detected by a thermocouple and the temperature difference between the cold and hot junctions of the thermocouple is a linear relation.

6.1.3 Thermistor

The graph for the calibration of the thermistor is,

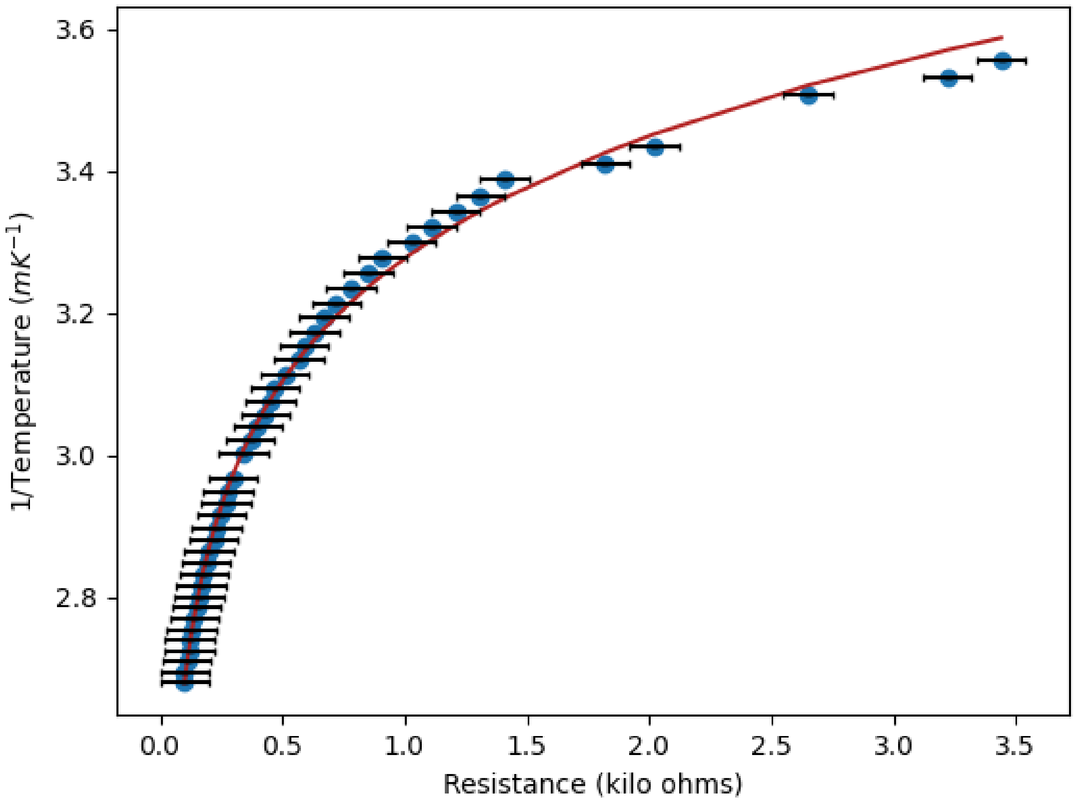

Figure 3: Calibration graph for thermistor

The equation for the fit in the graph is,

$$\frac{1}{T_{mercury}} = 3.276 + 0.248 \ln R + 0.002(\ln R)^3$$

Where the temperature is in mK and the resistance is in kilo ohms.

The data agrees with the theoretical prediction very well.

6.1.4 Alcohol Thermometer

The graph of the change in the length of alcohol in the alcohol thermometer versus the temperature change in the mercury thermometer is,

