

ACDB4011: Calorimetry

UNIVERSITY OF WALES TRINITY ST DAVID – OME PROGRAMME
GEORGE SIMPSON

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1.0 INTRODUCTION

Purpose

There are two objectives for the experiments:

Experiment 1 is to measure the heat capacity of the calorimeter ($HC_{\text{calorimeter}}$), and
Experiment 2 is to measure the specific heat capacity of a metal sample (Cp_{metal}).

The experiments used the principle in the First Law of Thermodynamics that energy cannot be created or destroyed and is transferred from one form to another.

Hypotheses to be Tested

For these experiments the hypotheses to be tested are:

Experiment 1: Calorimeter Capacity. To determine the heat capacity of the calorimeter and whether it introduces significant errors or biases, and

Experiment 2: Specific Heat Capacity. To investigate the specific heat capacity of a metal and whether it matches theoretical predictions or known values.

A method known as calorimetry will be used to calculate the heat capacity of a metal by measuring heat exchange between the metal and the calorimeter with a measured heat capacity.

It is likely that there will be accuracy errors in the experiment due to heat loss which although small, will influence the results. Consequently, the calorific value of the material tested will have a lower calculated value than its true value.

Equations

Calorimetry is a technique used in chemistry and thermodynamics to measure heat exchanges that occur during a chemical reaction or physical process. The main equation required for calorimetry is a heat transfer equation and its purpose is to calculate the total amount of heat absorbed or released when a substance or object undergoes any change in temperature.

The following equations will be used in this experiment:

Equation 1: $Q = mCp\Delta T$ where:

Q is the heat (Joules)

m is the mass of the substance (grams)

Cp represents the specific heat capacity of the substance ($J/g^{\circ}C$)

ΔT is the measured change in temperature (Celsius or Kelvin)

Equation 2: $-Q_{\text{metal}} = Q_{\text{water}} + Q_{\text{calorimeter}}$ where:

$-Q_{\text{metal}}$ is the heat lost by the metal (Joules)

Q_{water} is the heat gained by the water in the calorimeter (Joules)

$Q_{\text{calorimeter}}$ is the heat within the calorimeter system (Joules)

The negative and positive signs indicate the direction of heat flow. The sign is negative when heat is lost and positive when heat is gained.

Equation 3: $Q_{\text{calorimeter}} = HC_{\text{calorimeter}} \times \Delta T_{\text{calorimeter}}$

$Q_{\text{calorimeter}}$ is the heat gained (Joules)

$HC_{\text{calorimeter}}$ is the heat capacity of the calorimeter (J/g°C)

$\Delta T_{\text{calorimeter}}$ is the measured temperature difference in the calorimeter (Celsius or Kelvin)

Equation 4 is obtained by combining Equations 1, 2 and 3:

$$(m_{\text{metal}} \times C_{p\text{metal}} \times \Delta T_{\text{metal}} = -(m_{\text{water}} \times C_{p\text{water}} \times \Delta T_{\text{water}}) + (HC_{\text{calorimeter}} \times \Delta T_{\text{calorimeter}})$$

Equation 5: $-Q_{\text{hot-water}} = Q_{\text{cold-water}} + Q_{\text{calorimeter}}$ where:

$-Q_{\text{hot-water}}$ is the heat lost by the hot water (Joules)

$Q_{\text{cold-water}}$ is the heat gained by the cold water (Joules)

$Q_{\text{calorimeter}}$ is the heat within the calorimeter system (Joules)

The heat capacity of water ($C_{p\text{water}}$) is 4.186 J/g°C.

Equation 6: $\Delta T_{\text{calorimeter}} = \Delta T_{\text{max}} - \Delta T_{\text{cold}}$ where:

$\Delta T_{\text{calorimeter}}$ is the change in temperature in the calorimeter (Celsius or Kelvin)

ΔT_{max} is the maximum equilibrium temperature of the hot and cold-water mixtures (Celsius or Kelvin)

ΔT_{cold} is the original water temperature in the calorimeter (Celsius or Kelvin)

Variables

Independent variables. The independent variables for these experiments were the initial temperature of the water in the calorimeter and the temperature of the hot water and the metal immersed in the hot water.

Dependant variables. These were the temperature changes which were observed in the experiments. The temperature changes were used to calculate the heat capacity of the calorimeter and the metal.

Controlled variables. These were conditions kept constant throughout the experiments. In these experiments the controlled conditions were the ambient temperature and pressure although these variables were not specifically controlled but were assumed to be constant throughout the experiment.

