Physics Internal Assessment

Determining the specific heat capacity of cheese

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Contents

1 Introduction

This paper aims to find the specific heat capacity of cheese by heating a piece of cheese, and placing it inside of a brass cup filled with water and measuring the water's temperature increase.

Measuring the specific heat capacity of cheese should be no different to doing so for a solid, but in researching the topic, "melting" cheese became a debating point – whether it was just an amorphous substance changing viscosity or an actual change of phase. Furthermore, attempting to handle melted cheese posed an interesting challenge until settling on a procedure that was fairly different from how this type of experiment is done in classrooms. The procedure here could indeed be utilised for many amorphous substances .

2 Background Knowledge

Conservation of energy is central to our experiment. By assuming that the system is perfectly isolated, we say that no energy is being gained or lost by the system, which can be expressed by the following equation:

$$\sum \Delta H = 0 \tag{1}$$

where ΔH refers to heat, the amount of energy that is transferred from a hotter to a colder body due to their difference in temperature. This means that we can affirm that all energy lost by the warm cheese has to be gained by the water and the brass cup; that is:

$$\Delta H[cheese] = -(\Delta H[brass] + \Delta H[water]) \tag{2}$$

Furthermore, we may express a relationship between heat and the following characteristics of a material: mass (m), specific heat capacity (c) and the change in the temperature it undergoes (ΔT), as follows:

$$\Delta H = mc\Delta T \tag{3}$$

When dealing with a change in phase (such as from solid to liquid), it is also important to discuss the amount of energy required in order to undergo that change, however cheese seems to be amorphous and changing viscosity rather than changing phase (Miroshnychenko, Y., Personal communication, January, 2018). Therefore, we are able to completely disregard latent heat from our calculations, though a short consideration of its effect will be done in the evaluation.

Finally, Newton's law of cooling will be important when considering the sources of error and improvements to this experiment. In short, it states that the rate of heat loss is proportional to the difference in temperature between the bodies. It is easily understood by the following equation, though the mathematics of it will not be needed for our purposes

(Lienhard IV and Lienhard V, 2001, pp.12-18):

$$\frac{\partial T}{\partial t} \propto \frac{\partial^2 T}{\partial x^2} \tag{4}$$

where T is a function of temperature that depends on space (x) and time (t) and k is just a constant of proportionality.

3 Procedure

The equipment necessary is as follows:

- A water bath, or a pot filled with water to approximately 60 °C.
- pieces of cheese of approximately the same mass
- beakers
- 2 thermometers. One utilised on the cheese for stirring and verifying the uniformity of the temperature, and the other for the water cup.
- a thermally insulated brass cup with lid, filled with a known mass of water. This consisted of a brass cup placed inside of a thick styrofoam cup which in turn was inside another brass cup. The brass cup is chosen due to having a known specific heat capacity, but because brass is a good heat conductor, we surround it with styrofoam – a poor heat conductor – in order to "isolate" the system. The outermost cup is simply for transport.

The experimental procedure is the following:

1. Measure the mass of the inner brass cup alone (without the Styrofoam cup): 187.7 g ± 0.1 g
2. 47.3 g ± 0.1 g of water is placed inside the brass cup, and its temperature is recorded.
3. 38.49 g ± 0.20 g of cheese is placed inside a beaker, which is in turn placed in the water bath until reaching approximately 60 °C.
4. The cheese is then placed in the brass cup with water and the maximum temperature of the water is recorded.

Note that there is no particular reason for the control variables of 38.5 g of cheese or 47.3 g of water, they are simply the first measurements taken, which were replicated throughout the experiment. From previous attempts, it seems that the masses just have to be in the same order of magnitude.

3.1 Variables

- Independent: Initial temperature of cheese
- Control: mass of water and cheese, described in detail in Table 1

c(brass) $\mathrm{J\,g^{-1}\,K^{-1}}$	**m(brass)** $\mathrm{g} \pm 0.01\,\mathrm{g}$	**c(water)** $\mathrm{J\,g^{-1}\,K^{-1}}$	**m(water)** $\mathrm{g} \pm 0.1\,\mathrm{g}$	**m(cheese)** g $\pm 0.2\,\mathrm{g}$
0.380	187.74	4.186	47.3	38.5

Table 1: Control variables for the experiment. c denotes specific heat capacity and m denotes mass. Note that where not specified, value is taken from course book (Homer and Bowen-Jones, 2014) and uncertainty taken to be zero.