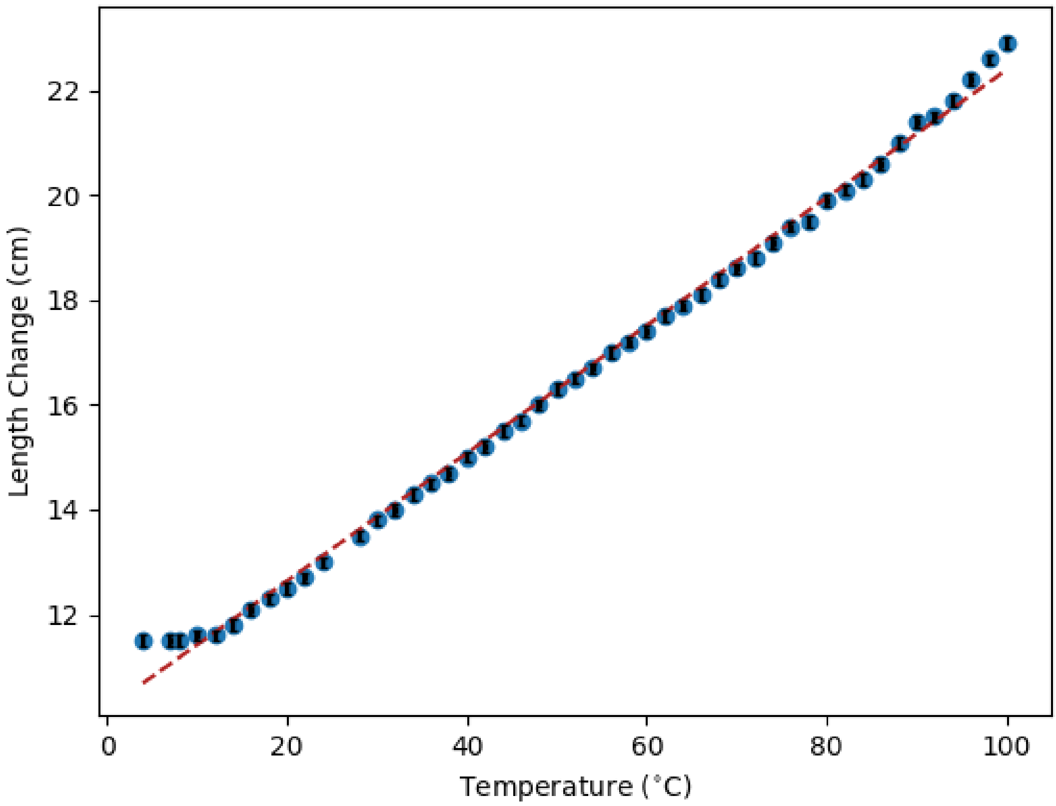

Figure 4: Length change of alcohol in alcohol thermometer for changes in temperature measured by the mercury thermometer

The equation of the fit in the graph is,

$$\Delta L_{alcohol} = 0.122T_{mercury} + 10.197$$

Where $\Delta L_{alcohol}$ is the change in the length of the alcohol inside the thermometer.

6.2 Part B: Melting Point of Unknown Solid

The heating curve for the unknown solid is obtained using the Pt100 is,

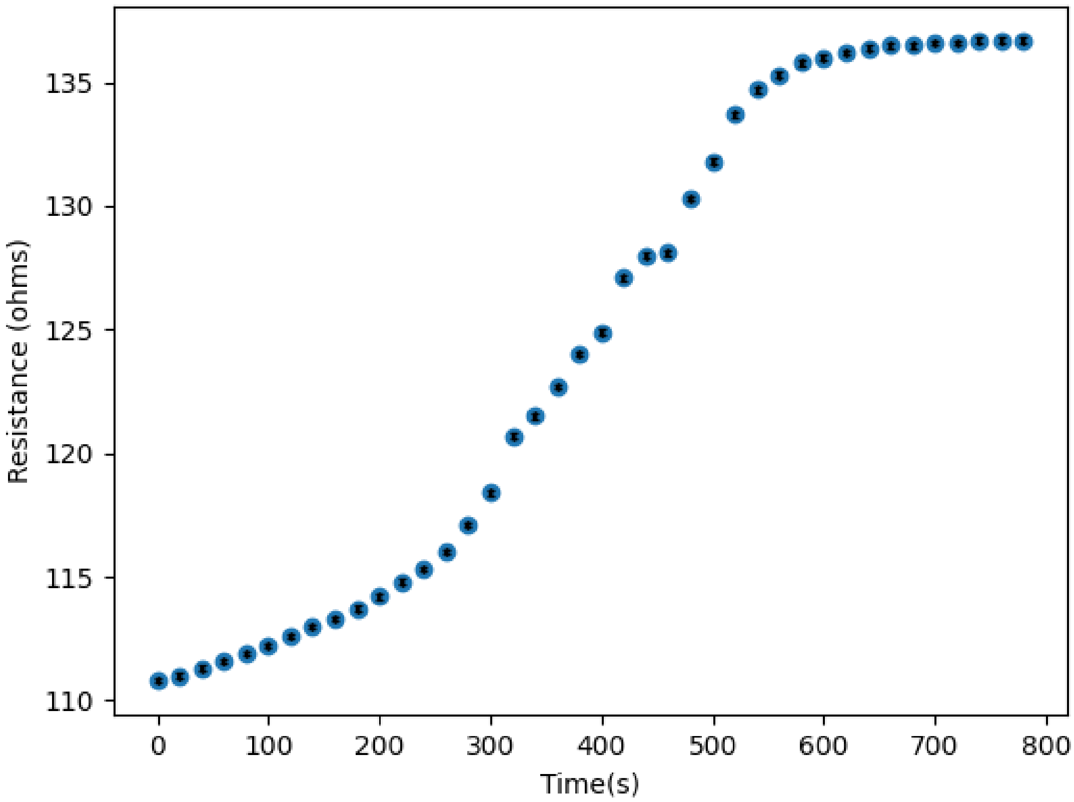

Figure 5: Heating curve for the unknown solid obtained using the Pt100 thermometer

