

Lab Report - Calorimetry

by George Butcher

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Lab Report 3

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Introduction.

This report is about the calorimetry experiment. Calorimetry is used to measure the amount of thermal energy transferred in a chemical or physical process between the system and the surroundings [1]. In this experiment there were three separate experiments. The first experiment was to measure the heat capacity of the calorimeter. This was done by adding 50mL of hot and cold water and then using the energy balance equations to work out the heat capacity. The second experiment was to measure the specific heat capacity of a metal. This was done by heating up the metal and placing it into 30mL of cold water, temperature readings were then taken every 10 seconds until the water cooled by 2 degrees. Equation 3 was then used to work out the specific heat capacity. The final experiment was to measure the molar heat of reacting hydrochloric acid (HCl) and sodium hydroxide (NaOH). This was done by adding 52.0mL of 1.0 M NaOH and 50.0mL of 1.0 M HCl of the same temperature into the calorimeter. Then a maximum temperature was recorded. This was then used to calculate the molar heat of reaction using equation 5. Step by step procedures for all experiments can be seen in Appendix 2.

Hypothesis:

1. The heat capacity of the calorimeter can be measured by mixing two known quantities of hot and cold water and applying the energy balance equations.
2. The specific heat of a sample metal can be determined using the principle of conservation of energy using an isolated system (Calorimeter).
3. The molar heat and energy change can be determined from the exothermic reaction of mixing HCl and NaOH using calorimetry.

Variables:

Independent variables:

- Initial temperature of the water added (T_{hot}) – Experiment 1
- Type of metal used and its initial temperature – Experiment 2
- Volume and concentration of acid and base used – Experiment 3

Dependent variables:

- Final temperature of the water in the calorimeter – Experiment 1
- Change in temperature (ΔT) of the water after metal was added – Experiment 2
- Temperature change of the solution after mixing HCl and NaOH – Experiment 3

Controlled variables:

- Mass and volume of water in the calorimeter – Experiment 1
- Mass and volume of hot water added to calorimeter – Experiment 1
- The calorimeter and the equipment used – Experiment 1
- Mass, volume and temperature of water in calorimeter – Experiment 2
- The calorimeter and the equipment used – Experiment 2
- Mass of the metal – Experiment 2

- Starting temperature of HCl and NaOH – Experiment 3
- The calorimeter and equipment used – Experiment 3

Equations:

Basic heat Transfer:

$$Q = m \times c_p \times \Delta T \quad (\text{Eq.1})$$

Energy conservation for the system:

$$-Q_{\text{metal}} = Q_{\text{water}} + Q_{\text{calorimeter}} \quad (\text{Eq.2})$$

Specific heat capacity of metal:

$$m_{\text{metal}} \times c_{p \text{ metal}} \times \Delta T_{\text{metal}} = - (m_{\text{water}} \times c_{p \text{ water}} \times \Delta T_{\text{water}} + HC_{\text{calorimeter}} \times \Delta T_{\text{calorimeter}}) \quad (\text{Eq.3})$$

Heat of neutralisation reaction:

$$Q_{\text{reaction}} = - (m_{\text{water}} \times c_{p \text{ water}} \times \Delta T_{\text{water}} + HC_{\text{calorimeter}} \times \Delta T_{\text{calorimeter}}) \quad (\text{Eq.4})$$

Heat capacity of calorimeter:

$$-Q_{\text{hot-water}} = Q_{\text{cold-water}} + Q_{\text{calorimeter}} \quad (\text{Eq.5})$$

$$Q_{\text{calorimeter}} = HC_{\text{calorimeter}} \times \Delta T_{\text{calorimeter}} \quad (\text{Eq.6})$$

Molar heat of reaction:

$$q_{\text{reaction}} = \frac{Q_{\text{reaction}}}{n_{\text{reactant}}} \quad (\text{Eq.7})$$

write all calculations clearly in the report, as using screenshots is not considered professional practice

Results.

Experiment 1 – Measuring heat capacity of the calorimeter ($HC_{\text{calorimeter}}$).

The results and calculations from the first experiment can be seen below in Figure 1.

University of Wales Trinity Saint David – OME Programme

DATA SHEET to RECORD OBSERVATIONS, CALCULATIONS and RESULTS

STUDENT'S NAME: George Aylmer

PARTNERS' NAMES: Lewis Galloway

REPORT IS DUE MAY 02, 2025 (DD May 09, 2025) submitted via Moodle

1. Measure the value of the heat capacity of the calorimeter ($HC_{\text{calorimeter}}$)

Use these entries to record your experimental data, results, and calculations.

