

Lab 15. Heat Capacity

By Jamu Alford

With help from

Sari Belzycki

Abstract

Using a Styrofoam cup as a calorimeter the specific heat of water was found to be $5.3 \pm 0.2 JK^{-1} g^{-1}$, having 25% error from the theoretical value of $4.184 JK^{-1} g^{-1}$. This demonstrated that a systematic error existed in our scientific procedure and that the lab required several modifications before a correct value of the specific heat could be obtained. By allowing lead shot to fall inside a closed pipe, we determined the specific heat of lead to be 833J/kgK. This compared very poorly with the theoretical value of 157J/kgK.

Introduction

One of the most fundamental physical properties is the relation between mechanical energy and heat. Thermodynamics principles were developed during the industrial revolution when the steam engine and later the gasoline engine became the focal point of intense research. At that time, it was found that the specific heat at constant volume (**Cv**) of a substance is defined to be its heat capacity per unit mass when all changes are made at a fixed volume. The specific heat at a constant pressure, **Cp** is defined as the heat capacity per unit mass when all changes are made from a fixed volume. For a body of mass *m* to experience a temperature change of ΔT the heat energy required (*Q*) is given by the first law:

$$Q = mC_v\Delta T + \Delta W \quad \text{Equation(1)}$$

In the equation given above, ΔW is the work done by the system on its environment. For the entirety of the lab, the work performed will be zero. In this case, Equation 1 is simplified to:

$$Q = mC_v\Delta T \quad \text{Equation(2)}$$

This equation is very important and will be used exhaustively during an experiment involving heat.

Experiment

In the first experiment we investigated the specific heat of water. The water was heated by use of an electric current passing through a resistor. Electrical heating allowed us to determine the heat entering the system to a high accuracy.

10061ml of water was placed in a Styrofoam cup weighing 2.2grams along with a 2Ω resistor. The resistor was wired directly to a voltage supply set to deliver 4.260.1A of current at 9.260.1V. This delivered 38.560.2W of power or 580J of energy every 15s. The results of the heating are show in Table1. The water was replaced with 20061ml of room temperature water and the experiment repeated. The results are shown in Table2. Next the resistor was exchanged for 6.8Ω resistor, the voltage supply changed to deliver 2.860.1A of current at 20.060.1V. This setup delivered 56.060.2W of power or 840J of energy every 1561s. Heating of both 100ml and 200ml samples was performed. See Table3, and Table4 for the results.

In the second experiment we considered the conversion of mechanical work to heat. The equation governing this is $-\Delta W = mC_v\Delta T$ where $-\Delta W$ is the work done on the system by its environment. Since the system was isolated we set $Q=0$.

By rotating a long tube filled with lead shot we approximated a fall of distance Nh where N is the number of times that the tube was rotated by 180 degrees and h is height. The work done on system is then $Nmgh$. Solving for the specific heat, $C_v = Nmgh/m\Delta T$, m is the mass of the shot and, g is of course gravity. The length of the tube was measured and an average distance of the falling show was found to be 90cm. The tube was inverted 30 times and the temperature of the air inside the tube and the shot was measured. This was repeated 2 more times and the final temperature measured each time. The results are given in Table5.

Results

The four following tables show the results of heating 100ml and 200ml samples of water first with 38.5W then with 56.0W.

Table1. Heating of 100ml of water with 38.5W.

Elapsed Time (s)	Temperature °c
0	21
15	22
30	24
45	26
60	27
75	28
90	30
105	30
120	32
135	33
150	34
165	36
180	37
195	38
210	39
225	40

Table2. Heating of 200ml of water with 38.5W.

Elapsed Time (s)	Temperature °c
0	23
15	24
30	24
45	25
60	26
75	26
90	27
105	27
120	28
135	29
150	29
165	30
180	30
195	31
210	32
225	32

Table3. Heating of 100ml of water with 56.0W.

Elapsed Time (s)	Temperature °c
0	26
15	29
30	30
45	32
60	33
75	35
90	37
105	38
120	40
135	42
150	44
165	45
180	47
195	49
210	50
225	52

Table4. Heating of 200ml of water with 56.0W.