The cooling curve obtained using the Pt100 is,

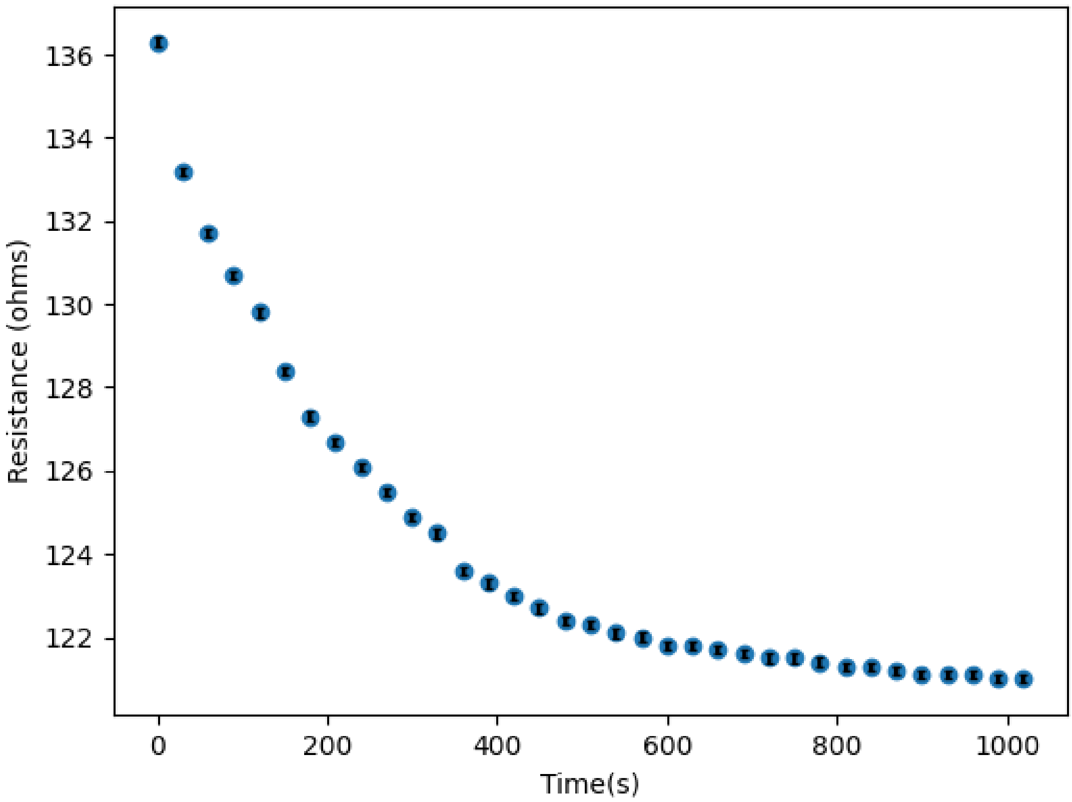

Figure 6: Cooling curve for the unknown solid obtained using the Pt100 thermometer

From the heating curve and the cooling curve the Pt100 readings obtained are 136.3 and 136.7 ohms. This means that from each, using the calibration formula the melting point is obtained as 78.8°C and 79.9°C respectively.

6.3 Part C: Newton's Law of Cooling

The cooling curves for 4 different sizes of beakers with the same amount of water filled in them is,

