

Determination of the Specific Heat Capacity of Aluminium via Calorimetry

By Conor Nolan, completed 02/05/2025

University of Wales Trinity St. David

Ordnance Munitions and Explosives Engineering Degree Apprenticeship

BEng

2025-2029

Contents

List of abbreviations:.....	2
Introduction	2
Results	3
Discussion.....	4
Conclusion.....	5
References.....	5
Appendix	6

List of abbreviations:

Abbreviation	Definition
H ₂ O	Water
C	Specific heat capacity
Q	Heat energy
J	Joule
g	Gram
K	Kelvin
T	Temperature
m	Mass
s	Seconds
Al	Aluminium
ΔT	Change in temperature
OME	Ordnance Munitions and Explosives
TBX	Thermobaric Explosive

Introduction

Calorimetry describes the method of measuring the change in energy of a system. This can be done by measuring how the temperature (T) of a closed system changed after undergoing a chemical reaction. Depending on the 'knowns' and 'unknowns' of the system, various quantities can be derived, such as the amount of energy it takes to raise a certain mass (m) of a substance by a certain increment of temperature. This quantity is known as the specific heat capacity (C) and is typically given in Joules per gram per Kelvin ($\text{Jg}^{-1}\text{K}^{-1}$). If the specific heat capacity of the system (experimentally this system would be a calorimeter), heat capacities of substances contained within the system can be determined. In this experiment, it can be hypothesized that if hot water (H₂O) is added to a calorimeter containing cold water, the specific heat capacity of the calorimeter can be obtained. From this a secondary hypothesis can be surmised: any other substance added to the calorimeter could be analysed to determine its specific heat capacity. In this experiment, the dependent variable is the change

in temperature of the water in the calorimeter, and the independent variables are the temperature of the substance added, the mass of the substance added, and the composition of the substance added. Additionally, the time taken for the temperature to change can be considered a dependent variable.

Given the relationship between temperature change (ΔT) and heat energy (Q) [eq.1], the heat energy of the hot and cold water can be obtained given a known mass.

$$(1) Q = mC\Delta T$$

This can be used to calculate the heat energy attributed to the calorimeter [eq.2], from which the specific heat capacity of the calorimeter can be derived [eq.3].

$$(2) Q_{cal} = Q_{hot} + Q_{cold}$$

$$(3) C_{cal} = \frac{Q_{cal}}{m\Delta T_{cal}}$$

From this specific heat capacity, the specific heat capacity of a piece of aluminium (Al) could be obtained by working in reverse and using [eq.3] with the quantities associated with aluminium instead of the calorimeter.

Results

The experimental quantities were measured for the calorimeter with both the addition of hot water and hot aluminium (into different samples of cold water), and experimental quantities were derived according to the methods detailed above. These quantities were tabulated in [table 1].

	Hot Water	Cold Water	Calorimeter	Max	Aluminium	Water (Al)	Calorimeter (Al)	Max (Al)
Mass (m / g)	50.0	50.0	100.0	n/a	18.6	50.0	68.6	n/a
Temperature (T / K)	331.0	295.1	295.1	318.2	361.0	295.0	295.0	303.2
Change in Temperature (ΔT / K)	-12.8	23.1	23.1	n/a	-57.8	8.2	8.2	n/a
Heat energy (Q / J)	-2677.8	4832.5	2154.8	n/a	-1190.7	1715.4	524.7	n/a
Specific heat capacity (C / Jg ⁻¹ K ⁻¹)	4.184	4.184	0.933	n/a	1.1075672	4.184	0.933	n/a

Table 1: All experimentally observed and derived values

Additionally, the time taken for the aluminium to reach its maximum temperature was plotted [fig.1].