Elapsed Time (s)	Temperature °c
0	33
15	36
30	37
45	38
60	38
75	39
90	40
105	41
120	42
135	42
150	43
165	44
180	45
195	46
210	46
225	47

Graphing the results from these four tables showed that the temperature increased linearly with time. See Graph1 as example. The linearity of the graphs shows that the change of temperature of the water is proportional to the time that the water was heated. This should not be taken to imply that all the heat is being delivered to the water. Evaporation, coduction and convection each increases in relative linearity with the difference of temperature between the air and the water. The ideal formula for the energy delivered to the system, and the energy stored in the system is:

$$IV\Delta t = m_w C_w \Delta T + m_{cup} C_{cup} \Delta T \quad \text{Equation(3)}$$

Where C_w is the specific heat of water at a constant pressure and C_{cup} is the specific heat at constant pressure and $IV\Delta t$ the energy delivered is some time Δt by the resistor.

The slope of the $Q/\Delta T$ would then be:

$$\frac{IV\Delta t}{\Delta T} = m_w C_w + m_{cup} C_{cup} \quad \text{Equation(4)}$$

Since we have taken two different measures we can eliminate the C_{cup} and m_{cup} terms from the problem.

Taking the data from the first trial, we graphed Q vs. ΔT and added a line of best fit. See Graph2. Next, the data was graphed ΔT vs. Q . See Graph3. The lines of best fit for the 100ml cup from Graph2 and Graph3 were:

$$Q = 452.3\Delta T - 220.1$$

$$\Delta T = 0.002198Q + 0.5441$$

Rearranging the second equation, $Q = 456.0\Delta T - 247.6$. The difference in the first and second equations is the result of the formula for line of best fit only accounting for error in the y-axis.

Taking the average, we have $Q = 454.62\Delta T - 234.614$

We repeated this procedure with the data taken from the second trial.

$$Q = 946.1\Delta T - 103.6$$

$$\Delta T = 0.001047Q + 0.1544$$

Rearranging the second equation, $Q = 955.1\Delta T - 147.5$. Taking the average, we have $Q = 950.65\Delta T - 125.622$.

Substituting these values into Equation (4).

$$456sWK^{-1} = 100gC_w + 2.2gC_{cup} \quad \text{Equation(5)}$$

$$950sWK^{-1} = 200gC_w + 2.2gC_{cup} \quad \text{Equation(6)}$$

Subtracting Equation (5) from (6) removes the terms related to the cup.

$$494sWK^{-1} = 100gC_w \quad \text{Equation(7)}$$

$$\text{Thus, } C_w = \frac{494sWK^{-1}}{100g} = 4.94JK^{-1}g^{-1}$$

Repeating for the 6.8Ω resistor,

$$C_w = \frac{558sWK^{-1}}{100g} = 5.58JK^{-1}g^{-1}$$

$$\text{Averaging, } C_w = 5.3 \pm 0.2JK^{-1}g^{-1}$$

Using the percent difference test:

$$\text{Difference} = \frac{|\text{Theoretical}-\text{Experimental}|}{|\text{Theoretical}+\text{Experimental}|/2} \times 100 = \frac{|4.1-5.3|}{|4.1+5.3|/2} \times 100 = 25\%$$

Comparison to the theoretical value of $4.1\text{JK}^{-1}\text{g}^{-1}$ gives an error of 25%. The experimental errors calculated from the slope of the curve were only about %1 yet the error of the experiment is 25%. Thus, there were systematic errors in the experiment. Some of the systematic errors are listed below.

Source of errors. There were so many, I don't even know where to start.

- 1) Loss of energy due to evaporation.
- 2) Energy added by stirring.
- 3) Unequal stirring during between trials.
- 4) Different starting temperatures of water.
- 5) Loss of energy through the cup into the air and table.

In the second experiment the values of shot temperature and air temperature were measured at each trial and are given in Table3

Table3 Measured temperatures
For each trial.

