Specific Heat of a Solid

Object: To determine the specific heat of lead or aluminum.

Apparatus: Double calorimeter, hypsometer, tripod, Bunsen burner, two thermometers, lead and aluminum pellets, balance, and graduated cylinder.

Foreword

Since heat is a form of energy, any experiment in an isolated system employing the transfer of heat must obey the principle of the conservation of energy. The generalization of the latter principle to include the equivalence of heat and energy is known as The First Law of Thermodynamics.

A method utilizing heat transfer, called the method of mixtures, will be used to determine the specific heat of a metal. Briefly, the experimental procedure involves the following operations. A known mass M_m of metal of unknown specific heat C_m is heated to a temperature T_{m_i} and then dropped into a known mass M_w of water at a temperature T_{w_i}. The mixture is then stirred until a steady equilibrium temperature T_E is reached. By equating the heat energy lost by the sample to that gained by the water, calorimeter cup, thermometer, and stirrer, the specific heat of the metal can be obtained.

Actually, the water is contained in the inner cup of a calorimeter which consists of two brightly polished vessels, one within the other. The outer vessel serves to insulate thermally the contents of the inner one from its surroundings. The mass M_c of the inner cup, the mass M_s of the stirrer employed, and the volume V_T of the thermometer in contact with the water must also be considered since they are part of the "isolated" system undergoing a temperature change. For any temperature change ΔT of a body of mass M, the associated energy change ΔE or heat change ΔQ is

(1) $$\Delta Q = MC\Delta T,$$

where C is the specific heat of the substance.

If the conservation of energy is used, the heat lost by the hot metal will equal the heat gained by the water, calorimeter, stirrer, and thermometer. The heat energy lost or gained by radiation is not negligible, but corrections can be made by having the water temperature initially a few degrees below the room temperature, and by having the final temperature of the calorimeter and contents above the room temperature by the same amount. Thus, heat gained by radiation will approximate that lost.

Since the heat energy lost equals that gained in the isolated system, we may write

(2) Heat lost by metal = Heat gained by (water + calorimeter cup + stirrer + thermometer),

which may be expressed algebraically as

(3) $$M_m C_m (T_{m_i} - T_E) = M_w C_w (T_E - T_{w_i}) + M_c C_c (T_E - T_{w_i}) + M_s C_s (T_E - T_{w_i}) + .45\, V_T (T_E - T_{w_i}),$$

where

M_m = mass of metal shot or pellets
M_w = mass of water
M_c = mass of calorimeter cup
M_s = mass of stirrer
V_T = volume of the thermometer immersed
C_m = specific heat of the metal (to be determined)
C_w = specific heat of water
C_s = specific heat of stirrer
T_{m_i} = initial temperature of the metal
T_{w_i} = initial temperature of the water, calorimeter, stirrer, and thermometer
T_E = final equilibrium temperature of the mixture

If we assume the specific heats for the various masses on the right side of the equation, and measure the M's and T's, C_m can be calculated. The last term (correction for the thermometer) is usually neglected but you will calculate its value in order to see if the omission is justifiable. The justification of this term is left to the student in question 1 at the end of the experiment.

Procedure

In using a calorimeter properly, several precautions should be observed:

1. Do not touch the inner calorimeter with your hands during the experiment as this will cause an unknown heat transfer between you and the experiment.
2. If the stirrer is used, wrap its handle with an insulating material (dry paper towel) in order to avoid heat transfer.
3. The contents should be well stirred before taking temperature readings.
4. Allow sufficient time for the contents to reach thermal equilibrium before taking temperature readings.
5. Do not splash any water out of the calorimeter during the experiment.

Part I.

Place about 250 gm of lead shot or about 75 gm of aluminum pellets in the hypsometer dipper. Place the dipper containing the metal in the hypsometer and bring the water to a boil; close all steam outlets.

While the water in the hypsometer is boiling and the metal is heating, determine and record the mass of the calorimeter and stirrer. Next fill the calorimeter about one-half full of water, determine and record the mass of the calorimeter and water, and then obtain the mass of the water. After the metal is heated to about 95° C, start monitoring the temperature of the water. Record the temperature of the water every minute and, after five minutes, carefully dump the metal into the water. Continue to monitor the temperature of the water until a new equilibrium temperature is established.