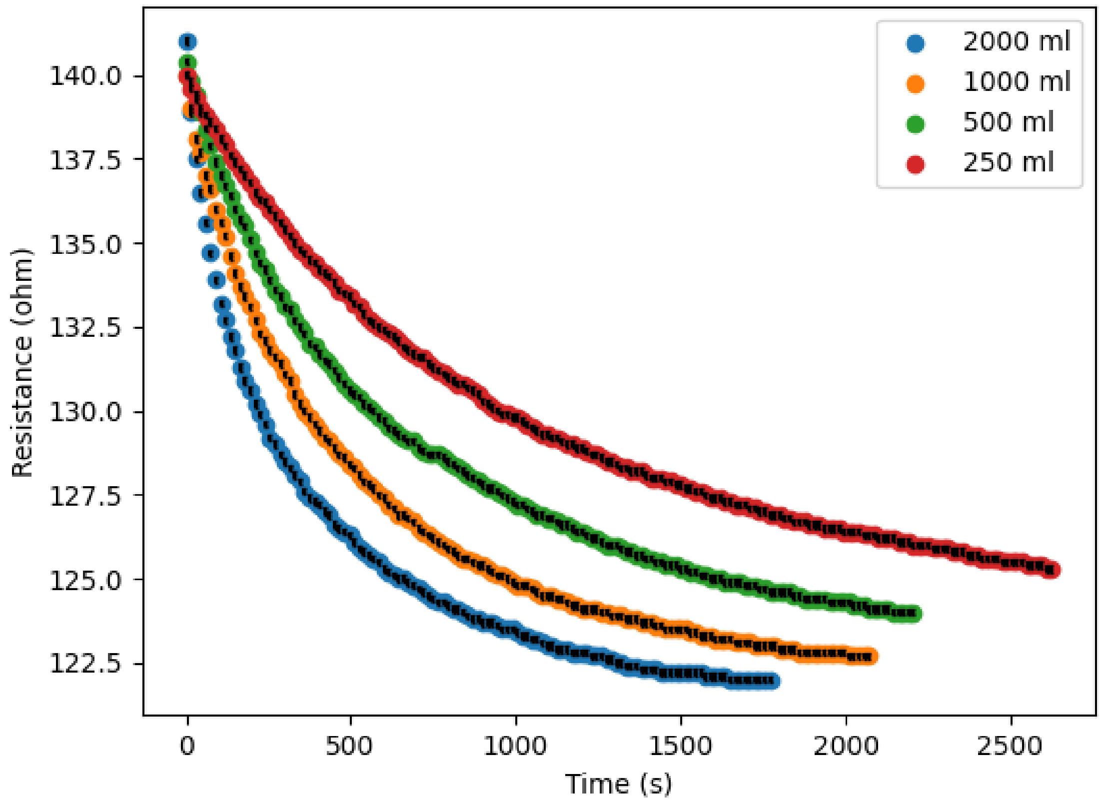

Figure 7: Cooling curves for 4 different beakers with 100 ml of water filled in them

The graph shows approximately a downward exponential trend for all the beakers. However the bigger the beaker is the faster the cooling rate is which is evident from the shapes of the graphs. This is because a 2000 ml beaker has a larger surface area of water in contact with the surrounding environment compared to the other beakers. This is so because there is a larger area through which the same amount of energy will be transferred to the environment. As a result the 2000 ml beaker takes the least amount of time to reach equilibrium while the 250 ml beaker took the most amount of time.

6.4 Part D: Heat Transfer Coefficient

The plots for the different beakers are,

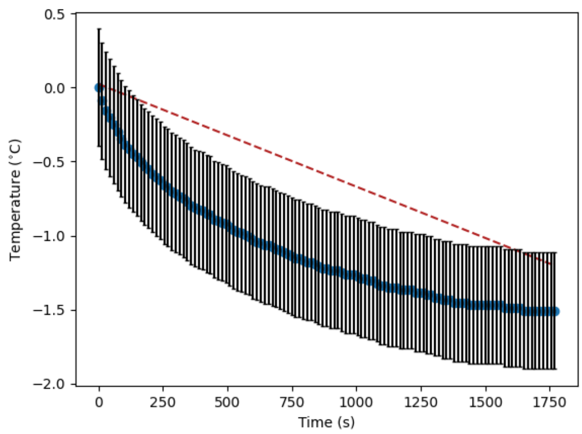

Figure 8: 2000 ml beaker

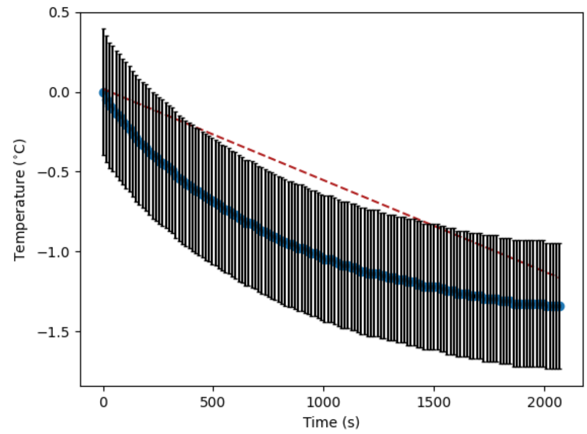

Figure 9: 1000 ml beaker

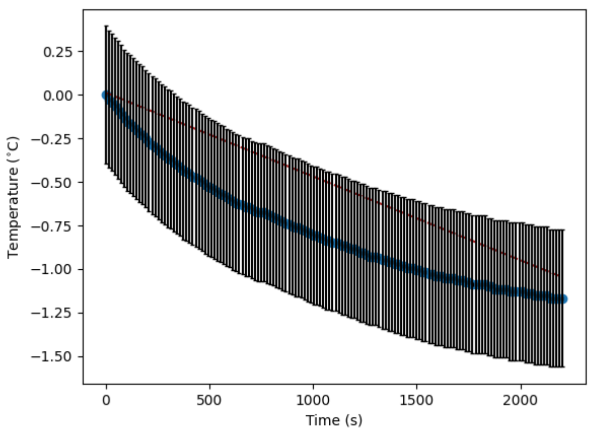

Figure 10: 500 ml beaker

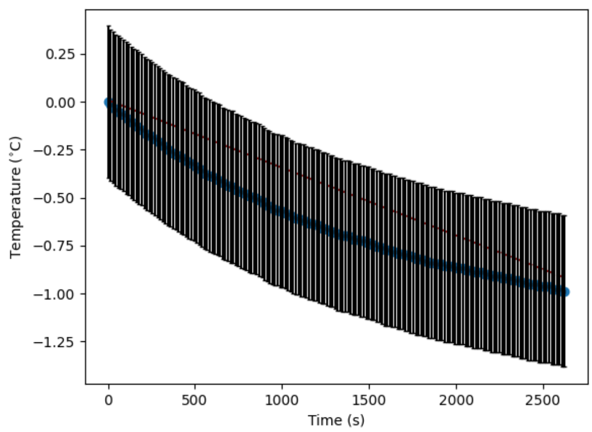

Figure 11: 250 ml beaker

The slope of the fit in each case gives the heat coefficient since the slope is equal to,