Trial	Temp. air (°C)	Temp. shot (°C)
0	23	23
1	23	23
2	24	24
3	24	23
4	25	24
5	25	24
6	25	25
7	26	25
8	26	25
9	27	26
10	27	26

The plot of change in shot temperature vs. number of inversions is given in Graph4 A line of best fit through the points in Graph4 given the following formula,
 $\Delta T = 0.0106K * N - 0.2273K$ where N is the number of inversions. Using the formula $C_v = gh / (\text{slope of } T \text{ vs. } N)$. The specific heat of lead was found to be $833\text{J/kg}^\circ\text{K}$. The theoretical value is 157°C . Using the percent difference test:

$$\text{Difference} = \frac{|\text{Theoretical-Experimental}|}{|\text{Theoretical+Experimental}|/2} \times 100 = \frac{|833-157|}{|833+157|/2} \times 100 = 137\%$$

The huge error was probably caused by thermal conduction from the lead into the tube itself. Possibly this problem could have been corrected for by turning the tube at a faster rate, which would have resulted in limiting the heat that could be conducted away into the surrounding material or by measuring the lead at the very moment that the rotation stopped.

Using the correct specific heat of $137\text{J/kg}^\circ\text{K}$, after 30 inversions of the tube the temperature of the lead shot should have been:

$$30 * 0.9m * 9.81ms^{-2} / 157Jkg^{-1}K^{-1} = 1.7^\circ K$$

In determining the smallest quantity of lead shot, points to take into consideration are:

- The mass of the air inside the tube in relation to the mass of the shot.
- The mass of the tube in relation to the mass of the shot.
- The rate of absorption between the tube and the shot.

The math formulas don't take into account these physics problems, but as experimentalist we must.

The function of an adiabatic wall is to totally prevent thermal transfer through the walls of the system. In an adiabatic process, the change in internal energy is equal an opposite to the work performed. Unfortunately, the tube we used in the experiment was an open system. The result is that heat escaped during the experiment, and infact the hotter the lead shot became the faster the heat escaped.

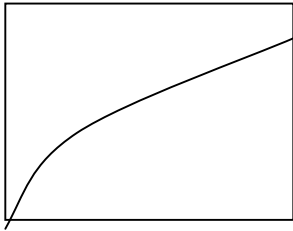
In a closed system, all the work done on the system is converted to stored energy (heat). The graph of work vs. temperature for such a system would be linear as the temperature increased. Conversely, in an open system the temperature would begin move assymptotically towards the temperature of the surroundings. If the surroundings were at a higher temperature then the system then the temperature of the system would rise quickly at first, but then level off as its temperature approached the temperature of the surroundings. See Sketch1. If the system were at a temperature higher then the surrounds, the slope of the shot temperature vs the number of times that thermal energy was added would start off steep but over time become increasingly horizontal. See Sketch2. Lastly, if the system were at the same temperature as the surroundings, there would be no net heat transfer between the system and the surroundings and the temperature would vary linearly with the work done on the system. See Sketch3.

Conclusions

The only use of this experiment was to show how not to do experiments. The styrofoam cup used in experiment 1 was a horrible example of a calorimeter. Adding energy to the cup and measuring the change in temperature of water allowed us to determine the specific heat to be $5.3 JK^{-1}g^{-1}$ 25% error from the theoretical value. This large error coupled with a measurement error of only %1 demonstrated that there was a huge systematic error in the experiment. In the second experiment involving the falling lead, we determined the specific heat of lead to be $833 J/kgK$. Using the percent difference test, this was found to have an error 137%. Using the correct formula and specific heat of lead we found that the temperature change from 30 inversions should have been 1.7K.

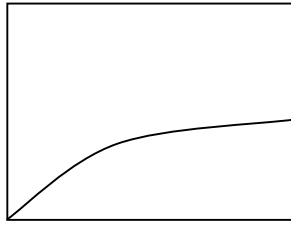
Sketch1. Surroundings at higher temperature than system.

Work done on system vs. Temperature



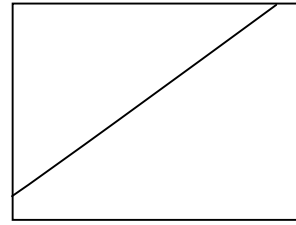
Sketch2. Surroundings at lower temperature than system.