$T_{\text{hot}} = 60^{\circ}\text{C}$ $m_{\text{hot water}} = 50\text{g}$ $\Delta T_{\text{hot water}} = -14.4^{\circ}\text{C}$

$T_{\text{cold}} = 23.6^{\circ}\text{C}$ $m_{\text{cold water}} = 50\text{g}$ $\Delta T_{\text{cold water}} = +22.0^{\circ}\text{C}$

$T_{\text{max}} = 45.6^{\circ}\text{C}$ $\Delta T_{\text{calorimeter}} = +22.0^{\circ}\text{C}$

$Q_{\text{cold water}} = 4604.60\text{J}$ $Q_{\text{hot water}} = -3011.52\text{J}$ $Q_{\text{calorimeter}} = ~~1590.68\text{J}~~ - 1590.68\text{J}$

$HC_{\text{calorimeter}} = ~~72.3\text{J}^{\circ}\text{C}~~ 72.3\text{J}^{\circ}\text{C}$ *negative value of HC is incorrect; the final temperature reading was measured too high (too early)*

Write the calculations for $Q_{\text{HOT WATER}}$, $Q_{\text{COLD WATER}}$, $Q_{\text{CALORIMETER}}$, and $HC_{\text{CALORIMETER}}$:

$Q_{\text{cold}} = m \times c_p \times \Delta T = 50.0 \times 4.186 \times 22 = 4604.60\text{J}$

$Q_{\text{hot}} = 50 \times 4.186 \times -14.4 = -3011.52\text{J}$

Equation 5

$-Q_{\text{hot}} = Q_{\text{cold}} + Q_{\text{calorimeter}} = +3011.52 = 4604.60 + Q_{\text{calorimeter}}$

$Q_{\text{calorimeter}} = +3011.52 - 4604.60 = ~~1590.68\text{J}~~ - 1590.68\text{J}$

$Q_{\text{calorimeter}} = 7616.12\text{J}$

Equation 6

$HC_{\text{calorimeter}} = \frac{Q_{\text{calorimeter}}}{\Delta T_{\text{calorimeter}}} = \frac{1590.68}{22.0} = ~~72.3\text{J}^{\circ}\text{C}~~ 72.3\text{J}^{\circ}\text{C}$

Figure 1 – Results and calculations from experiment 1.

In the first experiment, the heat capacity of the calorimeter (two Styrofoam cups) was determined by mixing equal masses (50g) of hot water (60°C) and cold water (23.6°C) and measuring the maximum equilibrium temperature (45.6°C). Then by working out the heat

gained by the cold water (+22.0°C) and the heat lost from the hot water (-14.4°C), the remaining heat unaccounted for was due to the calorimeter. $Q_{\text{calorimeter}}$ is found by using equations 1 and 6 as shown above. This then enables us to use equation 7 and work out the heat capacity of the calorimeter (72.3J/°C), shown above. This value is important because it allows more accurate energy measurements in the experiments that follow. It makes sure that the heat absorbed by the calorimeter itself is accounted for. *negative value not discussed*

Experiment 2 - Measure the specific heat capacity of a metal ($c_{p \text{ metal}}$).

The results and calculations from the second experiment can be seen below in Figure 2.