$$\text{slope} = -\frac{hA}{mc}$$

Where the symbols are the same as described in *Theoretical Background.* Thus the value of the heat transfer coefficient is,

$$h = -\frac{\text{slope} \times mc}{A}$$

6.5 Thermal Conductivity of glass disc

The graph for the cooling rate of the brass disc is,

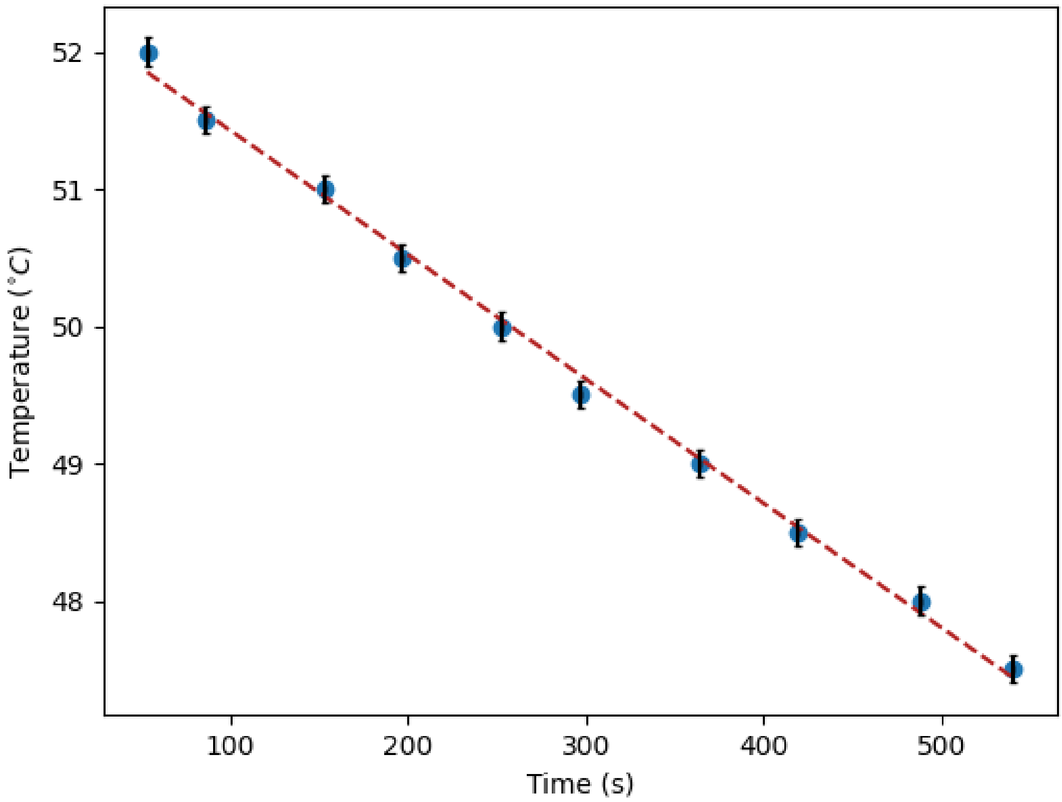

Figure 12: Graph of temperature change versus the time for a brass disc.

The equation for the fit is $T = -0.009t + 52.335$. This implies that the rate of cooling of the brass disc is 0.009°C/s.

Using the equation the thermal conductivity is 0.955 $Wm^{-1}K^{-1}$.

7 Error Analysis

For the calibration of all the thermometers the error bars correspond to the least count of all the measuring instruments used in the experiment. These include the ruler, multimeters, stopwatch and the mercury thermometer. For the thermistor the error in measuring $1/T$ is $|\Delta T/T^2|$ where ΔT is the least count of the mercury thermometer.

For the heating and cooling curve of for the unknown solid and the cooling curves to verify Newton's Law of cooling the magnitude of the errorbars are equal to the least counts of the instruments used to measure the relevant quantities, i.e., the multimeter and the stopwatch.

For the heat transfer coefficient the temperature is calculated using the calibration formula of the Pt100. Thus applying the general formula for finding the error in a function of multiple independent variables and adding in quadrature the relation obtained is,

$$\frac{\Delta T}{T} = \sqrt{\left(\frac{\Delta R}{R}\right)^2 + \left(\frac{\Delta m}{m}\right)^2 + \left(\frac{\Delta c}{c}\right)^2}$$

Where R is the resistance measured by the multimeter, m and c are the slope and the intercept of the calibration graph for the Pt100. This value of $\Delta T/T$ is the uncertainty in calculation of $\ln T$ for the plot which was used to find the heat transfer coefficient. Thus the magnitude of the errorbars are $\Delta T/T$ in the y-direction and it is the least count of the stopwatch in the x-direction.