Work done on system vs. Temperature

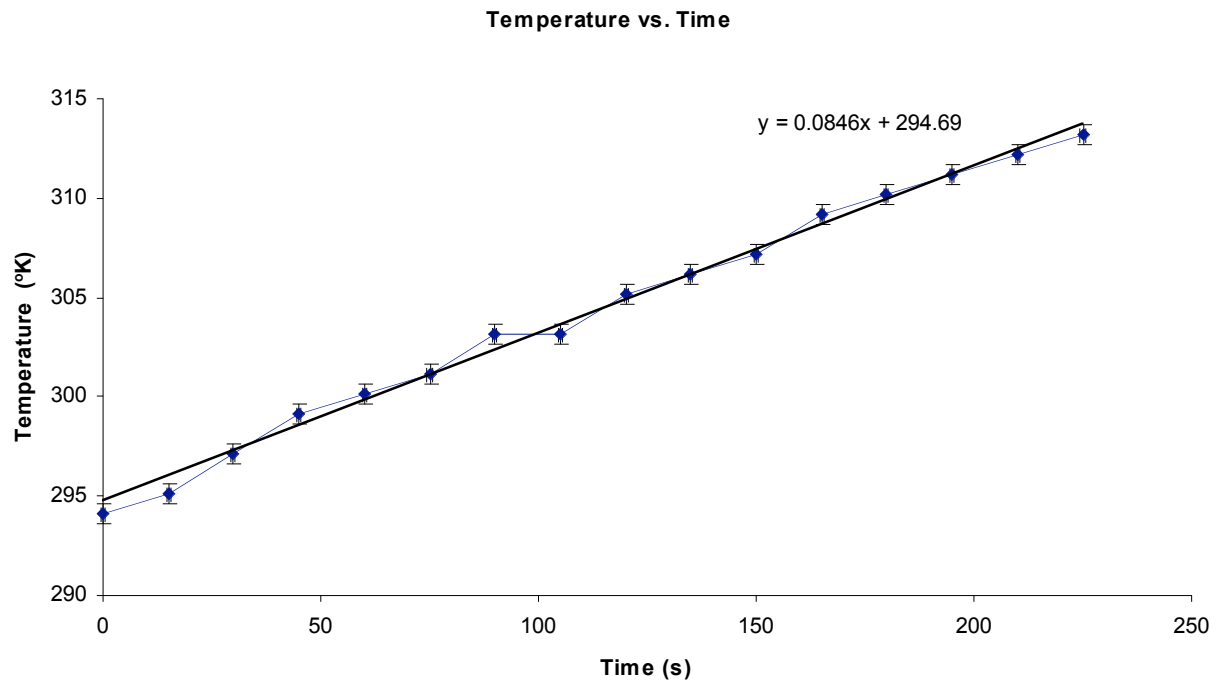


Sketch3. Surroundings at same temperature as system.