While the the mass of water and brass cup have instrumental uncertainty, the cheese was cut by hand to approximately 38.5 g, and so the value reflects taking the mean mass from all the pieces of cheese and the respective uncertainty.

4 Raw Data

The following table is the data collection through the experiment, such that T_0 is the initial temperature and T_f is final temperature

Index	T_0(Cheese) $\pm 0.1°C$	T_0(Water) $\pm 0.1°C$	T_f(Water) $\pm 0.1°C$
1	55.6	20.1	30.3
2	59.8	20.9	29.9
3	63.5	20.5	30.9
4	66.8	24.5	34.3
5	63.3	23.6	33.6
6	62.8	23.6	33.7
7	59.1	23.3	31.8

Table 2: Experiment's raw data

5 Analysis

Based on equation (2), we can find the heat lost by the cheese by calculating the heat gained by the brass cup and the water. We do so by utilising equation (3), demonstrated below with the median of our data set:

$$
\begin{aligned}
\Delta H &= mc\Delta T \\
\therefore \Delta H(brass) &= m(brass)c(brass)(T[brass]_f - T[brass]_0) \\
\therefore \Delta H(brass) &= 187.7\,\mathrm{g} \cdot 0.380\,\mathrm{J\,^\circ C^{-1}\,g^{-1}} \cdot (34.3 - 24.5)^\circ\mathrm{C} \\
\therefore \Delta H(brass) &= 699.1\,\mathrm{J}
\end{aligned} \tag{5}
$$

The calculation of the absolute uncertainty of the heat gained by the brass cup ($\Delta_{\Delta Hbrass}$) is done as follows:

$$
\begin{aligned}
\Delta(\Delta H[brass]) &= \Delta H(brass) \cdot \left(\frac{\Delta m}{m} + \frac{\Delta_{\Delta T}}{\Delta T} \right) \\
\therefore \Delta(\Delta H[brass]) &= 699.1 \cdot \left(\frac{0.1}{187.7} + \frac{0.1}{9.8} \right) \\
\therefore \Delta(\Delta H[brass]) &= 8\,\mathrm{J}
\end{aligned} \tag{6}
$$

The same is done for the water:

$$
\begin{aligned}
\Delta H(water) &= 47.3\,\mathrm{g} \cdot 4.186\,\mathrm{J\,^\circ C^{-1}} \cdot (34.3 - 24.5)^\circ\mathrm{C} \\
\therefore \Delta H(water) &= 1940.4\,\mathrm{J} \pm 20.0\,\mathrm{J}
\end{aligned} \tag{7}
$$

As per equation (2):

$$
\begin{aligned}
\Delta H(cheese) &= -(\Delta H[brass] + \Delta H[water]) \\
\therefore \Delta H(cheese) &= -2639.5\,\mathrm{J} \pm 28.0\,\mathrm{J}
\end{aligned} \tag{8}
$$

Now applying equation (3) to $\Delta H(cheese)$, we can isolate $c(cheese)$:

$$\begin{aligned} c(cheese) &= \frac{\Delta H(cheese)}{m(cheese) \cdot \Delta T(cheese)} \\ \therefore c(cheese) &= \frac{-2639.5\,\text{J}}{-32.5\,°\text{C} \cdot 38.49\,\text{g}} \pm \left(\frac{28.0}{2639.5} + \frac{0.1}{32.5} + \frac{0.20}{38.49}\right) \\ \therefore c(cheese) &= (2.11 \pm 0.04)\ \text{J}\,°\text{C}^{-1}\,\text{g}^{-1} \end{aligned} \tag{9}$$

We repeat the above calculations for the rest of the data and arrive at the following:

Index	$\Delta H(brass)$	$\Delta H(water)$	$\Delta H(cheese)$	$c(cheese)$
3	727.7	2,019.6	-2,747.3	**2.81**
4	642.1	1,782.0	-2,424.1	**2.11**
5	741.9	2,059.2	-2,801.1	**2.23**
6	699.1	1,940.4	-2,639.5	**2.11**
7	713.4	1,980.0	-2,693.4	**2.34**
8	720.5	1,999.8	-2,720.3	**2.44**
9	606.4	1,683.0	-2,289.4	**2.18**

Table 3: Processed data

Finally, we can calculate the mean value and the respective statistical/experimental uncertainty:

$$\frac{2.81 + 2.11 + 2.23 + 2.11 + 2.34 + 2.44 + 2.18}{7} \pm \frac{2.81 - 2.11}{2} = 2.32 \pm 0.35 \tag{10}$$

Given that the statistical uncertainty, approximately 15%, is much greater than the instrumental uncertainty, approximately 2%, we can favour the former. Hence, the specific heat capacity of the cheese used in this experiment is:

$$c(cheese) = (2.32 \pm 0.40)\ \text{J}\,°\text{C}^{-1}\,\text{g}^{-1}$$

6 Conclusion

In this experiment we were able to experimentally determine the specific heat capacity of a particular type of cheese to be $2.32\,\mathrm{J\,^{\circ}C^{-1}\,g^{-1}}$. This was done by melting a known mass of cheese, pouring it into a cup of water, and measuring the water's temperature increase. Utilising the idea of conservation of energy we expected all of the heat lost by the cheese to move to the water, but this was not necessarily the case as some is lost to the environment.

The uncertainty associated with the instruments was largely made irrelevant by the relative size of the experimental uncertainty (15% vs 2%). As such, there is a fairly low degree of certainty in the results found.

Cheese was assumed to be amorphous, and while I'm still confident in this assumption, it might be interesting to briefly discuss if the supposition is wrong. With energy being released from liquid to solid, we would expect a higher final temperature, and consequently we would find a smaller specific heat capacity.

7 Evaluation

The uncertainty in this experiment is overwhelmingly experimental, approximately 15%, which mostly reflects the difficulty in assessing the thermal equilibrium. Perhaps the biggest change that can be done is improving the insulation of the brass cup. This means that irrespective of the reduced cooling rate (as per Newton's law of cooling), as no heat is lost to the environment, we are able to wait a long time for thermal equilibrium. As it stands, we are likely to perceive a smaller change in the water's temperature, similar to the data collected before the ultimate experimental procedure – a comparison of which can be seen below.

Index	T_0(Cheese) ± 0.1°C	T_0(Water) ± 0.1°C	T_f(Water) ± 0.1°C
Outlier	59.8	27.5	31.8
1	55.6	20.1	30.3

Handling cheese as it changes viscosity also posed various difficulties, from arriving at a procedure that works, to the best way to handle the beakers, and how to make accurate measurements. The very first attempt at a procedure was similar to how the experiment is done for solids, utilising a clamp to hold the beaker containing cheese inside a kettle. Given enough time it was likely that it would work, but between the heating clamp and the agitation of the water inside the kettle, the risk of getting burnt was far too high.

The procedure that was settled on showed itself to be much safer, as the beakers were placed in a pot with warm water (as opposed to boiling). This had the added benefit of allowing the cheese inside the beakers to be stirred in order to achieve a uniform temperature. While it was a clear improvement to the previous procedure, it was still difficult to verify that the cheese had a uniform temperature, though we can be far more certain.

As the cheese was placed into the water, the outside would cool immediately, slowing down the conduction of heat to the inside, as per Newton's law of cooling. The solution was to swirl the cheese inside the water, which we expected to improve the cooling by conduction.

Perhaps the cheese could be separated into smaller portions as it is poured into the liquid. It is somewhat impractical to do consistently (that is, all smaller pieces to have the same size), but it might be better than more repetitions of a smaller mass of cheese – which would result in a larger relative uncertainty.

8 Bibliography

References

J. H. Lienhard IV and J. H. Lienhard V. *A heat transfer textbook*. J.H. Lienhard V, 2001.

D. Homer and M. Bowen-Jones. *Physics course companion*. Oxford University Press, 2014.