

Pyokyeong Son  
IB Physics HL  
Mr. Peter Marsh  
January 23rd, 2018

## **Lab Report: Determination of Specific Heat Capacity**

### I. Apparatus

- DC Power supply
- Electrical wires
- Ammeter
- Voltmeter
- Electrical heater
- Aluminium calorimeter sample
- Digital thermometer
- Glycerol
- Bubble wrap
- Wooden panel (to prevent the table from heat damage)
- Digital scale
- Crumbled pieces of paper

### II. Method

1. Wire the electrical circuit according to figure 3.1., without switching on the power supply.
2. In the two corresponding holes in the aluminum calorimeter sample, insert the electrical heater and the digital thermometer, using glycerol to maintain sufficient thermal contact between them and the aluminum sample.
3. Wrap the aluminum calorimeter sample in bubble wrap and fill the top with crumbled pieces of paper to ensure maximum insulation from the surrounding environments, and place it on the wooden panel
4. Switch on the power supply, and adjust the voltage and current dials so that the ammeter in the circuit show 4A, and note the voltage at this current.
5. Start the stopwatch, and immediately record the temperature displayed on the thermometer
6. Wait 60 seconds, and record the temperature displayed on the thermometer, making sure that the current and voltage displayed is constant
7. Repeat step 6 until the reading in the thermometer reaches 80 °C
8. Clean out the calorimeter throughly, and measure the mass of the sample

## III. Diagrams

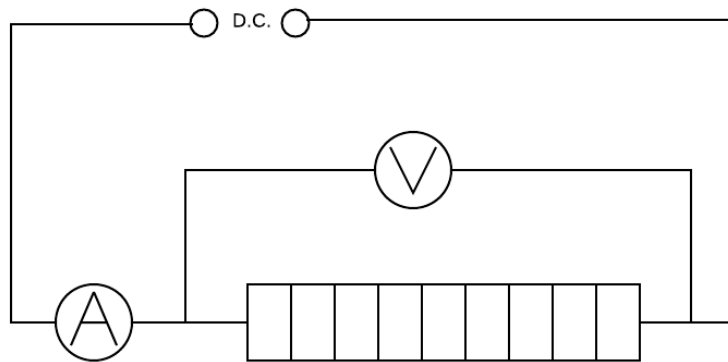


Fig. 3.1. Circuit diagram of electric circuit in the experiment

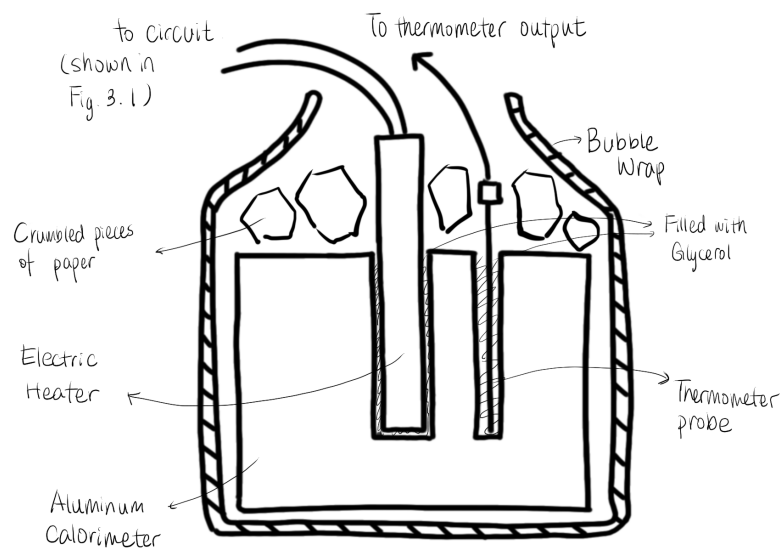


Fig. 3.2. Diagram of the aluminum sample, electrical heater, and digital thermometer

## IV. Expectations

When thermal energy is supplied to an object made of single material without a change of state, it can be modeled by the following equation:

$$\Delta Q = m \cdot c \cdot \Delta\theta$$

Where:

$\Delta Q$  = thermal energy supplied(J)

$m$  = mass of object (g)

$c$  = specific heat capacity of material ( $J \cdot g^{-1} \cdot K^{-1}$ )

$\Delta\theta$  = temperature change (K)

Note that the unit of mass is grams, not kilograms, to simplify calculations and numbers, while not causing a problem within the equation, as there is no single unit for specific heat capacity.

