MEASUREMENT OF SPECIFIC HEAT

Objective: To determine the specific heat of a solid sample.

Apparatus: Calorimeter, stirrer, centigrade thermometer, boiler with heater, balance, metal sample, water.

Theory:

Heat is defined as the flow of thermal energy, and as such, has S.I. units of Joules. A quantity of heat can not be measured directly; a measurement for the amount of thermal energy in transit (heat) can be made by determining its effects on matter. When a substance gains heat, its total internal energy is increased, the total internal energy of a substance being defined as the sum of the potential and kinetic energies of all the molecules in the substance. Temperature is a measure of the average kinetic energy of the molecules in a substance, and the two are directly proportional. The greater the average kinetic energy of the molecules (i.e. the faster the molecules move), the greater the temperature of the substance. Thus, heat transferred to a substance increases its total internal energy, hence the average kinetic energy of its molecules, hence its temperature. The temperature change in an object is therefore a measure of the heat flow to or from that object. The amount of heat, Q, is directly proportional to the temperature change in an object (ΔT), where units of temperature can be °C.

When two different substances are supplied with the same amount of heat, their temperatures may change by a significantly different amount. This implies that the heat flow and temperature change in an object are related by some proportionality constant that is unique to the specific substance. This proportionality constant is the specific heat, c, of a substance, and is measured in units of J/kg°C.

$$Q = mc\Delta T \qquad \textbf{(eq. 1)}$$

The second law of thermodynamics states that when two objects of different temperatures are brought into contact, heat flows from the warmer object to the cooler object. If these objects remain in contact for enough time, they will reach equilibrium at the same final temperature, T_f. The first law of thermodynamics tells us that thermal energy is conserved. In other words, the same amount of heat flows out of the warmer object as flows into the cooler object, or

$$\text{heat lost} = \text{heat gained} \qquad \textbf{(eq. 2)}$$

A calorimeter is simply a container that isolates substances from their environment in order to minimize any heat flow of the surroundings into or out of the system. It allows measurement of the specific heat of a substance (eg. a metal) by equating the heat lost from the metal with the heat gained by another substance in the calorimeter (usually water) and heat gained by the calorimeter itself. Equation 2, as applied to that system, is thus expressed as

$$Q_{metal} = Q_{water} + Q_{calorimeter}$$
$$m_{metal}\, c_{metal}\, (T_h - T_f) = m_{water}\, c_{water}\, (T_f - T_c) + m_{cal}\, c_{cal}\, (T_f - T_c) \qquad \textbf{(eq. 3)}$$

In this experiment, the specific heat of an unknown metal, c_{metal}, will be obtained by mixing a known mass of a hot metal sample (at temperature T_h) with cool water in a calorimeter (at temperature T_c) and observing the final temperatures of the mixture, T_f.

Solving for c_{metal} yields:

$$c_{metal} = \frac{(m_{water}c_{water} + m_{cal}c_{cal})(T_f - T_c)}{m_{metal}(T_h - T_f)} \qquad \textbf{(eq. 4)}$$

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Procedure and Data Analysis:

PART I. Measurement of heat flow.

CAUTION : The metal sample, the inner cup of the boiler, and the calorimeter set must be dry.

1. Put a sample of metal large enough to fill the inner cup of the boiler, up to 35% to 50% of the volume of the cup.
2. Heat the metal sample over boiling water for at least 25 minutes or until the sample is in thermal equilibrium with the steam which is 100 °C at sea level. This is the temperature of the sample, T_h, recorded on your data sheet.

CAUTION : Be sure that there is water in the boiler and that the inner cup of the boiler with the sample is over the surface of water.

3. While the metal sample is heating, weigh the inner calorimeter cup and stirrer with a balance to 0.001 kg. Record the mass on your data sheet as m_{cal}.
4. Put enough water in the inner calorimeter cup to cover the sample when it is added later.
5. Weigh the cup, stirrer, and water. Record the mass on your data sheet as m_1.
6. Measure the temperature of the cool water in the calorimeter cup, T_c, and record this value on your data sheet.
7. Quickly transfer the metal sample to the calorimeter, cover the cup and agitate gently.
8. Once the sample has come into thermal equilibrium with the water, record the final temperature, T_f, on your data sheet.
9. Record the combined weight of the cup, stirrer, water, and metal sample as m_2 on your data sheet.

PART II. Calculation of specific heat capacity and determination of the identity of the metal.

1. Calculate the mass of the water by subtraction: $m_{water} = m_1 - m_{cal}$.
2. Calculate the mass of the metal sample by subtraction: $m_{metal} = m_2 - m_1$.
3. Using equation 4, calculate the metal's specific heat, c_{metal}, given that the specific heat of the calorimeter, c_{cal}, is 900 J/kg°C and the specific heat of water, c_{water}, is 4186 J/kg°C.
4. Using the values for the specific heats of three metals given here, try to identify the metal. (A metal may or may not be positively identified by specific heat alone because of the large number of alloys possible.)

$c^t_{Aluminum}$ = 920 J/kg°C
c^t_{Copper} = 390 J/kg°C
c^t_{Lead} = 130 J/kg°C

5. Once the metal has been identified, calculate the relative percent deviation between your measured value and the accepted value using the equation:

$$\% \text{ error} = \left(\frac{\mathrm{c}_{\mathrm{metal}} - c^t_{metal}}{c^t_{metal}} \right) \times 100\%$$

Discussion Questions:

1. To what three variables are the heat flow for an object proportional? Describe why the heat flow should be proportional to the mass of an object.
2. Discuss three different possible sources of error for this experiment (i.e. do not use measurement uncertainty more than once). For each, was this systematic or random error?
3. We could have instead calculated heat lost from the metal sample, Q_{lost}, for the temperature difference $\Delta T = T_h - T_f$. Presume we had done this experiment five times with different absolute temperature ranges so that we obtained five different values for Q_{lost} and ΔT. How could we have plotted this information on a graph and fit the data in order to find c_{metal}? How would this yield a better determination of the specific heat than the experiment which you performed?

Lab Report Format:

Your lab report for this experiment should contain:

1. Pre-lab (objective, theory, and procedure).
2. Neatly written copy of your experimental data sheet.
3. Sample calculations: For this lab, you need to show your calculations for m_{water}, m_{metal}, c_{metal}, and the % difference from the accepted value for c_{metal}.
4. Results: State your results (in complete sentences) for the determined values for c_{metal}. Make sure all values are properly rounded and have the correct number of significant digits. Report the % difference from the accepted value. Is this value large or small (within 10% error)?
6. Conclusions: Answer the discussion questions above.