The potential variation due to apparatus differences was also controlled. The same type of thermometer was used for the duration of the experiment because during a previous experiment a variation in temperature between different types of thermometers had been observed.

2.0 RESULTS

Measurement of Maximum Equilibrium Temperature ($T_{\max}$)				
1st Attempt				
Step 1				
Temperature	[°C]	Mass	[g]	
T_{hot}	60	m_{hot}	50	
T_{cold}	24	m_{cold}	50	
T_{max}	42	m_{max}	100	
Calculation of Heat (Q_{hotwater} & $Q_{\text{coldwater}}$) using Equation 1				
1st Attempt				
Step 2	Q [J]	m [g]	C_p [J/g°C]	ΔT [°C]
Q_{hotwater}	-3,767.4	50	4.186	-18
$Q_{\text{coldwater}}$	3,767.4	50	4.186	18
Calculation of Heat ($Q_{\text{calorimeter}}$) using Equation 5				
1st Attempt				
Step 3	Q_{hotwater} [J]	$Q_{\text{coldwater}}$ [J]	$Q_{\text{calorimeter}}$ [J]	
$Q_{\text{calorimeter}}$	-3,767.4	3,767.4	0.0	

Experiment 1

Table 1 – First Attempt at Experiment 1

In the first attempt at the experiment, no apparent heat loss associated with the calorimeter was calculated as shown in Table 1. It was realised that a $Q_{\text{calorimeter}}$ of 0J was incorrect and that in reality there had to be some energy gain by the calorimeter. It was unclear why the measurement was incorrect but it could have been because the measurement was taken before the calorimeter had reached its equilibrium temperature or that the actual temperature was too small to be accurately shown on the thermometer.

A second attempt was made to complete experiment 1. A gain to the calorimeter equating to 4°C was assumed and equally applied to the hot and cold water as shown in Table 2. The calculated $T_{\max}$ reduced from 42°C (as shown in Table 1) to 38°C as shown in Table 2. The heat capacity ($HC_{\text{calorimeter}}$) was calculated to be 119.6 J.

Measurement of Maximum Equilibrium Temperature (T_{max})			
2nd Attempt			
Step 1			
Temperature	[°C]	Mass	[g]
T_{hot}	60	m_{hot}	50
T_{cold}	24	m_{cold}	50
T_{max}	38	m_{max}	100

Calculation of Heat (Q_{hotwater} & $Q_{\text{coldwater}}$) using Equation 1				
2nd Attempt				
Step 2	Q [J]	m [g]	C_p [J/gC]	ΔT [°C]
Q_{hotwater}	-4,604.6	50	4.186	-22
$Q_{\text{coldwater}}$	2,930.2	50	4.186	14

Calculation of Heat ($Q_{\text{calorimeter}}$) using Equation 5			
2nd Attempt			
Step 3	Q_{hotwater} [J]	$Q_{\text{coldwater}}$ [J]	$Q_{\text{calorimeter}}$ [J]
$Q_{\text{calorimeter}}$	-4,604.6	2,930.2	1,674.4

Calculation of Calorimeter Temperature Difference ($\Delta T_{\text{calorimeter}}$) using Equation 6			
2nd Attempt			
Step 4	ΔT_{max} [°C]	ΔT_{cold} [°C]	$\Delta T_{\text{calorimeter}}$ [°C]
$\Delta T_{\text{calorimeter}}$	38	24	14

Calculation of Heat Capacity of Calorimeter ($HC_{\text{calorimeter}}$) using Equation 3			
2nd Attempt			
Step 5	$\Delta T_{\text{calorimeter}}$ [°C]	$Q_{\text{calorimeter}}$ [J]	$HC_{\text{calorimeter}}$ [J/C]
$HC_{\text{calorimeter}}$	14	1,674.4	119.6

Table 2 Second Attempt at Experiment 1

Key Findings in Experiment 1

The $Q_{\text{calorimeter}}$ theoretically represents the heat within the Styrofoam cups, the lid, the thermometer and stirring rod. The key finding from Experiment 1 was that the 1°C increments on the thermometer may lead to inaccurate recording of temperature. Although, the energy absorbed by the calorimeter appeared high, the value was still used to calculate the heat capacity of the calorimeter as there was no obvious alternative at the time.