We can also measure the amount of energy supplied by the heater by using the following equation:

$$E = VIt$$

Where:

$E$  = electric energy converted ( $J$ )

$V$  = potential difference ( $V$ )

$I$  = current ( $A$ )

$t$  = time ( $s$ )

When we use an electrical heater to heat such an object, we can combine these two equations to model the relationship between the potential difference, current, time of heating by the electric heater, and the mass, specific heat capacity, and temperature change of the object:

$$\Delta Q = E$$

$$m \cdot c \cdot \Delta\theta = V \cdot I \cdot \Delta t$$

In this experiment, we will be keeping the potential difference and the current constant as the controlled variable, while measuring the temperature between a 60 second time interval.

Therefore, we can rearrange this equation to fit our needs:

$$\Delta\theta = \frac{V \cdot I}{c \cdot m} \cdot \Delta t \quad \dots\dots\dots \text{Equation 1}$$

Therefore, when we draw a graph of temperature against heating time, the gradient of the best-fit line will indicate:

$$\frac{\Delta\theta}{\Delta t} = (\text{Gradient}) = \frac{V \cdot I}{c \cdot m} \quad \dots\dots\dots \text{Equation 2}$$

Note that, although a graph of temperature ( $T$ , in degrees Celsius) against the total heating time ( $t$ , in seconds) is measured and will be graphed, the gradient will be calculated as the change of temperature ( $\Delta\theta$ ) over change in time ( $\Delta t$ ). Therefore, the best-fit line in the graph will not represent Equation 1 (and therefore is not expected to pass the origin, nor does it have to begin at  $t = 0$ ). The gradient, which indicates change in values, is the significant quantity and can be measured from the graph. If the gradient is correctly calculated, the above relationship will hold true, and it will be possible to calculate the specific heat capacity.

As we kept the voltage and current constant, while the mass of the object does not change, we can figure out the specific heat capacity of the material using the following equation:

$$c = \frac{V \cdot I}{m \cdot (\text{Gradient})}$$

According to the NIST Chemistry Webbook, the specific heat capacity of aluminum at 300K is about  $24.25 J \cdot mol^{-1} \cdot K^{-1}$  while its average molecular mass is around 26.9815g, and it can be calculated that the specific heat capacity in our desired units is  $0.8988 J \cdot g^{-1} \cdot K^{-1}$

It is important to note that there will inevitably be some heat lost to the surroundings as well as heat used to heat up the thermometer and the heater itself, we will be measuring more heat supplied than what is actually used to increase the temperature of the sample. This means that our

specific heat capacity of the material will measure out to be higher than it truly is. This error is evaluated more rigorously in section VIII.

## V. Results

Table 5.1. Temperature of Calorimeter heated for different lengths of time

Time heated $t / s$	Temperature of sample $T / ^\circ C$	Control Variables	
		Potential difference on heater $V / V$	Current of circuit $I / A$
$\pm 1$	$\pm 1.0$	(See below)	(See below)
0	23.1	12.77	4.00
60	24.3	12.24	3.99
120	26.8	12.28	3.99
180	29.7	12.28	3.99
240	32.7	12.28	3.99
300	35.3	12.28	3.98
360	38.0	12.32	3.98
420	40.9	12.32	3.98
480	43.8	12.33	3.98
540	46.8	12.33	3.99
600	48.9	12.33	3.99
660	51.6	12.37	3.99
720	54.4	12.43	4.00
780	57.0	12.43	4.00
840	59.5	12.43	4.00
900	62.1	12.45	4.00
960	64.6	12.45	4.00
1020	67.1	12.45	4.00
1080	70.1	12.40	4.00
1140	72.1	12.40	4.00
1200	74.6	12.40	4.00
1260	76.9	12.40	4.00
1320	79.4	12.40	4.00

\* Temperature values that are highlighted in red are not considered, as there were significant fluctuations in voltage and current, and therefore, the energy transferred to the sample was inconsistent

The thermometer used in the experiment updated its readings approximately every 2 seconds, and therefore the absolute uncertainty of time is  $\pm 1\text{s}$ , while the difference in the temperature readings every 2 seconds were at most  $2.0\text{K}$ , leading to the absolute uncertainty of  $\pm 1.0\text{ }^\circ\text{C}$  (further explained in section VIII).

