

Specific Heat Capacity Lab

Vincent Edwards, Ali Mortada

Mt. San Antonio College, Physics 4B, CRN 42240
March 3, 2023

1. Purpose

The goal of the experiment was to determine the specific heat capacities of various substances based on measurements of mass, temperature, power, and/or time. For parts 1 and 2 the material was known, so the calculated specific heat capacities could be compared to the accepted values. For part 3 the material was unknown, so its identity was guessed based on the calculated specific heat capacity.

2. Results

In part 1 of the experiment, a sample of DI water stored in a foam calorimeter was heated using an immersion heater for about 2 minutes, causing the temperature of the water to increase. Table 1 contains the measured values. m_c is the mass of the dry calorimeter. m_{c+w} is the combined mass of the water and calorimeter. T_i is the initial temperature of the water. T_f is the final temperature of the water. H is the heat current delivered by the immersion heater, measured using a Watt meter. t is the time the immersion heater was on, measured using a stopwatch.

Table 1. Part 1 Measurements

Quantity	Value
m_c	33.02 ± 0.01 g
m_{c+w}	439.19 ± 0.01 g
T_i	20.2 ± 0.4 °C
T_f	38.5 ± 0.4 °C
H	293 ± 1 W
t	120.2 ± 0.2 s

Table 2 contains a material key. A number was given to each material for which the specific heat capacity was calculated. In addition, the table notes the lab part where the substance was examined. These numbers are used to index tables 3 and 4.

Table 2. Material Key

Key	Lab Part	Material
1	1	Water
2	2	Aluminum (1 piece)
3	2	Lead
4	2	Aluminum (2 pieces)
5	3	Unknown green rock (letter D)

In parts 2 and 3 of the experiment, samples of various materials were submerged in boiling water for about 2 minutes to heat them up to a high temperature (the boiling point of water). One at a time, these samples were transferred to a foam calorimeter

containing room temperature DI water. This caused the sample temperature to decrease and the water temperature to increase until they reached thermal equilibrium. Table 3 contains the measured values. m_c is the mass of the dry calorimeter. m_{c+w} is the combined mass of the water and calorimeter. m_m is the mass of the sample material. T_{iw} is the initial temperature of the water. T_{im} is the initial temperature of the sample material. T_f is the final temperature of the water and sample material.

Table 3. Part 2 and Part 3 Measurements

Key	m_c (g)	m_{c+w} (g)	m_m (g)	T_{iw} (°C)	T_{im} (°C)	T_f (°C)
2	31.85 ± 0.01	531.6 ± 0.1	88.26 ± 0.01	21.5 ± 0.4	99.1 ± 0.4	24.4 ± 0.4
3	31.85 ± 0.01	531.3 ± 0.1	370.26 ± 0.01	24.2 ± 0.4	99.1 ± 0.4	26.0 ± 0.4
4	31.85 ± 0.01	530.3 ± 0.1	175.42 ± 0.01	25.9 ± 0.4	99.1 ± 0.4	30.9 ± 0.4
5	31.85 ± 0.01	529.9 ± 0.1	161.14 ± 0.01	30.0 ± 0.4	99.1 ± 0.4	33.3 ± 0.4

Table 4 contains the calculated specific heat capacity (c) for each material examined in the experiment. In addition, it contains the accepted, true specific heat capacity for those materials (c_{true}) and how far off the experimental values were from the true values ($c - c_{\text{true}}$).

Table 4. Specific Heat Capacity Values

Key	c (J/(kg K))	c_{true} (J/(kg K))	$c - c_{\text{true}}$ (J/(kg K))
1	4700 ± 100	4186	600 ± 100
2	900 ± 200	910	10 ± 200
3	140 ± 40	130	9 ± 40
4	900 ± 100	910	-38 ± 100
5	600 ± 100	750	-200 ± 100

3. Uncertainty

All the mass measurements in the experiment were made using a digital balance. The uncertainty was taken to be the smallest increment of measure, since that is the precision of the equipment. A full increment of measure was used rather than a half increment because the school balance is likely worn out after lots of use.