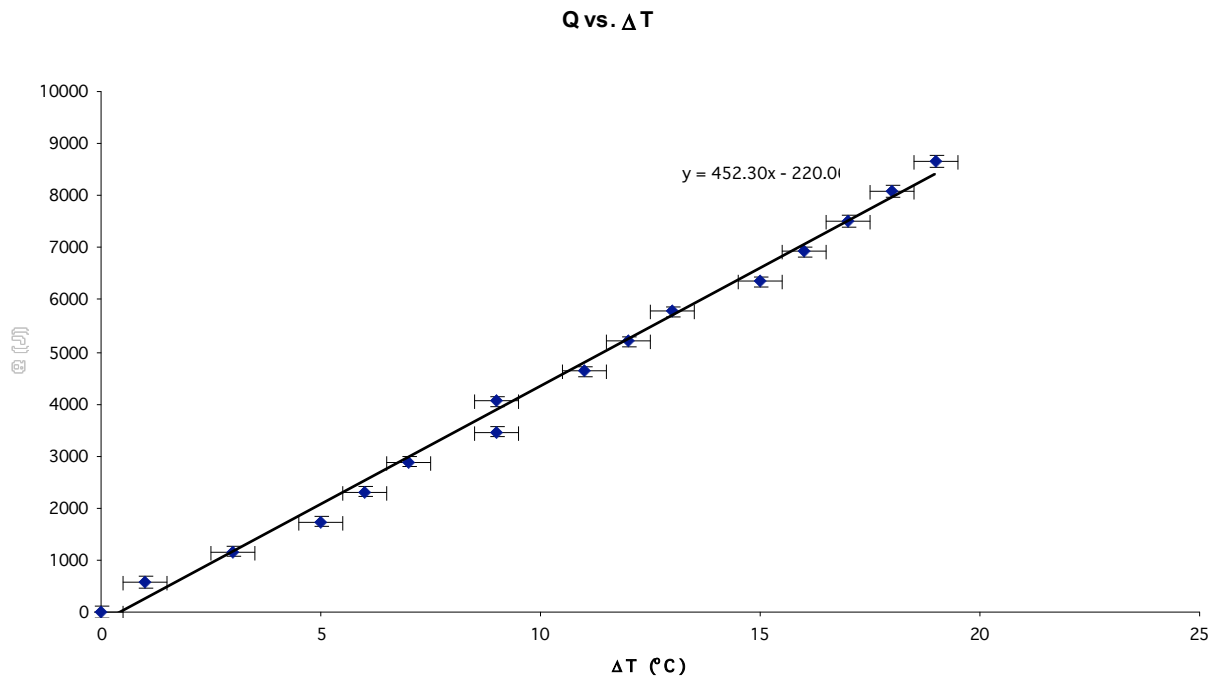
Work done on system vs. Temperature



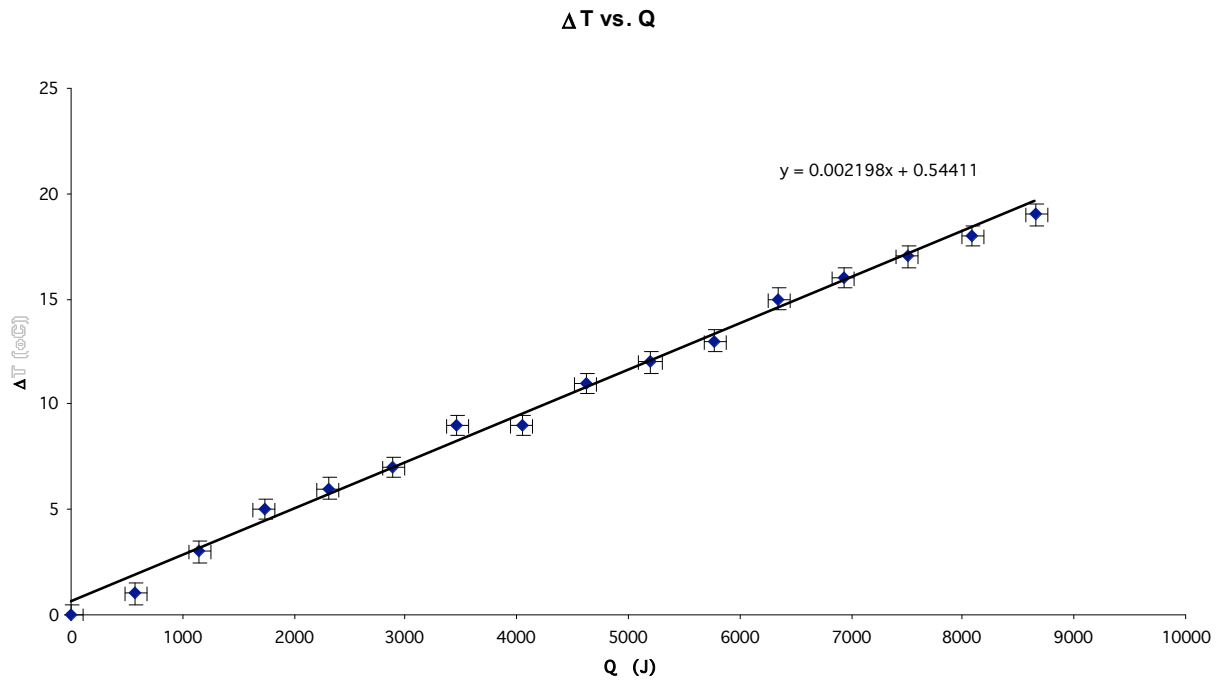
Graph1. 100grams of water with 20hm resistor.



Graph2. 100grams of water with 20hm resistor Q vs ΔT .



Graph3. 100grams of water with 20Ohm resistor ΔT vs. Q .



Graph4. Temperature of lead shot per number of inversions.

ΔT vs. Number of Inversions