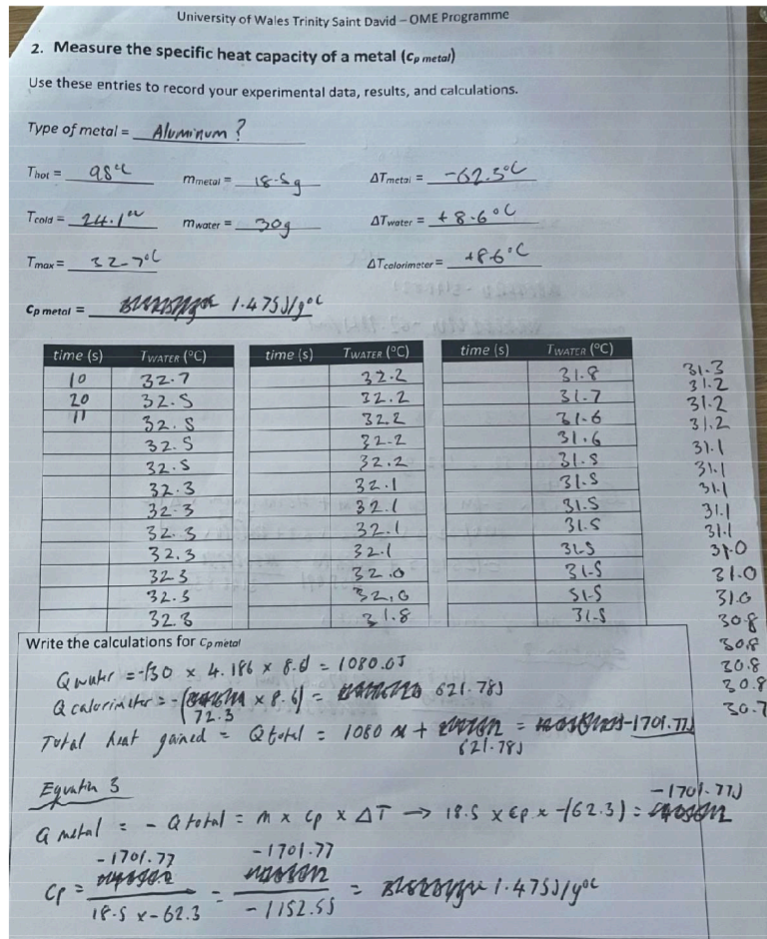


Figure 2 – Results and calculations from experiment 2.

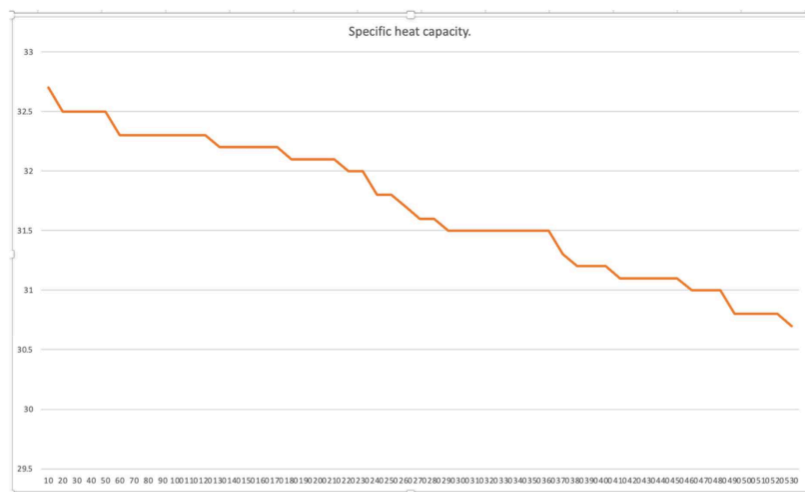


Figure 3 – Graph showing heat transfer from Experiment 2

In the second experiment, an 18-gram metal sample was heated to 95°C and added to 30g of 24.1°C water inside the calorimeter. The temperature change was recorded every 10 seconds until the water had decreased by 2°C from the initial reading. A graph of the heat transfer can be seen in figure 3 above. The results gave us a T_{max} of 32.7°C and took 530 seconds to cool by 2°C. Using the heat gained by the water and calorimeter, plus the temperature change of the metal, equation 3 was used to work out the specific heat capacity of the metal sample (1.48J/g°C). After comparing the specific heat capacity of the sample metal to other metals [2], the value was too high for any typical metal. The sample metal was most likely Aluminium as this has the highest heat capacity of the common metals. The error of the experiment was most likely due to inaccurate measurements of mass or temperature (human error), heat lost to the environment or incorrect assumption of equilibrium temperature. Determining the specific heat capacity of a material is very useful in material science, it reveals how well a material can store and transfer heat. Important in applications that need to thermal manage. the error is due to incorrect HC

Experiment 3 - Measure the molar heat of reaction of HCl with NaOH (q_{reaction}).

The results and calculations from the third experiment can be seen below in Figure 3.