All three parts of the experiment involved a calculation of the mass of a sample of DI water (m_w). In the experiment, m_{c+w} (the combined mass of the water and the foam calorimeter it was in) and m_c (the mass of the dry calorimeter) were measured. Thus, m_w could be calculated using equation 1.

$$m_w = m_{c+w} - m_c \quad (1)$$

The uncertainty of m_w is given by equation 2.

$$\begin{aligned}\Delta m_w &= \sqrt{\left(\frac{\partial m_w}{\partial m_c} \Delta m_c\right)^2 + \left(\frac{\partial m_w}{\partial m_{c+w}} \Delta m_{c+w}\right)^2} \\ &= \sqrt{(\Delta m_c)^2 + (\Delta m_{c+w})^2}\end{aligned}\quad (2)$$

All the temperature measurements were made using a temperature probe. In order to get an idea of the uncertainty present in readings with the temperature probe, a special set of “uncertainty trials” were performed. A beaker of DI water was boiled on a hot plate. To measure the temperature, the probe was placed in the boiling water, the reading was allowed to stabilize, that stable temperature was recorded, and the temperature probe was removed from the water. This process was repeated 25 times, and the measured values are shown in table 5. Since the water was at its boiling point, its temperature would remain constant. Thus, any variation in the measured temperature of the water could be attributed to the uncertainty of the temperature probe. Care was taken to make sure that the probe did not make contact with the glass beaker, as that could have been at a slightly different temperature than the water. The uncertainty in the temperature measurements was taken to be the max absolute deviation from the mean, as that gives an upper bound for how much the temperature readings tend to fluctuate. That value came out to be about 0.4 °C.

In part 1, measurements of H and t were made. The reading for H given by the Watt meter fluctuated. Thus, the uncertainty in the measurement was taken to be size of the fluctuations, as that gives an upper bound for how much the value could have varied. The uncertainty in t was taken to be human reaction time (0.2 s). The stopwatch uncertainty was negligible compared to the much larger uncertainty in starting/stopping the stopwatch.

The experimental specific heat capacity for part 1 was calculated using equation 3.

$$c = \frac{Ht}{m_w(T_f - T_i)} \quad (3)$$

The uncertainty of c for part 1 is given by equation 4.

$$\begin{aligned}\Delta c &= \left[\left(\frac{\partial c}{\partial H} \Delta H \right)^2 + \left(\frac{\partial c}{\partial t} \Delta t \right)^2 + \left(\frac{\partial c}{\partial m_w} \Delta m_w \right)^2 + \left(\frac{\partial c}{\partial T_i} \Delta T_i \right)^2 + \left(\frac{\partial c}{\partial T_f} \Delta T_f \right)^2 \right]^{\frac{1}{2}} \\ &= \frac{Ht}{m_w(T_f - T_i)} \left[\left(\frac{\Delta H}{H} \right)^2 + \left(\frac{\Delta t}{t} \right)^2 + \left(\frac{\Delta m_w}{m_w} \right)^2 + \left(\frac{\Delta T_i}{T_f - T_i} \right)^2 + \left(\frac{\Delta T_f}{T_f - T_i} \right)^2 \right]^{\frac{1}{2}}\end{aligned}\quad (4)$$

The experimental specific heat capacities for parts 2 and 3 were calculated using equation 5.

$$c = \frac{m_w c_w (T_f - T_{iw})}{m_m (T_{im} - T_f)} \quad (5)$$

Table 5. Uncertainty Trials

Run	T (°C)
1	99.0
2	99.1
3	98.8
4	98.7
5	98.6
6	99.0
7	99.1
8	99.1
9	99.0
10	98.9
11	98.8
12	98.8
13	99.1
14	99.2
15	99.1
16	99.2
17	99.1
18	99.1
19	99.2
20	99.1
21	99.0
22	99.1
23	99.3
24	99.0
25	98.8

The uncertainty of c for parts 2 and 3 is given by equation 6.

$$\begin{aligned}
\Delta c = & \left[\left(\frac{\partial c}{\partial m_w} \Delta m_w \right)^2 + \left(\frac{\partial c}{\partial m_m} \Delta m_m \right)^2 \right. \\
& \left. + \left(\frac{\partial c}{\partial T_{iw}} \Delta T_{iw} \right)^2 + \left(\frac{\partial c}{\partial T_{im}} \Delta T_{im} \right)^2 + \left(\frac{\partial c}{\partial T_f} \Delta T_f \right)^2 \right]^{\frac{1}{2}} \\
= & \frac{m_w c_w (T_f - T_{iw})}{m_m (T_{im} - T_f)} \left[\left(\frac{\Delta m_w}{m_w} \right)^2 + \left(\frac{\Delta m_m}{m_m} \right)^2 \right. \\
& \left. + \left(\frac{\Delta T_{iw}}{T_f - T_{iw}} \right)^2 + \left(\frac{\Delta T_{im}}{T_{im} - T_f} \right)^2 + \left(\left(\frac{1}{T_f - T_{iw}} + \frac{1}{T_{im} - T_f} \right) \Delta T_f \right)^2 \right]^{\frac{1}{2}}
\end{aligned} \tag{6}$$

4. Conclusion

I conclude...that we are bad at lab. Science is a lie

5. Citations

- [1] Karen Schnurbusch, *Physics 4B Lab Book*, Mt. San Antonio College, 2023, pp. 11-16.