Experiment 2

Measurement of Water Temperature (T_{water})			
Step 1			
Temperature	[°C]	Mass	[g]
T_{water}	26.0	$m_{\text{cold-water}}$	130.0
$T_{\text{calorimeter}}$	26.0		
Measurement of Maximum Equilibrium Temperature (T_{max})			
Step 2			
Temperature	[C]	Mass	[g]
T_{hot}	90.0	m_{hot}	18.5
T_{water}	26.0	m_{water}	130.0
T_{max}	30.5		

Table 3 Calculation of Maximum Equilibrium Temperature (T_{max})

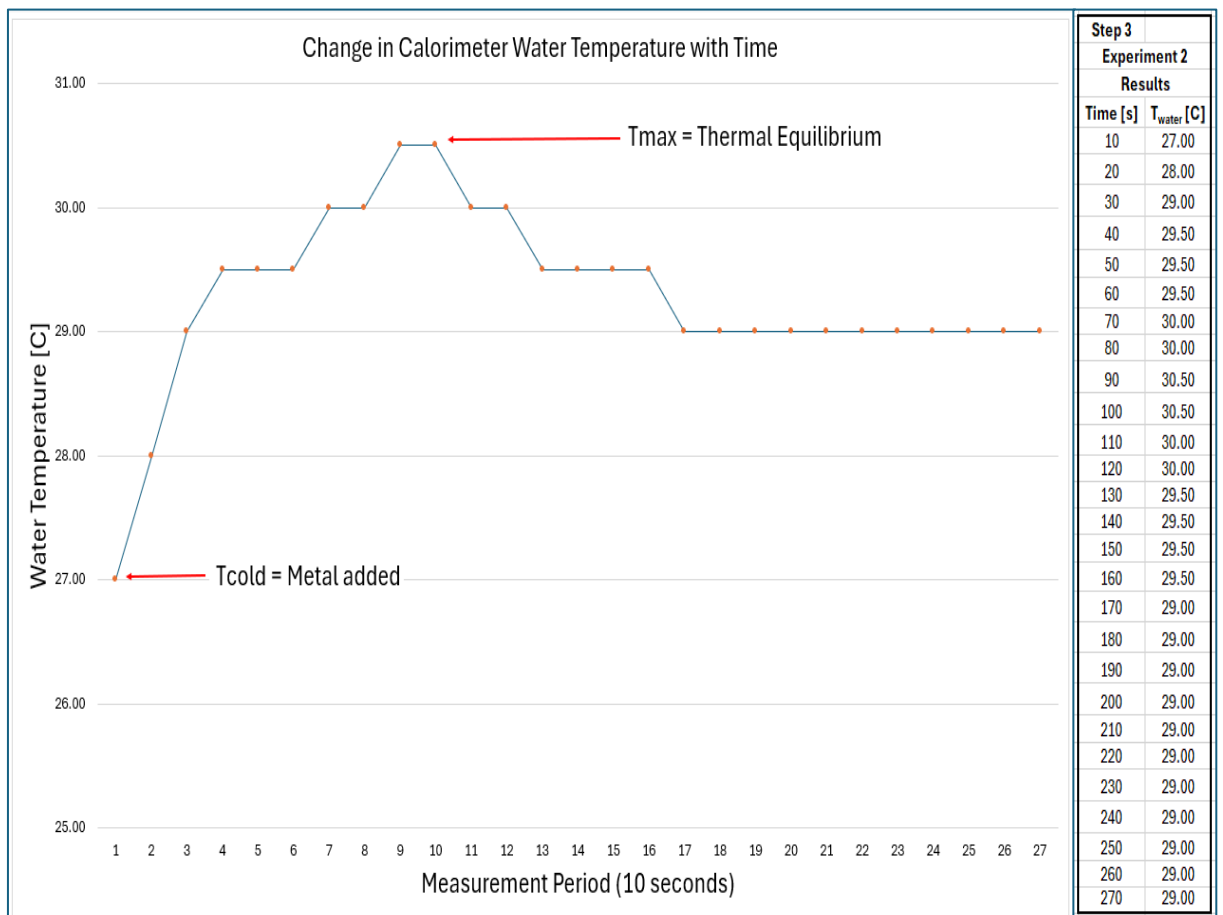


Figure 1 Graph of Calorimeter Water Temperature with Time

Calculation of Temperature Differences [C]								
Step 3	T _{start} [C]	T _{end} [C]	ΔT [°C]					
ΔT _{metal}	90.0	30.5	-59.5					
ΔT _{water}	26.0	30.5	4.5					
ΔT _{calorimeter}	26.0	30.5	4.5					
Calculation of Heat Capacity of Metal (C _{p,metal}) using Equation 4								
Step 4	m _{hot/metal} [g]	ΔT _{metal} [°C]	m _{water} [g]	C _{p,water} [J/gC]	ΔT _{water} [C]	HC _{calorimeter} [J/C]	ΔT _{calorimeter} [C]	C _{p,metal} [J/gC] 2 dp
C _{p,metal}	18.5	-59.5	130.0	4.186	4.5	119.6	4.5	2.71