To find the error in calculating the thermal conductivity of the glass disc we do the same thing as above and we get the relative error as,

$$\frac{\Delta k}{k} = \sqrt{\left(\frac{\Delta M}{M}\right)^2 + \left(\frac{\Delta \frac{\mathrm{d}T}{\mathrm{d}t}}{\frac{\mathrm{d}T}{\mathrm{d}t}}\right)^2 + \left(\frac{\Delta h}{h}\right)^2 + 4\left(\frac{\Delta r}{r}\right)^2 + \left(\frac{\Delta x}{x}\right)^2}$$

Where $\Delta M = 0.1$ kg, $\Delta \frac{\mathrm{d}T}{\mathrm{d}t} / \frac{\mathrm{d}T}{\mathrm{d}t}$ is the error in calculating the slope of the cooling curve of the brass disc, Δh, Δx and Δr are equal to 0.02 mm. This gives the error in calculating the value of thermal conductivity as 0.0025 $Wm^{-1}K^{-1}$.

8 Discussion

8.1 Part A: Calibration

The results for the calibration of all the thermometers are as expected. For the Pt100 one would expect that the y-intercept would be 100 since the resistance of the Pt100 at 0° is 100 ohms hence the name. However it is not 100 because the platinum rod of the Pt100 was placed in an ice-water mixture which was not at 0°C and thus the intercept was more than 100. Even for the thermocouple it is expected that the intercept would be 0 since the temperature T in the equation is the temperature of the junction at a higher temperature and initially the hot junction is placed inside ice. Thus the temperature difference should be 0 but it evidently is not. This could again be for the same reason as that for the Pt100, the ice-water mixture was not at 0°C initially but at a higher temperature.

8.2 Part B: Melting Point of Unknown Solid

The melting point obtained from the heating and the cooling curves are a little different. From the cooling curve the temperature obtained is 79.9°C and 78.8°C respectively. They should ideally be the same but they are not. This means that the temperature had not fully stabilized while taking the heating curve and the data should have been taken for a bit longer. Since the cooling curve provides the higher temperature it has been chosen as the correct value of the melting point.

8.3 Part C: Newton's Law of Cooling

The graphs qualitatively follow the trend that is expected.

8.4 Part D: Heat Transfer Coefficient

All discussions done in *Graphs and Analysis*

9 Results

9.1 Part A: Calibration

The calibrations for the different thermometers are,

1. Pt100: $R = 0.37T + 107.09$
2. Thermocouple: $V = 0.04T - 0.04$
3. Thermistor: $\frac{1}{T} = 3.276 + 0.248 \ln R + 0.002(\ln R)^3$
4. Alcohol thermometer: $\Delta L_{alcohol} = 0.122T + 10.197$

9.2 Part B: Melting point of unknown solid

The melting point of the unknown solid is 79.9°C.

9.3 Part C: Newton's Law of Cooling

The cooling curves were obtained and plotted above. The results follow the behaviour predicted by Newton's law of cooling.

9.4 Part D: Heat Transfer Coefficient

Surface area (m^2)	Heat Transfer Coefficient ($Wm^{-2}K^{-1}$)
0.0137	21.076 ± 0.00048
0.0089	27.019 ± 0.00042
0.0054	37.324 ± 0.00038
0.0038	38.936 ± 0.00022

Table 2: Heat transfer coefficients for the different beakers, 2000 ml, 1000 ml, 500 ml and 250 ml.

9.5 Thermal conductivity of glass disc

The thermal conductivity of the brass disc is $0.955 \pm 0.002\ Wm^{-1}K^{-1}$.

10 Appendix

The relation for the Newton's law of cooling can be understood as follows. The rate of heat radiated from a certain object is directly proportional to the difference in the temperature between the object and the surrounding and to the surface area of the object. Thus,

$$\frac{\mathrm{d}Q}{\mathrm{d}t} \propto A(T - T_s) \implies \frac{\mathrm{d}Q}{\mathrm{d}t} = hA(T - T_s)$$