Excluding the values highlighted in red, the potential difference on the heater fluctuates from  $12.28\text{V}$  to  $12.45\text{V}$  during the experiment. As the potential value is a controlled variable, the average value of the two extreme values are taken, and the uncertainties are decided so that the range includes all of the values that were measured. The value for the current is calculated in the same manner. The mass of the sample was taken twice, which yielded the same value, and the uncertainty is taken from the uncertainty indicated on the digital scale. This yields the following values of the controlled variables:

Table 5.2. Values of Controlled Variables

Mass of sample $m / \text{g}$	Potential difference on heater $V / \text{V}$	Current of circuit $I / \text{A}$
$\pm 0.01$	$\pm 0.1$	$\pm 0.02$
1005.93	12.3	4.00

## VI. Graph

Graph 6.1. Temperature of sample against time heated (Attached)

As expected, we see a linear increase in the temperature, as the heater supplies constant energy per time period. We can draw worst-fit lines to figure out the gradient of the line representing the relationship, in the process of calculating our specific heat capacity.

Although uncertainty boxes were small (a mere  $4\text{ K} \cdot \text{s}$ ) it was possible to draw a straight line through them, possibly indicating that our data may be fairly reliable.

Using the graph, we can calculate the gradient of the worst-fit lines:

$$\text{(Biggest Gradient)} = \frac{35}{774} \text{ K} \cdot \text{s}^{-1}$$

$$\text{(Smallest Gradient)} = \frac{41}{966} \text{ K} \cdot \text{s}^{-1}$$

And the gradient was calculated to be within the range of:

$$0.0424 \text{ K} \cdot \text{s}^{-1} \leq \text{(Gradient)} \leq 0.0452 \text{ K} \cdot \text{s}^{-1}$$

Therefore, with the range of uncertainties, it can be determined to be:

$$\text{(Gradient)} = 0.0438 \pm 0.0014 \text{ K} \cdot \text{s}^{-1}$$

## VII. Conclusion

Using the gradient and the measurement of the controlled variables, we can calculate the specific heat capacity of aluminum using the following equation from section IV:

$$(\text{Gradient}) = \frac{V \cdot I}{c \cdot m} \quad \dots\dots\dots \text{Equation 2}$$

As we now know the gradient, we can rearrange Equation 2 for specific heat capacity  $c$ :

$$c = \frac{V \cdot I}{m \cdot (\text{Gradient})}$$

Using this equation, we can calculate the specific heat capacity of aluminum:

$$\begin{aligned} c &= \frac{12.3 \pm 0.1 \cdot 4.00 \pm 0.02}{1005.93 \pm 0.01 \cdot 0.0438 \pm 0.0014} \\ &= \frac{49.2 \pm 0.6}{44.1 \pm 1.4} \\ &= 1.12 \pm 0.05 \text{ J} \cdot \text{g}^{-1} \cdot \text{K}^{-1} \end{aligned}$$

This value of the specific heat capacity of aluminum deviates greatly from the literature value researched from section IV, which is  $0.8988 \text{ J} \cdot \text{g}^{-1} \cdot \text{K}^{-1}$ , even if the uncertainties are taken into account; the lowest possible value from the calculation compared with the literature value:

$$(1.12 - 0.05) - 0.90 = 0.17 \text{ J} \cdot \text{g}^{-1} \cdot \text{K}^{-1}$$

And we can see that the literature value is smaller than the lowest value in the uncertainty range. Thus, it can be concluded that the empirical results do not agree with the theory. As it is very unlikely that the theory is wrong, it can be assumed that there were many errors in the experiment, which are evaluated in the following section.