Table 4 Calculation of Heat Capacity of Metal

Key Findings in Experiment 2

The heat capacity calculated by experiment for the metal was 2.71 J/gC which does not suggest a common metal. The metal used in the experiment looked like a sample of titanium or aluminium based on appearance and mass. The published data for the heat capacity for aluminium is 0.9 J/gC and the heat capacity for titanium is 0.52 J/gC both of which are significantly less than the heat capacity calculated by the experiment. This suggests that the maximum equilibrium temperature (T_{max}) temperature and/or the corresponding heat capacity calculated for the calorimeter (HC_{calorimeter}) contained experimental errors.

3.0 DISCUSSION

Interpretation and Significance of Results and Potential Sources of Experimental Error

Incorrect Calculation of Heat Capacity of Calorimeter in Experiment 1

Experiment 1 demonstrated the First Law of Thermodynamics in that it was possible to calculate and apportion all the heat energy from the hot material to the cold material and the calorimeter (Figure 2).

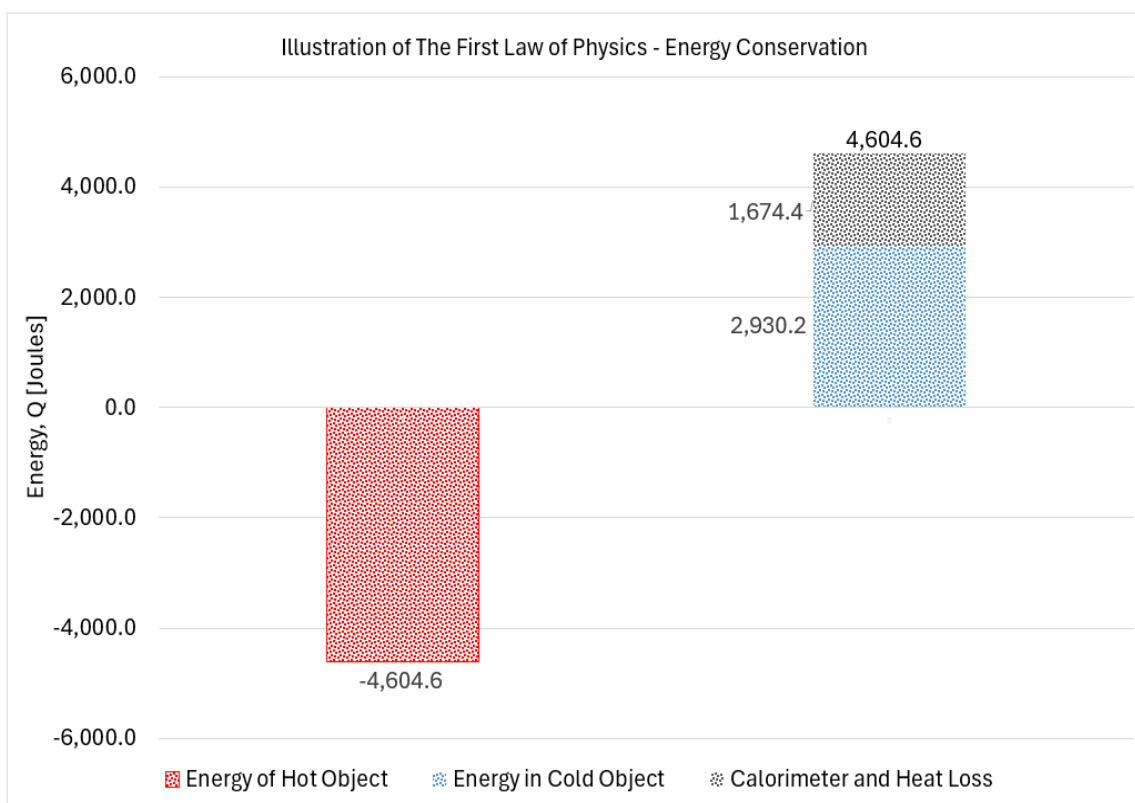


Figure 2 Illustration of The First Law of Physics in Experiment 1

However, Figure 2 shows that the energy absorbed by the calorimeter represents 36% of the heat exchange from the hot metal which seems excessive given the construction and material of the calorimeter. Therefore, it is believed that the calculated heat capacity of the calorimeter is incorrect.