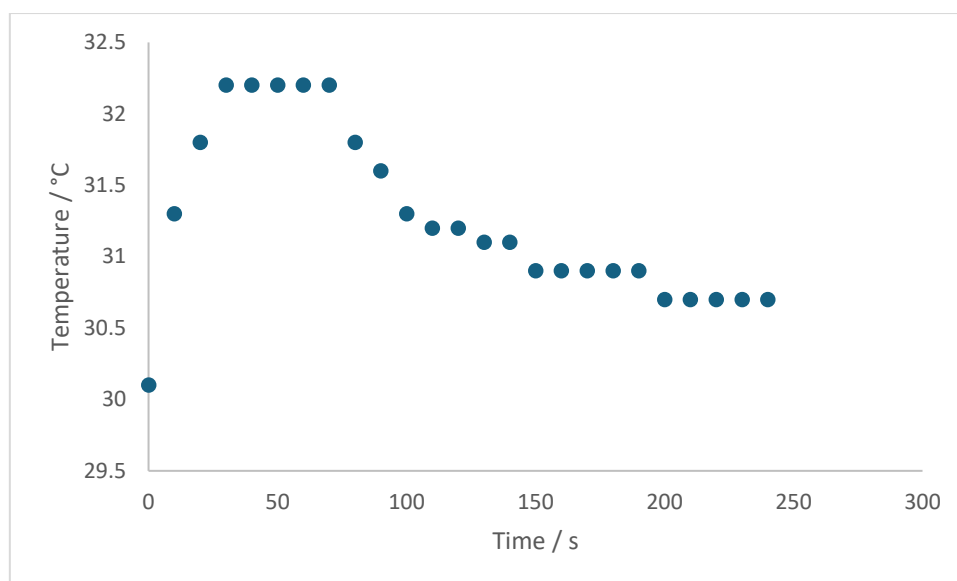


Figure 1: Time to reach temperature equilibrium plotted against temperature

Discussion

Accuracy and Error

The generally accepted specific heat capacity of Aluminium is approximately $0.90 \text{ Jg}^{-1}\text{K}^{-1}$ which is somewhat different from the experimentally obtained $1.11 \text{ Jg}^{-1}\text{K}^{-1}$. The experimentally obtained value is in fact 23.3% higher than the expected value. There are several reasons why this might be the case.

The first and most prominent is that the material of the calorimeter was prone to being punctured by the temperature probe which lead to potential leaks of water from the system. Even a slight loss of water mass would lower the specific heat capacity significantly, so this may explain why the experimental value is so much higher, as it is being assumed that the water mass is 50.0 g. Additionally, the thermal isolation of the calorimeter was likely not complete or consistent throughout each experiment, allowing energy external to the system to affect the outcome. Use of a bomb calorimeter would solve both issues as such instruments have been designed to mitigate or eliminate these problems.

Equipment faults are also a possibility as there was only one temperature probe used to measure any given volume of water. This may have acted as a single point of failure and more probes should be used in future to corroborate the values given.

One final source of error would be the physical measurements taken, such as the masses of the aluminium and water. This error would have easily propagated through the calculated values to cause large uncertainty in the outcomes. A more thorough investigation into the associated errors of each measuring instrument should be done in future to account for this uncertainty.

Ordnance, Munitions and Explosives (OME) applications

An obvious utility of calorimetry in the OME industry is for the basic study and analysis of explosives and their reactions. While simply finding the heat of detonation of an explosive might seem like the most likely application, Bunyan et al. [1] used calorimetry techniques to investigate the behaviour of energetic compounds under various storage conditions to gain insight into the failure modes of stored compounds. Behaviour under varying temperature was studied and wisdom was gained in relation to the processes which lead to failure, some of which were often overlooked.

Determining the heat of combustion of a HE compound carries additional utility. Once the enthalpy is known, the effects of additives to explosives can be determined by finding the difference between the known heat of combustion of the HE and the experimental value obtained from the mixture. An example of this can be seen in the work of Kiciński & Trzciński [2], wherein the effects of different particle sizes of aluminium powder were investigated via detonation in a calorimetric bomb.

Calorimetry is particularly important for the testing of thermobaric explosives (TBXs) performed by Nammo Defense Systems Inc. [3]. This is because it is essential for a TBX to contain a compound with a high heat of combustion such that the temperature of the fireball after the initial detonation is high enough to generate an extremely high blast pressure. Since a specific enthalpy of combustion is so vital to the effectiveness of a TBX, calorimetry must be used to determine this quantity.

Another application of calorimetry in the OME industry is for the detection and identification of explosives using known enthalpy data. For example, Liu et al. [4] designed a miniature calorimeter system to move past the traditional limitations of size and long timescale typically associated with it. This allowed for a portable in-field energetic compound characterisation device utilising calorimetry.

Conclusion

In conclusion, the specific heat capacities of the calorimeter and the aluminium sample were obtained with the latter being approximately 23.3% higher than the known value. This suggests that while the hypothesis was correct that this method for calorimetry could be used to calculate these values, a more appropriate set up in future work might be a bomb calorimeter as it would carry fewer sources of error.

References

[1] P. Bunyan, C. Baker, and N. Turner, "Application of heat conduction calorimetry to high explosives," *Thermochimica Acta*, vol. 401, no. 1, pp. 9–16, May 2003, doi: [https://doi.org/10.1016/s0040-6031\(03\)00053-4](https://doi.org/10.1016/s0040-6031(03)00053-4).