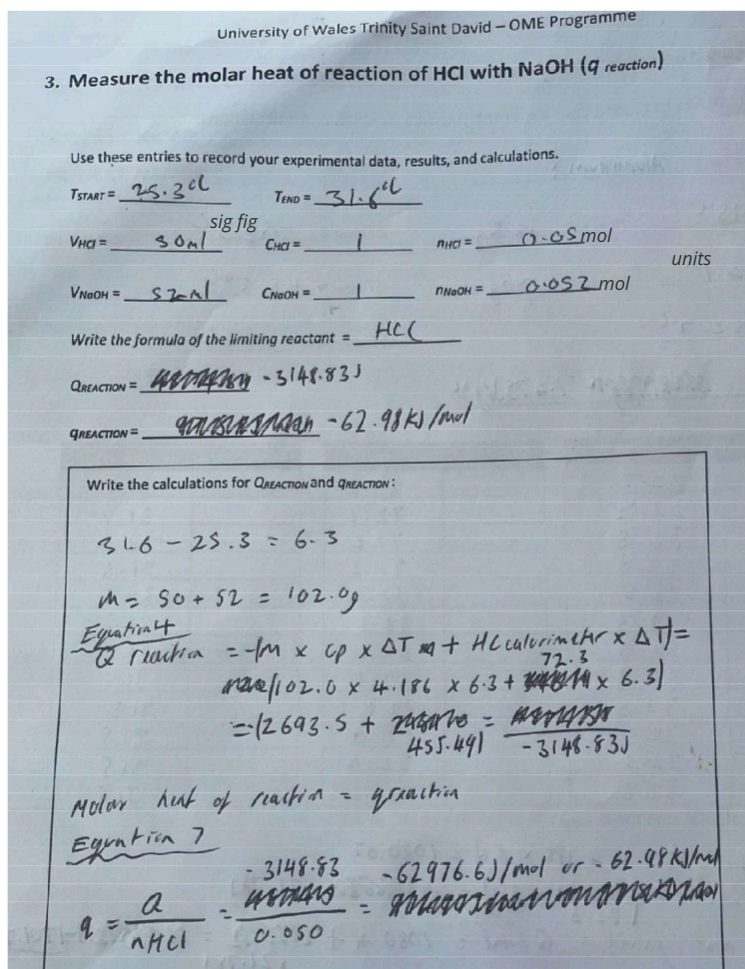


Figure 3 – Results and calculations from experiment 3.

In the third experiment, a neutralising reaction between HCl and NaOH was performed in the calorimeter. 50mL of 1 mole HCl was mixed with 52mL of 1 mole NaOH, both solutions were the same temperature of 25.3°C. The solutions were mixed and the temperature increased to a max of 31.6°C. This was then used to calculate the total energy released by the reaction by using equation 4 (-3148.83J), shown above. Then the molar heat of the

limiting reactant (HCl) was worked out using equation 7 (-62.98 kJ/mol), shown above. This value indicated how much energy is released during the neutralisation of 1 mole of HCl. This value is important when using processes that involve exothermic reactions, ensuring safe use of materials and chemicals.

Discussion.

The results from all three calorimetry experiments provide key understanding of heat transfer, specific heat and energy transfer in chemical reactions. In experiment 1, the heat capacity of the calorimeter was worked out to be $72.3\text{ J/}^\circ\text{C}$, this value represents how much heat the calorimeter absorbs during an experiment. This is essential because it allows us to accurately calculate the energy changes in the following 2 experiments. In experiment two, the specific heat of a sample metal was found to be $1.475\text{ J/g}^\circ\text{C}$, which suggests there was an error made in the experiment as this doesn't link accurately to any typical metals specific heat, however it was most likely aluminium [2]. By working out the specific heat of a material it allows for correct material application. For example, copper has a very low specific heat, meaning that the heat can be lost and transferred very quickly throughout it. Meaning it makes perfect material for wire and water pipes [3]. In experiment 3, the neutralisation reaction between HCl and NaOH released -3148.83 J of energy, and the molar heat of reaction was calculated to be 62.98 kJ/mol .

The 3 calorimetry experiments can all be linked to OME. In OME the understanding of heat transfer and energy release is crucial when designing and handling explosives and propellants. The heat capacity of materials, as measured in experiment 2, is vital for predicting how casings, liners or other components will react with rapid temperature changes during detonation and combustion [4]. In experiment 3, measuring the enthalpy of a neutralisation reaction simulates the kind of exothermic reactions that happens when mixing energetic materials. It is key to know how much energy is released during a reaction as it will help assess the power, stability and safety of the explosive material.