As shown in the results for Experiment 1, the initial temperatures recorded indicated a $\Delta T_{\text{cold water}} = \Delta T_{\text{hot}}$ at 18°C resulting in a heat capacity calculation of 0 J/C for the calorimeter. Having analysed the 4°C adjustment during the analysis of results, a more appropriate adjustment would have been in the region of 0.5°C. Table 5 shows the results of Experiment 1 using a revised T_{max} of 41.5°C. The revised heat capacity for the calorimeter is 11.96 J/C which represents 2.1% of the energy transfer and is a more realistic value.

Measurement of Maximum Equilibrium Temperature ($T_{\max}$)				
Experiment 1 - Discussion				
Step 1				
Temperature	[°C]	Mass	[g]	
T_{hot}	60	m_{hot}	50	
T_{cold}	24	m_{cold}	50	
$T_{\max}$	41.5	$m_{\max}$	100	

Calculation of Heat (Q_{hotwater} & $Q_{\text{coldwater}}$) using Equation 1				
Experiment 1 - Discussion				
Step 2	Q [J]	m [g]	C_p [J/g°C]	ΔT [°C]
Q_{hotwater}	-3,872.1	50	4.186	-18.5
$Q_{\text{coldwater}}$	3,662.8	50	4.186	17.5

Calculation of Heat ($Q_{\text{calorimeter}}$) using Equation 5			
Experiment 1 - Discussion			
Step 3	Q_{hotwater} [J]	$Q_{\text{coldwater}}$ [J]	$Q_{\text{calorimeter}}$ [J]
$Q_{\text{calorimeter}}$	-3,872.1	3,662.8	209.3

Calculation of Calorimeter Temperature Difference ($\Delta T_{\text{calorimeter}}$) using Equation 6			
2nd Attempt			
Step 4	$\Delta T_{\max}$ [°C]	ΔT_{cold} [°C]	$\Delta T_{\text{calorimeter}}$ [°C]
$\Delta T_{\text{calorimeter}}$	42	24	18

Calculation of Heat Capacity of Calorimeter ($HC_{\text{calorimeter}}$) using Equation 3			
2nd Attempt			
Step 5	$\Delta T_{\text{calorimeter}}$ [°C]	$Q_{\text{calorimeter}}$ [J]	$HC_{\text{calorimeter}}$ [J/°C]
$HC_{\text{calorimeter}}$	18	209.3	11.96

Table 5 Revised Calculations for Experiment 1

Recalculation of Heat Capacity of Metal in Experiment 2

The calculations for Experiment 2 were repeated with a revised heat capacity for the calorimeter from 119.6 J/C to 11.96 J/C and the heat capacity for the metal reduced from 2.71J/gC to 2.27J/gC as shown in Table 6.

Measurement of Water Temperature (T_{water})			
Step 1			
Temperature	[°C]	Mass	[g]
T_{water}	26.0	$m_{\text{cold-water}}$	130.0
$T_{\text{calorimeter}}$	26.0		

Measurement of Maximum Equilibrium Temperature (T_{max})			
Step 2			
Temperature	[C]	Mass	[g]
T_{hot}	90.0	m_{hot}	18.5
T_{water}	26.0	m_{water}	130.0
T_{max}	30.5		

Calculation of Temperature Differences [C]			
Step 3	T_{start} [C]	T_{end} [C]	ΔT [°C]
ΔT_{metal}	90.0	30.5	-59.5
ΔT_{water}	26.0	30.5	4.5
$\Delta T_{\text{calorimeter}}$	26.0	30.5	4.5

Calculation of Heat Capacity of Metal (CP_{metal}) using Equation 4								
Step 4	$m_{\text{hot/metal}}$ [g]	ΔT_{metal} [°C]	m_{water} [g]	CP_{water} [J/g°C]	ΔT_{water} [C]	$HC_{\text{calorimeter}}$ [J/C]	$\Delta T_{\text{calorimeter}}$ [C]	CP_{metal} [J/g°C] 2 dp
CP_{metal}	18.5	-59.5	130.0	4.186	4.5	11.96	4.5	2.27

Table 6 Revised Calculation of Heat Capacity of Metal for Experiment 2 with Revised Calorimeter Heat Capacity

Mass of Water in Calorimeter for Experiment 2

Whilst the calculation for the heat capacity of the metal is an improvement on the original calculation, there must still be other experimental errors. The experiment brief was misunderstood, and the apparatus used for Experiment 2 included the 100g mass of water already in the calorimeter from Experiment 1. The 30g mass of water was added making a total water mass in the calorimeter of 130g as shown in Tables 3 and 6.