## VIII. Evaluation

The assumption of the theory behind the equations from section IV is that there is no heat loss from the sample to its surroundings. Although the sample was insulated with multiple layers of plastic bubble wrap and crumbled pieces of paper, there is, inevitably, a loss of heat from the sample to the surroundings if the sample has a higher temperature. This was evident when, at the end of the experiment, the bubble wrap surrounding the sample was warm to the touch and clearly warmer than its surroundings; heat energy generated from the heater was conducting out to the surface of the bubble wrap and into the surrounding air.

Also, the heating of the heater or the thermometer was not taken into consideration. The heater especially had a fairly large mass, and the energy that was used to raise its temperature before the sample was heated, would have accounted for a fairly large error.

If this is the case, we can take another look at our equations to see how the error has deviated our results from the literature value:

$$\begin{aligned} \Delta Q &= m \cdot c \cdot \Delta\theta \\ E &= VIt \end{aligned}$$

The electrical energy supplied,  $E$ , is the amount of energy the heater converts from electric to thermal (not taking into consideration the relatively negligible resistance of the wires, ammeter, or voltmeter). But, not all of this energy is used to heat the sample; some of it is conducted away to

the surroundings, and some of it is used to heat up the heater or the thermometer. Therefore, our assumption from section IV, that  $\Delta Q = E$ , is not true, and the following is more reflective of the real value:

$$\Delta Q < E$$

$$m \cdot c \cdot \Delta\theta < V \cdot I \cdot \Delta t$$

Rearranging this equation:

$$c < \frac{V \cdot I}{m \cdot (\text{Gradient})} \quad \dots\dots \text{Equation 3}$$

We have calculated the specific thermal heat using the right-hand side of Equation 3, but due to the error, we can see that the calculated value is inevitably bigger than the real value of  $c$ .

There are various ways to reduce this error. A realistic suggestion is to put the sample into an insulating water-bottle style container, that has two layers of reflective walls between which is vacuum. Bubble wrap is a good insulator because the air trapped in the bubbles are a good insulator. But in vacuum there are no molecules for heat to transfer to, and it will conduct almost no heat, except for the connection between the two walls. Also, the reflectiveness of the walls will reduce the radiation from the inside and out, while the vacuum also prevents convection. This will greatly reduce the amount of heat loss to the surroundings, which can reduce the unaccountable errors in the experiment and bring the measured value closer to what is expected, especially compared to using the bubble wrap. One thing to note, however, is that if the inner container of the double-walled container has a large heat capacity, this can increase, rather than decrease, our error, and the measured specific heat capacity.

Also, a heater with a smaller thermal capacity can be used, possibly one that is made from a different material with a lower thermal capacity, or which has a smaller mass. The thermometer probe's heat capacity, on the other hand, is negligible compared to the other flaws, and may not require any change, although it is still clearly a source of an uncertain uncertainty.

Apart from the flaws in the design of the experiment, there were uncertainties in the measurements of the various quantities, although they are comparatively less relevant. The biggest uncertainty in the experiment was the temperature reading from the thermometer, with relative uncertainties ranging from 1.2% to 3.7%, a rather impressively low value. This uncertainty is due to the stochastic read-outs from the thermometer—the one used in the experiment updated its readings approximately every 2 seconds, and the difference between those readings was at most 2.0K, which led to the absolute uncertainty of  $\pm 1.0^\circ\text{C}$ . This can be easily resolved by using a thermometer that would give reading at more frequent intervals. A thermometer that would read every 0.5 seconds would reduce the absolute uncertainty of time to  $\pm 0.5\text{s}$  as the stopwatch, which only displayed intervals of 1s, would become the biggest source of uncertainty, and would reduce the uncertainty of temperature as the smaller intervals would reduce the temperature difference between such

readings, to whatever quantitative value the maximum temperature difference between those two readings are. However, it is important to note that the error of imperfect insulation would need to be resolved before the improvement in uncertainties are realized, and even after it has been, the uncertainties would be low enough to yield reasonable results, in the setting of a high-school physics lab.