There are several limitations and potential sources of error for all three experiments. The main issue being heat loss to the surroundings. Even with the use of the Styrofoam calorimeter and the use of the lid, it isn't perfectly sealed, heat will still be lost. For example, in experiment 2, heat could have been lost when transferring the metal sample into the calorimeter. Also, the use of the tongs would have allowed for heat transfer to the tongs themselves. Another big limitation is human error. This could be from taking inaccurate readings of temperatures, volume measurements and even time. This is a hard limitation to overcome but is highly mitigated through practice and having multiple people carrying out the same experiment.

Conclusions.

In conclusion, the results from all three experiments support the initial hypotheses. The experiments successfully determined the heat capacity of the calorimeter ($72.3\text{ J/}^{\circ}\text{C}$), the specific heat capacity of the sample metal ($1.475\text{ J/g}^{\circ}\text{C}$), and the molar heat of neutralisation for HCl and NaOH (-62.98 kJ/mol). However, the results are fairly inaccurate due to the specific heat of the sample metal not being close to any typical metals specific heat. Overall calorimetry is an accurate form of experiment to work out specific heat, energy release and molar heat of a reaction. In the future, measurements should be double checked to confirm their validity.

For future research, to increase the accuracy of the experiments, more advanced insulation in the calorimeter could be used as well as using a digital thermometer to minimise heat loss and improve precision. For future research it could also be useful to investigate how temperature and energy release changes under different atmospheric conditions. For example, humidity and pressure. This will provide more realistic operational environments for different explosives.

References

- [1] M. UWTSd, "Log in to the site | Home," *Uwtsd.ac.uk*, 2025, *not a reference*
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- [2] Engineers Edge, "Specific Heat Capacity of Metals Table Chart," *Engineersedge.com*, Jan. 11, 2015.
https://www.engineersedge.com/materials/specific_heat_capacity_of_metals_13259.htm
- [3] AACT, "Classroom Resources | Dramatic Demonstration of Thermal Conductivity and Specific Heat Capacity," AACT. <https://teachchemistry.org/classroom-resources/dramatic-demonstration-of-thermal-conductivity>
- [4] R. L. Shoemaker, J. A. Stark, L. G. Koshigoe, and R. E. Taylor, "Thermophysical Properties of Propellants," *Springer eBooks*, pp. 199–211, Jan. 1985, doi: https://doi.org/10.1007/978-1-4684-4916-7_22.

Appendix

Appendix 1 – Materials and equipment.

For the calorimeter:

- Two Styrofoam coffee cups (one inside the other).
- Lid
- Thermometer
- Stirring rod
- Stand and clamp

An example can be seen in Figure 4 below.



Figure 4. Apparatus used to perform all calorimetric measurements.

To complete the experiments, you also need:

- Bunsen burner with stand
- Beaker for water bath
- Measuring beaker
- Metal sample
- Tongs
- Stop watch
- 1 M NaOH
- 1 M HCl

Appendix 2 – Procedures.

Experiment 1 - Measure the value of the heat capacity of the calorimeter.

Procedure to measure $HC_{\text{calorimeter}}$:

1. Add 50.0 mL of water to the Styrofoam coffee cups, and close with a lid. Add the thermometer and stirring rod to set up your calorimeter.
2. Take 50.0 mL of water in a separate beaker and heat to about 80 °C. Close the gas and wait till the temperature reaches 60 °C. When the "hot water" is ready, record its temperature as T_{hot} .
3. Measure the temperature of the water in the calorimeter, and record it as T_{cold} .
4. Add the hot water to the water in the calorimeter, and mix thoroughly, while watching the thermometer. Record the maximum equilibrium temperature of the mixture, record it as T_{max} .
5. Calculate the heat capacity of the calorimeter, $HC_{calorimeter}$, using Eq. 1, Eq.5, and Eq.6:
 - $-Q_{hot-water} = Q_{cold-water} + Q_{calorimeter}$ (Eq.5)
 - $Q_{calorimeter} = HC_{calorimeter} \times \Delta T_{calorimeter}$ (Eq.6)

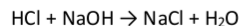
Experiment 2 - Measure the specific heat capacity of a metal ($C_{p\ metal}$).