The larger mass of water affected the temperature difference recorded in Experiment 2. The temperature difference was 4.5°C resulting in possible error because the smallest increment on the thermometer was 1°C. With the larger mass of water, a 0.5°C reading error would result in a 10% calculation error whereas a 0.5°C reading error on the smaller 30g mass of water with a larger temperature difference and so the relative effect of a 0.5°C error would be reduced.

Evaluation of Results WITHOUT the Calorimeter

It was decided to explore by calculation the error in the temperature readings because of the errors outline above. On the assumption that the metal was aluminium, the starting point was the published heat capacity for aluminium of 0.89J/gC [1] Equation 4 was used but without the terms relating to the calorimeter to calculate the heat capacity of the metal and water as shown in Table 7.

Calculation of Heat Capacity using Equation 1			
Experiment 2 - Discussion			
	m.Cp [J/C]	m [g]	Cp [J/gC]
HC _{metal} [°C]	16.02	18.0	0.9
HC _{water} [°C]	544.18	130	4.186

Table 7 Calculation of Heat Capacity for each material. Based on the heat capacity ratios the temperature difference for each material was calculated as shown in Table 8.

Calculation of Temperature Differences with 130g water				
Experiment 2 - Discussion				
	m.Cp [J/C]	ΔT _{Total}	HC _{ratio}	ΔT [°C]
ΔT _{metal}	16.47	64.0		62.06
ΔT _{water}	544.18	64.0	33.05	1.94

Table 8 Calculation of Total Temperature Difference for Experiment 2 using 130g of water used the following calculations:-

$$m_m C_p \Delta T_m = m_w C_p \Delta T_w$$

$$\Delta T_m = m_w C_p \Delta T_w / m_m C_p \quad (\text{Equation 1.})$$

$$\Delta T_m = ((130 \times 4.186) / (18.5 \times 0.89)) \times \Delta T_w = 33.04 \Delta T_w$$

Using the data from experiment 2 we calculate ΔT by using:-

$$T_{\text{water}_H} - T_{\text{water}_C} = 90^\circ\text{C} - 26^\circ\text{C} = 64^\circ\text{C} \quad (\text{Equation 2})$$

Substituting from Equation 1:-

$$33.04 \times \Delta T_w + \Delta T_w = 64^\circ\text{C}$$

$$\Delta T_w = 64 / 34.04 = 1.94^\circ\text{C}$$

$$\Delta T_m = 33.04 \times 1.88 = 62.06^\circ\text{C}$$

As a double check applying these calculated temperature changes to the spreadsheet used for the experiment we obtain the heat capacity of aluminium using the formula in Equation 4 as

Calculation of Heat Capacity of Metal ($C_{p_{metal}}$) using Equation 4						
	$m_{hot/metal}$ [g]	ΔT_{metal} [°C]	m_{water} [g]	$C_{p_{water}}$ [J/gC]	ΔT_{water} [C]	$C_{p_{metal}}$ [J/gC] 2 dp
$C_{p_{metal}}$	18.5	62.1	130.0	4.186	1.88	-0.89

shown in Table 9.

Table 9 Calculation of Heat Capacity of Metal without Calorimeter

The above calculations were repeated with a water mass of 30g as shown in Tables 10 and 11.

Calculation of Heat Capacity using Equation 1			
Experiment 2 - Discussion			
	$m.C_p$ [J/C]	m [g]	C_p [J/gC]
HC_{metal} [°C]	16.47	18.5	0.9
HC_{water} [°C]	125.58	30	4.186

Table 10 Calculation of Heat Capacity for each material with 30g water

Calculation of Temperature Differences with 30g water				
Experiment 2 - Discussion				
	$m.C_p$ [J/C]	ΔT_{Total}	HC_{ratio}	ΔT [°C]
ΔT_{metal}	16.47	64.0		55.61
ΔT_{water}	125.58	64.0	7.63	8.39

Table 11 Calculation of Total Temperature Difference for Experiment 2 with 30g water

From these results with the incorrect calorimeter mass of 130g and a 1°C increment thermometer it would be difficult to accurately record a temperature change in the water of 1.88°C. However using the correct mass of 30g resulted in a greater change in temperature of the water which would have resulted in a lower margin of error of because the ratio between the water and metal temperature changes is less. A temperature change of 8.39°C is easier to read than 1.94°C using a thermometer that has 1°C increments.

