

Experiment 4

Specific Heat of Solids

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Synopsis

In this experiment we try to measure specific heat capacity of solids.

I. THEORY AND PROCEDURE

A. Apparatus

- Calorimeter
- Shots of material(s)
- Weighing balance
- Steam chamber
- Steam generator
- Electric heater
- Thermometer

B. Theory

The change in temperature ΔT of a material when supplied with a fixed amount of heat ΔQ depends on the type of material and is inversely proportional to the mass m of the material. The material dependence is given the quantity called the specific heat c of the substance. The interdependence of these quantities is summarised by the equation

$$\Delta Q = cm\Delta T$$

The amount of heat required to raise the temperature of a unit mass of a substance by 1°C is called the specific heat of the substance. The SI unit of specific heat is $[\text{J kg}^{-1} \text{K}^{-1}]$. The specific heat of water is among the highest of all substances. Historically, the specific heat of water is arbitrarily set at $1\text{cal g}^{-1} \text{C}^{-1}$. The equivalent SI value is $4184 \text{J kg}^{-1} \text{K}^{-1}$. A related quantity is the molar specific heat c_m , which is the specific heat for 1 mol of a substance.

If c_s is the heat capacity of shots, $\Delta T_s \equiv T_f - T_s$ is the change in temperature of shots and m_s is the mass of shots, then the heat lost by the shots is

$$\Delta Q_s = c_s m_s \Delta T_s$$

Similarly, heat gained by the water is

$$\Delta Q_w = c_w m_w \Delta T_w$$

with c_w , m_w , T_w and ΔT_w have their proper meanings.

Now, if there is no heat absorbed by the calorimeter, then $\Delta Q_w = \Delta Q_s$, but that is not the case. To make the equation equal, we replace m_w by $m_w + m_f$ where m_f is the equivalent water mass of the calorimeter. Hence we get

$$c_s = \frac{c_w(m_w + m_f)\Delta T_w}{m_s\Delta T_s} \quad (1)$$

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C. Procedure

First we measure the mass of the shots of each material. Then we place shots of material into the steam chamber and close them using a cork with hole through which we put a thermometer to measure the T_s . We raise the temperature of steam generator using electric heater. When the temperature reaches equilibrium, we turn the chamber over and quickly pour all the material into a calorimeter with measured mass and temperature of water. We stir it using a different thermometer and measure the equilibrium temperature T_f . We repeat this same procedure for different materials and then to measure m_f of the calorimeter, we put water of higher temperature $\theta_{i1} \approx 60^\circ\text{C}$ ¹ into room temperature water inside calorimeter and measuring the equilibrium temperature θ_f ; using the same principle:

$$m_f = \frac{m_1\Delta\theta_1 - m_2\Delta\theta_2}{\Delta\theta_2} \quad (2)$$

II. OBSERVATIONS

Material	m_s (g)	m_w (g)	T_w ($^\circ\text{C}$)	T_f ($^\circ\text{C}$)
Copper	100.1	90.0	23.5	30.1
Acrylic	44.5	45.0	24.9	35.0
Copper ^a	183.5	52.0	23.0	39.1
Ceramic	31.4	69.0	23.9	29.3

^a Took the copper out earlier than equilibrium temperature

TABLE I. With calorimeter of type-1, data was taken on 23 Jan 2025

Data for Type 1:

$$\begin{aligned} m_2 &= 62.2 \text{ g} \\ T_2 &= 20.7 \text{ }^\circ\text{C} \\ m_1 &= 41.5 \text{ g} \\ T_1 &= 56.6 \text{ }^\circ\text{C} \\ T_f &= 33.8 \text{ }^\circ\text{C} \end{aligned}$$

Material	m_s (g)	m_w (g)	T_s ($^\circ\text{C}$)	T_w ($^\circ\text{C}$)	T_f ($^\circ\text{C}$)
Copper	55.0	176.4	—	26.1	30.0
Copper ^a	171.1	154.0	90–91	25.1	31.2
Acrylic	52.3	144.4	87–88	25.1	29.3
Ceramic	39.6	132.4	80	24.8	28.6
Copper	180.0	180.0	—	22.3	28.5

^a Spillage while pouring water

TABLE II. With calorimeter of type-2, data taken on 29 Jan 2025

Data for Type 2:

$$\begin{aligned} m_2 &= 129.7 \text{ g} \\ T_2 &= 19.2 \text{ }^\circ\text{C} \\ m_1 &= 87.5 \text{ g} \\ T_1 &= 56.6 \text{ }^\circ\text{C} \\ T_f &= 33.8 \text{ }^\circ\text{C} \end{aligned}$$

III. UNCERTAINTIES AND SOURCES OF ERROR

A. Uncertainties from precision of instrument

- Weight Measurements: All weight values have an uncertainty of $\Delta m = \pm 0.05 \text{ g}$ due to instrument resolution.
- Temperature Measurements: Temperature values have an uncertainty of $\Delta T = \pm 0.005 \text{ K}$ due to instrument resolution.