Procedure to measure $C_{p\ metal}$:

1. Using the same apparatus as experiment 1, obtain a piece of the metal sample. Weigh the metal and record its mass as m_{metal} .
2. Set up a water bath, heat the water until boiling, and then carefully put your metal into it. Keep boiling for another 5 minutes, to allow the metal to reach the same temperature as the water. Try to avoid heating the metal directly! To reduce the effect of direct heating, close the gas after 5 min and wait 2 minutes for the temperature of boiling water and piece of metal to equilibrate.
3. While this is being done, measure 30.0 mL of water and add it to the calorimeter. Measure the temperature of the water in the calorimeter, as done previously, and record it as T_{cold} .
4. Once the metal has reached "thermal equilibrium" with the boiling water, measure and record the temperature of the hot water as T_{hot} , and quickly add the metal to the water in the calorimeter using the tongs.
5. Stir the water and record the temperature every 10 seconds, filling in the datasheet provided at the end of this script with the entries (*time*, T_{water}). The temperature will increase at the start. Continue until the temperature of the water has reached a maximum and then cooled down by about 2 °C. Record the maximum temperature reached by the water as T_{max} .
6. Calculate $C_{p\ metal}$ the specific heat of the metal using Eq.3 and the value of heat capacity of the calorimeter found previously. Assume that calorimeter and water are in thermal equilibrium, $C_{p\ water} = 4.186\ J/(g^{\circ}C)$.

Experiment 3 - Measure the molar heat of reaction of HCl with NaOH.

Procedure to measure q_{reaction} :



1. Using the same apparatus as experiment 1 and 2, place 52.0 mL of 1.0 M NaOH into the calorimeter and pour 50.0 mL of 1.0 M HCl into a beaker.
2. Place the two side-by-side until they attain the same temperature. Record this value as T_{start} .
3. Add the HCl quickly to the calorimeter and record the temperature when it reaches a maximum as T_{end} .
4. Calculate Q_{reaction} , the heat of reaction, using Eq.4 and the heat capacity of the calorimeter found previously. Again, assume that calorimeter and water are in thermal equilibrium, $c_{\text{p water}} = 4.186 \text{ J/(g}^\circ\text{C)}$.
5. Calculate q_{reaction} , the molar heat of reaction, as the heat of reaction per mole of the limiting reactant, i.e.:

$$q_{\text{reaction}} = \frac{Q_{\text{reaction}}}{n_{\text{reactant}}}$$

where the number of moles of reactant is: $n_{\text{reactant}} = V_{\text{reactant}} \times C_{\text{reactant}}$, where V_{reactant} is the volume of LIMITING reactant and C_{reactant} is the concentration of LIMITING reactant.

Lab Report - Calorimetry

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

66/100

Engagement with Literature Skills 10/15

Four references are cited, mostly websites and one textbook, with limited relevance to experimental results. Ref 1 is not a viable source. IEEE style is applied inconsistently. Literature is mainly used for background and OME context, not for critical evaluation or result comparison.

Feedback: Apply IEEE correctly and use literature more actively to support your calculations and discuss deviations from expected values.

Knowledge and Understanding Skills 13/20

The aim and hypotheses are clear and relevant, and the report defines experimental variables well. Equations are correctly used, but specific heat of aluminium ($1.48 \text{ J/g}\cdot^\circ\text{C}$) is overestimated. Calculation steps are shown, yet no check or discussion of why the value deviates so far from literature is provided. Units and equations are otherwise handled correctly.

Feedback: Clearly analyse abnormal results and compare calculated values to literature to demonstrate full understanding.

Cognitive and Intellectual Skills 17/25

The report identifies experimental errors (heat loss, tongs absorbing heat) and briefly mentions how they affect accuracy. The relevance to OME is clearly explained, linking calorimetry to material behaviour under explosive conditions. However, analysis remains mostly descriptive, with no comparison to literature values for heat of reaction or specific heat.

Feedback: Strengthen your evaluation by comparing all experimental results with accepted values.

Practical Application Skills 16/25

The experimental method is thorough and data collection is systematic. Calculations are correct, but there are errors in units and significant figures. Heat of reaction and calorimeter capacity are reasonable, but specific heat of metal is inaccurate and not questioned.

Feedback: Check your results critically, explain discrepancies,

Transferable/Professional Skills 10/15

The report is well-organised with a table of contents, headings, and structured appendices. Writing is mostly scientific, though first-person phrases occasionally appear, and one figure is included but not fully explained. Data presentation is clear, but narrative connection to visuals could be stronger.

Feedback: Maintain structure and tone but fully integrate all visuals and avoid first-person writing.

PAGE 1

PAGE 2

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PAGE 6

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Comment 5

such statement should be supported by literature

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