Relevance of Experiments to OME

Calorimetry plays an important role in understanding and predicting the energy contained within ordnance, munitions, and explosives. Calorimetry experiments, like the assignment experiments, are used to accurately calculate the thermal energy released when explosive materials decompose. The energy released is directly related to the molecular mass of an explosive and by using stoichiometric formulas the mass per Mol of explosive can be used to calculate the energy (J)/Mol. The use of calorimetry is a non-destructive test method that enables the power of an explosive to be measured without the need for full scale testing.

Figure 3 shows a bomb calorimeter where the explosive sample is placed within a sealed container of fixed volume so that there is no pressure-volume work into the surroundings [3]. Therefore, all the heat put into the water of the calorimeter is exactly equal to the energy

generated by the explosive sample. The sample is ignited by fuse wires and the heat generated and absorbed by the water is measured by an electronic thermometer.

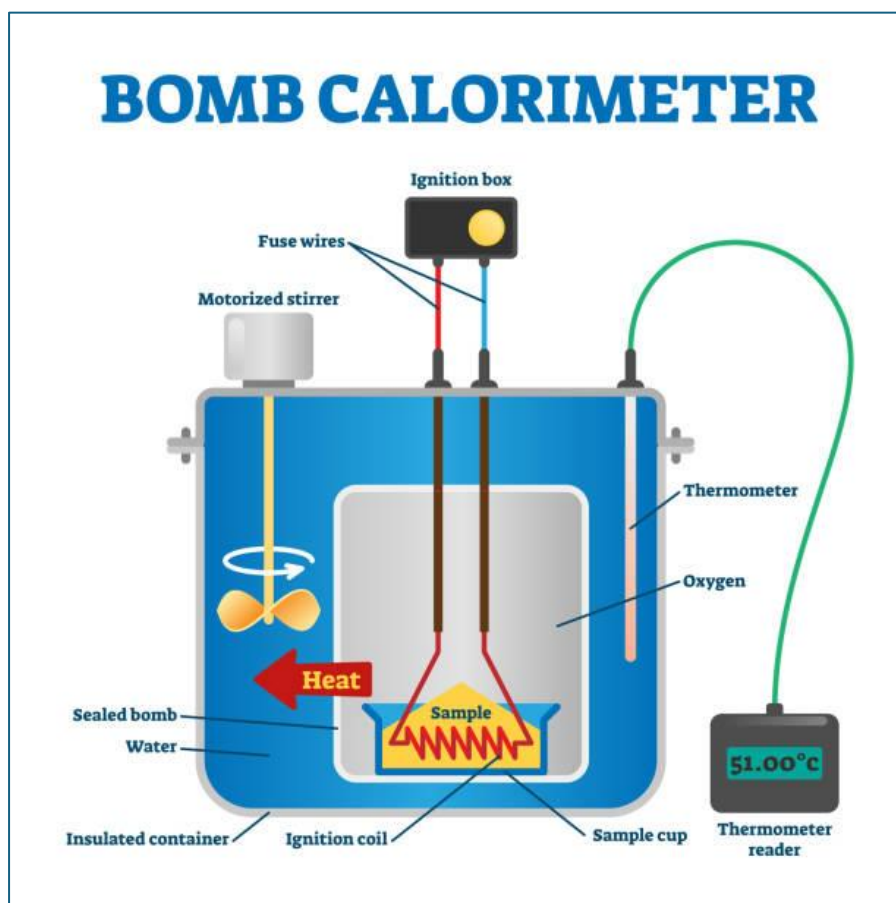


Figure 3 Diagram of Bomb Calorimeter [2]

Limitations

The resolution of the thermometers used in the experiment was 1°C intervals which made measuring temperature in anything other than whole or half a degree quite challenging and therefore limited the accuracy of the results. It is reasonable to conclude that using a calibrated electronic thermometer may have increased the ease and accuracy of the experiments.

4.0 CONCLUSIONS

Summary of Main Findings

The hypothesis of experiment 1 is supported by the results. Figure 2 demonstrates that the heat energy was equal to the cold energy and the calculated calorimeter capacity, even though the heat capacity of the calorimeter was too a high a proportion of the heat absorbed.