¹ this is to reduce loss in evaporation and other convective losses

- Mercury Thermometer: The thermometer used to measure T_s has an uncertainty of $\Delta T_m = \pm 0.5$ K

B. Systematic Errors and Precautions

Potential systematic errors included spillage during transfers, residual material retention in containers, unintended material escape from the calorimeter, heat dissipation through radiation (according to Newton's law of cooling), assumptions of instrument calibration accuracy, post-experiment temperature inconsistencies in the calorimeter due to inadequate calibration, and uneven heating.

Precautionary measures included preheating reused materials to eliminate residual moisture, repeating tests with procedural anomalies to replace outliers, and maintaining calorimeter thermal stability by refilling them with tap water after each run to standardize initial conditions.

IV. CALCULATION AND ERROR ANALYSIS

From Table-I and Table-II we discard the two copper data points which had some error when performing before doing the calculation.

A. Error Propagation

The heat capacity of copper is given by Equation-1. The uncertainty in c_s is given by the equation:

$$\frac{\Delta c_s}{c_s} = \sqrt{(\partial m_w \Delta m)^2 + (\partial m_f \Delta m)^2 + (\partial m_s \Delta m)^2 + (\partial T_w \Delta T)^2 + (\partial T_f \Delta T)^2 + (\partial T_s \Delta T_m)^2}$$

Where these partials are calculated by

$$\begin{aligned} \partial m_w &= \frac{c_w \Delta T_w}{m_s \Delta T_s} & \partial T_w &= \frac{c_w (m_w + m_s)}{m_s} \Delta T_s \\ \partial m_s &= \frac{c_w (m_w + m_f) \Delta T_w}{m_s^2 (t_s - t_f)} & \partial T_f &= \frac{c_w (m_w + m_f) \Delta T_w}{m_s \Delta T_w^2} \\ \partial m_f &= \frac{c_w \Delta T_w}{m_s \Delta T_s} & \partial T_s &= \frac{c_w (m_w + m_f) \Delta T_w}{m_s \Delta T_s^2} \end{aligned}$$

B. Calculation

For the data points which have not initial temperature, we take the same value corresponding to them in Table-II. We discard the two data points which have some kind of spillage or error from our calculation. Since there is only one observation to calculate the water equivalent of the container, and seeing that the error in water equivalent doesn't affect the error that much, we shall take 20% error for both values in calculation. Calculating errors described above and, from equations described in theory we get:²

² Refer to ? for calculations

Material	m_s (g)	T_s ($^{\circ}\text{C}$)	m_w (g)	T_w ($^{\circ}\text{C}$)	T_f ($^{\circ}\text{C}$)	m_f (g)	c_s (J/g/ $^{\circ}\text{C}$)	Δc_s (J/g/ $^{\circ}\text{C}$)
Copper	55.0	90.5	176.4	26.1	30.0	10.0	0.914	0.021
Copper	100.1	90.5	90.0	23.5	30.1	5.3	0.435	0.011
Copper	180.0	90.5	180.0	22.3	28.5	5.3	0.431	0.008
Acrylic	52.3	87.5	144.4	25.1	29.3	10.0	0.891	0.021
Acrylic	44.5	87.5	45.0	24.9	35.0	5.3	0.910	0.038
Ceramic	39.6	80.0	132.4	24.8	28.6	10.0	1.112	0.029
Ceramic	31.4	80.0	69.0	23.9	29.3	5.3	1.054	0.034

TABLE III. Experimental data and calculated heat capacities.

V. RESULT

The order of heat capacity we get is:

$$c_{\text{copper}} < c_{\text{ceramic}} < c_{\text{acrylic}}$$

with values of heat capacities calculated by weighted mean, in $\text{J g}^{-1} \text{ } ^{\circ}\text{C}^{-1}$ are:

$c_{\text{copper}} = 0.432 \pm 0.006$ $c_{\text{ceramic}} = 0.895 \pm 0.018$ $c_{\text{acrylic}} = 1.088 \pm 0.022$

Appendix A: Theoretical Values

The theoretical values are in same units are³:

$$\begin{aligned} c_{\text{copper}} &\approx 0.385 \\ c_{\text{ceramic}} &\approx 0.8 - 1.1 \\ c_{\text{acrylic}} &\approx 1.46 - 2.16 \end{aligned}$$

REFERENCES

- “Properties of acrylic for cast,” matweb.com/search/datasheet.aspx?bassnum=01303&ckck=1, accessed: 2025-02-11.
- “Specific heat capacity of ceramic fiber,” ccewool.com/what-is-the-specific-heat-capacity-of-ceramic-fiber/, accessed: 2025-02-11.

³ ?, acr, cer