But it also known that the rate of heat transfer is related to the rate of temperature change as,

$$\frac{\mathrm{d}Q}{\mathrm{d}t} = -mc\frac{\mathrm{d}T}{\mathrm{d}t}$$

Where m is the mass of the object and c is the specific heat capacity and the negative sign since the object is cooling. Thus equating the two we get a differential equation as,

$$\frac{\mathrm{d}T}{T - T_s} = -\frac{hA}{mc}\mathrm{d}t$$

Thus solving this differential equation for the temperature going from T_0 to some T we get the above relation,

$$T = T_s + e^{-\frac{hA}{mc}t}(T_0 - T_s)$$

The data for the calibration of all the thermometers are,

Temperature	Resistance (ohms)	Voltage (mV)	Length change (cm)	Resistance (kilo ohms)
4	107.8		11.5	
7	108.2	0.3	11.5	
8	110.2	0.3	11.5	3.44
10	111.2	0.5	11.6	3.22
12	111.3	0.5	11.6	2.65
14	111.8	0.5	11.8	
16	112.4	0.6	12.1	
18	113.3	0.7	12.3	
20	114.2		12.5	1.82
22	115.7	0.8	12.7	1.41
24	116.4	0.9	13.0	1.31
26				1.21
28	117.2	1.0	13.5	1.11
30	118.6	1.1	13.8	1.03
32	119.0	1.2	14.0	0.91
34	119.5	1.3	14.3	0.85
36	120.1	1.4	14.5	0.78
38	121.0	1.5	14.7	0.72
40	122.1	1.6	15.0	0.67
42	123.5	1.7	15.2	0.63
44	124.1	1.7	15.5	0.59
46	124.8	1.8	15.7	0.57
48	125.5	1.9	16.0	0.51
50	126.2	2.0	16.3	0.47
52	127.0	2.0	16.5	0.45
54	127.6	2.1	16.7	0.43
56	128.5	2.2	17.0	0.4
58	129.1	2.2	17.2	0.37
60	129.9	2.3	17.4	0.34
62	130.5	2.4	17.7	
64	131.1	2.5	17.9	0.3
66	131.7	2.6	18.1	0.28
68	132.4	2.7	18.4	0.27
70	133.2	2.8	18.6	0.25
72	133.8	2.8	18.8	0.23
74	134.6	2.9	19.1	0.22
76	135.1	3.0	19.4	0.2
78	136.0	3.1	19.5	0.19
80	136.6	3.1	19.9	0.18

82	137.0	3.2	20.1	0.17
84	137.7	3.3	20.3	0.16
86	138.5	3.4	20.6	0.15
88	139.3	3.5	21.0	0.14
90	139.7	3.6	21.4	0.13
92	140.6	3.7	21.5	0.12
94	141.1	3.8	21.8	0.12
96	142.3	3.9	22.2	0.11
98	143.9	3.9	22.6	0.1
100	144.3	4.0	22.9	0.1

Table 3: Calibration Data for the Pt100, thermocouple, alcohol thermometer and the thermistor respectively.

The data for the heating curve of the unknown solid is,

Time(s)	Resistance (ohms)
0	110.8
20	111.0
40	111.3
60	111.6
80	111.9
100	112.2
120	112.6
140	113.0
160	113.3
180	113.7
200	114.2
220	114.8
240	115.3
260	116.0
280	117.1
300	118.4
320	120.7
340	121.5
360	122.7
380	124.0
400	124.9
420	127.1
440	128.0
460	128.1
480	130.3
500	131.8
520	133.7
540	134.7
560	135.3
580	135.8

600	136.0
620	136.2
640	136.4
660	136.5
680	136.5
700	136.6
720	136.6
740	136.7
760	136.7
780	136.7

Table 4: Resistance measured by Pt100 at regular time intervals for the heating curve of the unknown solid

The data for the cooling curve is,

Time(s)	Resistance (ohms)
0	136.3
30	133.2
60	131.7
90	130.7
120	129.8
150	128.4
180	127.3
210	126.7
240	126.1
270	125.5
300	124.9
330	124.5
360	123.6
390	123.3
420	123.0
450	122.7
480	122.4
510	122.3
540	122.1
570	122.0
600	121.8
630	121.8
660	121.7
690	121.6
720	121.5
750	121.5
780	121.4
810	121.3
840	121.3
870	121.2

900	121.1
930	121.1
960	121.1
990	121.0
1020	121.0

Table 5: Resistance measured by Pt100 for the cooling curve of the unknown solid

The maximum time taken was by the 250 ml beaker which was 43.75 minutes. The times taken by the 500 ml, 1000 ml and 2000 ml beakers were 36.75, 34.5 and 29.5 minutes respectively. The resistance values as measured by the Pt100 thermometer at regular intervals of 15 seconds each were,