The hypothesis of experiment 2 is supported by the subsequent analysis and discussion results. It is probable that the metal was aluminium and that the incorrect calculation of its heat capacity was due to cumulative experimental error.

There are several sources of experimental error. The first was in the accuracy of the thermometers because it was difficult to measure increments smaller than half a degree.

The second source of error was a misunderstanding of the experiment brief and the use of an incorrect mass of water in Experiment 2.

The cumulation of small errors in the experiments resulted in a large error in the calculation of the heat capacity of the metal. This demonstrates the importance of using instruments which have the appropriate sensitivity, resolution and range and the need for very clear brief instructions to prevent experiment procedure errors.

Future Research based on Findings

The findings suggest that future research into different types of thermometers with increased levels of resolution and accuracy may be worthwhile for future experiments.

The findings prompted research into bomb calorimeters which was interesting and illustrates how fundamental laws of physics can be applied to complex developments such as modern missiles and munitions.

5.0 REFERENCES

- [1] nuclear power, "Specific Heat Capacity of Materials," *Material Properties*, Feb. 19, 2017. <https://material-properties.org/heat-capacity-of-materials/> (accessed May 16, 2024).
- [2] "bomb calorimeter image," *Istockphoto.com*, 2024. <https://media.istockphoto.com/vectors/bomb-calorimeter-vector-illustration-labeled-educational-explain-vector-id1197976471?k=6&m=1197976471&s=612x612&w=0&h=CeFTv4QKMr1hAO9G-TN5lTgVmKpWACfv984z0nPs4-l=> (accessed May 16, 2024).
- [3] J. E. Brady and G. E. Humiston, *General Chemistry*. John Wiley & Sons, 1980.

6.0 APPENDIX A – Materials

Materials Required for Experiment 1

- Two Styrofoam cups
- One cup lid
- Two mercury thermometers
- One stirrer
- Measuring beaker
- Beaker for heating water
- Bunsen burner
- Stand and clamp for calorimeter.
- Stand for heating beaker
- Pen and assignment for recording results
- 100g of water

Materials for Experiment 2

- As for Experiment 1 with the addition of:
- A sample of metal

- Weighing scales
- Tongs
- Stop watch
- 30g of water
- Pen and assignment for recording results

APPENDIX B – Methodology

Methodology Experiment 1

Set Up. Construct a calorimeter as shown in Figure A1.



Figure A1 – Set up of Experiment 1 – source assignment notes

Step 1.

- Add 50 ml water to the calorimeter, replace the lid and record the temperature, T_{cold} when temperature has stabilised.
- Heat 50ml water in a beaker to approximately 80°C . Turn of the Bunsen burner and wait until the temperature is approximately 60°C using a second thermometer.
- Add the 60°C water to the calorimeter and replace lid quickly and stir to mix the hot and cold water thoroughly while watching the thermometer.
- Record the maximum equilibrium temperature, T_{max} of the water.

Step 2

- Calculate the Energy of the hot water, $Q_{\text{hot-water}}$ using equation 1.
- Calculate the Energy of the hot water, $Q_{\text{cold-water}}$ using equation 1.

Step 3

- Calculate the Energy of the hot water, $Q_{\text{calorimeter}}$ using equation 5.

Step 4

- Calculate the calorimeter temperature difference using equation 6.

Step 5

- Calculate the heat capacity of the calorimeter using equation 3.

Methodology Experiment 2

Set Up. Using the same apparatus as in Figure A1 but WITHOUT any water in the calorimeter, weigh a piece of metal and record its mass.

- Place the metal in a beaker of water and boil for 5 minutes to enable the metal to reach an equilibrium temperature with the water. Shut off the Bunsen burner and wait two minutes for the temperature of the metal and water to reach equilibrium.
- While the beaker is boiling, add 30 ml of water to the calorimeter and record the temperature as T_{cold} .

Step 1

- Measure the temperature of the hot water and record as T_{hot} .
- Using the tongs, add the hot metal to the calorimeter and replace the lid quickly, and stir.

Step 2

- Using a stopwatch record the temperature every 10 seconds until the water reaches a maximum temperature and begins to cool.
- Identify the maximum equilibrium temperature of the mixture, T_{max} .

Step 3

- Calculate the temperature difference for the metal, the water, and the calorimeter.

Step 4

- Using the heat capacity of the calorimeter calculated in experiment 1, calculate the heat capacity of the metal using equation 4.