Now make a plot of Temperature vs. time and from this plot determine ΔT, the rise in temperature of the water and calorimeter. Now that we know ΔT, we can minimize the effect of radiation by running the experiment over a temperature range ΔT, which is symmetric about room temperature. That is, if we use the same amount of metal and water and have an initial temperature of the calorimeter and water which is $\Delta T/2$ below room temperature, the final temperature of the calorimeter and contents will be $\Delta T/2$ above room temperature. Thus, during the first half of the experiment, heat will radiate from the environment to the experiment and during the last half of the experiment, it will radiate from the experiment to the environment. The heat radiated into the experiment will be approximately equal to the heat radiated out of the experiment, hence the effect of radiation on the experiment has been minimized. Determine the initial temperature of the water and calorimeter for the specific heat determination.

Part II.

Obtain the same amount of dry metal shot or pellets as was used in **Part I**. Place the metal in the dipper and then place the dipper in the hypsometer and again bring the water to a boil; close all steam outlets. While the water in the hypsometer is boiling and the metal is heating, place the same amount of water in the calorimeter cup as was used in **Part I** and adjust its temperature to the initial value T_{w_i} determined in **Part I**. This can be done by adding a small amount of ice or by adding cool water from the drinking fountain. When the temperature of the metal reaches 90° C to 95° C, stir carefully, and ascertain and record its temperature to the nearest 0.2° C. Also, read the temperature of the water in the calorimeter cup and immediately pour the hot metal into the calorimeter cup. Stir carefully and record the highest equilibrium temperature of the mixture. Perform the calculations outlined in the **Data and Calculation Summary** to obtain the specific heat of the metal and the percent error.

Questions and Problems

1. If the specific heats of mercury and pyrex are 0.032 and 0.20 cal/gm/° C, respectively, and the densities are 13.6 and 2.23 gm/cc, show that the term used in equation (2) for the thermometer is valid.
2. Suppose the water in **Part II** were not precooled. Would the value of C_m be too large or too small? Substantiate your answer.
3. If the stirrer and the thermometer were not considered in **Part II**, what percent error would have been introduced in the specific heat of the metal?

NAME ______________________ SECTION ______________ DATE ________

DATA AND CALCULATION SUMMARY

Part I.

Type of metal used .... ______________

Mass of dipper .... $M_d =$ ______________

Mass of dipper and metal .... $M_d + M_m =$ ______________

Mass of metal .... $M_m =$ ______________

Mass of stirrer .... $M_s =$ ______________

Mass of calorimeter .... $M_c =$ ______________

Mass of calorimeter and water .... $M_c + M_w =$ ______________

Mass of water .... $M_w =$ ______________

Room temperature .... $T_R =$ ______________

Initial temperature of the water and calorimeter .... $T_{w_i} =$ ______________

Initial temperature of the metal .... $T_{m_i} =$ ______________

Record of time and temperature

Time (min)	1	2	3	4	5	6	7	8	9	10	11	12
Temper-ature ° C												

Time (min)	13	14	15	16	17	18	19	20	21	22	23	24
Temper-ature ° C												

Rise in temperature of the water and calorimeter from the temperature vs time plot .... $\Delta T =$ ______________

Initial temperature of the water and calorimeter for the specific heat determination .... $T_R - \Delta T/2 = T_{w_i} =$ ______________

Part II.

Mass of dipper (Part I) .... M_d = ____________

Mass of dipper and metal .... $M_d + M_m$ = ____________

Mass of metal .... M_m = ____________

Mass of calorimeter cup (Part I) .... M_c = ____________

Mass of calorimeter cup + water .... $M_c + M_w$ = ____________

Mass of water .... M_w = ____________

Mass of stirrer (Part I) .... M_s = ____________

Initial temperature of the metal .... T_{m_i} = ____________

Initial temperature of the water and
calorimeter cup .... T_{w_i} = ____________

Final equilibrium temperature .... T_E = ____________

Volume of the thermometer in the water .... V_T = ____________

Specific heat of water .... C_w = ____________

Specific heat of calorimeter cup .... C_c = ____________

Specific heat of the stirrer .... C_s = ____________

Heat gained by the thermometer .... Q_T = ____________

Heat gained by the water .... Q_w = ____________

Heat gained by the calorimeter cup .... Q_c = ____________

Heat gained by the stirrer .... Q_s = ____________

Total heat gained by the thermometer, water,
calorimeter cup, and stirrer .... $Q_{T_{gain}}$ = ____________

Total heat lost by the metal .... $Q_{T_{loss}}$ = ____________

Experimentally determined specific heat of the metal .... $C_{m_{exp}}$ = ____________

Accepted value for the specific heat of the metal .... $C_{m_{accepted}}$ = ____________

Percent error of the experimentally determined value of
the specific heat .... % error = ____________