Resistance of Pt100 for each beaker (ohms)			
250 ml	500 ml	1000 ml	2000 ml
140.0	140.4	140.0	141.0
139.6	139.8	139.0	138.9
139.3	139.4	138.1	137.5
139.0	138.9	137.7	136.5
138.8	138.4	137.0	135.6
138.6	137.9	136.6	134.7
138.4	137.4	136.0	133.9
138.1	137.0	135.6	133.2
137.9	136.7	135.2	132.7
137.6	136.4	134.6	132.2
137.4	136.0	134.1	131.8
137.2	135.7	133.7	131.3
137.0	135.5	133.4	130.9
136.8	135.1	133.1	130.6
136.5	134.7	132.7	130.2
136.3	134.4	132.3	129.9
136.2	134.2	132.1	129.6
136.0	133.9	131.8	129.2
135.8	133.6	131.6	129.0
135.6	133.4	131.4	128.7
135.4	133.1	131.1	128.5
135.2	133.0	130.9	128.3
135.0	132.7	130.5	128.1
134.8	132.5	130.2	127.9
134.7	132.3	130.0	127.6
134.5	132.0	129.8	127.4
134.4	131.9	129.6	127.3
134.2	131.7	129.4	127.2
134.1	131.5	129.2	127.0
134.0	131.4	129.1	126.9
133.8	131.2	128.9	126.6

133.6	131.0	128.7	126.5
133.5	130.8	128.6	126.4
133.4	130.6	128.4	126.3
133.2	130.5	128.3	126.1
133.1	130.4	128.1	125.9
132.9	130.2	127.9	125.8
132.7	130.1	127.8	125.7
132.6	130.0	127.7	125.6
132.5	129.8	127.5	125.5
132.4	129.7	127.4	125.3
132.3	129.5	127.2	125.2
132.2	129.4	127.1	125.1
132.1	129.3	126.9	125.0
131.9	129.2	126.9	125.0
131.8	129.1	126.8	124.9
131.7	129.1	126.7	124.8
131.6	128.9	126.5	124.7
131.6	128.8	126.4	124.6
131.4	128.7	126.3	124.5
131.3	128.7	126.2	124.4
131.2	128.7	126.1	124.3
131.1	128.6	126.0	124.3
131.0	128.5	125.9	124.2
130.9	128.4	125.8	124.1
130.8	128.3	125.7	124.1
130.8	128.2	125.6	124.0
130.7	128.1	125.6	123.9
130.6	128.0	125.5	123.8
130.5	127.9	125.4	123.8
130.3	127.8	125.4	123.7
130.2	127.7	125.3	123.7
130.1	127.7	125.2	123.7
130.0	127.6	125.1	123.6
129.9	127.5	125.1	123.5
129.9	127.4	125.0	123.5
129.8	127.3	124.9	123.5
129.8	127.2	124.8	123.4
129.7	127.2	124.8	123.3
129.6	127.1	124.8	123.3
129.5	127.0	124.7	123.2
129.4	126.9	124.6	123.2
129.3	126.9	124.5	123.1
129.3	126.8	124.5	123.0
129.2	126.8	124.5	123.0
129.2	126.7	124.4	122.9

129.1	126.6	124.4	122.9
129.0	126.6	124.3	122.9
129.0	126.5	124.2	122.8
128.9	126.4	124.2	122.8
128.9	126.4	124.1	122.8
128.8	126.3	124.1	122.8
128.7	126.2	124.1	122.7
128.7	126.2	124.1	122.7
128.6	126.1	124.0	122.7
128.5	126.0	124.0	122.6
128.5	126.0	123.9	122.6
128.4	126.0	123.9	122.5
128.3	125.9	123.9	122.5
128.3	125.8	123.8	122.4
128.2	125.8	123.8	122.4
128.2	125.7	123.8	122.4
128.2	125.7	123.7	122.3
128.1	125.6	123.7	122.3
128.0	125.6	123.7	122.3
128.0	125.5	123.6	122.3
128.0	125.5	123.6	122.2
127.9	125.4	123.5	122.2
127.9	125.4	123.5	122.2
127.8	125.4	123.5	122.2
127.8	125.3	123.5	122.2
127.7	125.3	123.5	122.2
127.7	125.2	123.4	122.2
127.6	125.2	123.4	122.2
127.6	125.1	123.3	122.2
127.5	125.1	123.3	122.1
127.4	125.0	123.3	122.1
127.4	125.0	123.2	122.1
127.4	125.0	123.2	122.1
127.3	124.9	123.2	122.1
127.3	124.9	123.2	122.0
127.2	124.9	123.1	122.0
127.2	124.9	123.1	122.0
127.2	124.8	123.1	122.0
127.1	124.8	123.1	122.0
127.1	124.8	123.0	122.0
127.0	124.7	123.0	122.0
127.0	124.7	123.0	122.0
126.9	124.6	123.0	122.0
126.9	124.6	123.0	
126.9	124.6	122.9	

126.8	124.6	122.9	
126.8	124.6	122.9	
126.7	124.5	122.9	
126.7	124.5	122.8	
126.7	124.4	122.8	
126.6	124.4	122.8	
126.6	124.4	122.8	
126.6	124.4	122.8	
126.5	124.4	122.8	
126.5	124.3	122.8	
126.5	124.3	122.8	
126.5	124.3	122.8	
126.4	124.3	122.8	
126.4	124.3	122.7	
126.4	124.2	122.7	
126.4	124.2	122.7	
126.3	124.2	122.7	
126.3	124.1	122.7	
126.3	124.1		
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