- [2] W. Kiciński and W. A. Trzciński, "Calorimetry studies of explosion heat of non-ideal explosives," *Journal of Thermal Analysis and Calorimetry*, vol. 96, no. 2, pp. 623–630, Apr. 2009, doi: <https://doi.org/10.1007/s10973-008-9100-5>.
- [3] A. R. Davis, S. D. Hall, and G. D. Knowlton, "Detonation Calorimeter: Application and Operation for Thermobaric Explosive Characterization and Evaluation.," in *North American Thermal Analysis Society*, Aug. 2008, p. 417. Accessed: May 02, 2025. [Online]. Available: https://www.academia.edu/8202938/Detonation_Calorimeter_Application_and_Operation_for_Thermobaric_Explosive_Characterization_and_Evaluation
- [4] Y.-S. Liu, V. M. Ugaz, S. W. North, W. J. Rogers, and S. M. Mannan, "Development of a miniature calorimeter for identification and detection of explosives and other energetic compounds," *Journal of Hazardous Materials*, vol. 142, no. 3, pp. 662–668, Apr. 2007, doi: <https://doi.org/10.1016/j.jhazmat.2006.08.050>.

Appendix

Method:

1. First, a calorimeter was filled with 50.0 g of cold water.
2. Next 50.0 g water was heated over flame.
3. The temperature of each was recorded before combining the two in the calorimeter.
4. The temperature of the calorimeter was monitored, and the maximum temperature was recorded.
5. Next the calorimeter was filled again with 50.0 g of cold water.
6. A cube of aluminium weighing 18.6 g was heated in water to reach 90.0 °C.
7. The temperature of each was recorded before combining the two in the calorimeter.
8. The temperature of the calorimeter was monitored, and the maximum temperature as well as the time taken to reach this temperature was recorded, alongside a temperature at each time interval.

Equipment:

- Calorimeter consisting of two polystyrene cups and a cork lid
- Digital temperature probe
- Bunsen Burner, heat mat and tripod
- Glass beakers
- Volumetric cylinders

Copies of worksheet:

DATA SHEET to RECORD OBSERVATIONS, CALCULATIONS and RESULTS

STUDENT'S NAME: Callum

PARTNERS' NAMES: Conor

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.

$T_{\text{hot}} = \underline{60}$ $m_{\text{hot water}} = \underline{50}$ $\Delta T_{\text{hot water}} = \underline{60 - 47.2} = \underline{12.8}$

$T_{\text{cold}} = \underline{24.1}$ $m_{\text{cold water}} = \underline{50}$ $\Delta T_{\text{cold water}} = \underline{23.1}$

$T_{\text{max}} = \underline{47.2}$ $\Delta T_{\text{calorimeter}} = \underline{23.1}$

$Q_{\text{cold water}} = \underline{4834.83}$ $Q_{\text{hot water}} = \underline{-2532.53}$ $Q_{\text{calorimeter}} = \underline{-(Q_H + Q_C)}$

$HC_{\text{calorimeter}} = \underline{\cancel{2532.53} - 99.666}$

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

$Q_{\text{cold}} = (50)(c)(\cancel{24.1}) \rightarrow 4.186 \text{ J/g}$

$Q_{\text{hot}} = (50)(c)(-12.8) \rightarrow 4834.83$
 $\rightarrow -2532.53$

$Q_{\text{cal}} = -(Q_{\text{cold}} + Q_{\text{hot}})$

$HC_{\text{cal}} =$

$cm_{\text{cal}} = \frac{Q}{\Delta T}$

$Q = mc\Delta T$

$c = \frac{Q}{m\Delta T}$

$cm_{\text{cal}} = \frac{-(Q_c + Q_H)}{\Delta T}$

$\cancel{2532.53}$
 $\underline{23.1}$

$\underline{-(-2532.53 + 4834.83)} = \underline{-99.666}$
 $\underline{23.1}$

2. Measure the specific heat capacity of a metal ($c_p \text{ metal}$)

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

$$\Delta T_{\text{calorimeter}} =$$

0.82631

[illegible]

Write the calculations for $c_{p \text{ metal}}$

$$C_{pm} = - \frac{(M_w C_{pw} T_w + H C_c T_c)}{M_m T_m}$$

$$= - \left(\begin{matrix} 50 \\ \cancel{140} \end{matrix} \right) (4.18J) \left(\begin{matrix} \cancel{12} \\ \cancel{12} \\ 8.2 \end{matrix} \right) + \left(\begin{matrix} -99.6 \\ \cancel{889.6} \end{matrix} \right) \left(\begin{matrix} 8.2 \\ \cancel{28} \end{matrix} \right)$$

~~$$64 \times (837.2 - 318.96) \times (18.6)(67.8)$$~~

~~$$\frac{80.9}{2 \times} = 8037.2 - 318.96$$~~