Specific Heat and Calorimetry

Introduction:

The amount of heat, Q, required to raise the temperature of a solid body at constant pressure depends on the change in temperature, ΔT, of the body, its mass, m, and a characteristic of the material forming the body called its specific heat, C. This relationship is expressed by the equation $Q = mC\Delta T$ and the dimensions of C are thus heat per unit mass per unit temperature change. The values of C do depend on temperature with those of common metals such as aluminum and brass increasing a few percent as the temperature increases from 20 °C to 100 °C, for example, while that for iron or steel increases about 10% over the same range. Since these are not large changes, average specific heats are often quoted in handbooks for such fairly broad temperature ranges.

Historically the amount of heat, Q, was originally expressed in terms of calories. The calorie was defined most accurately as the amount of heat required to raise the temperature of 1 *gram* of water from 14.5 °C to 15.5 °C at 1 atmosphere pressure. With this definition the specific heat of water between 0 °C and 100 °C is 1.00 *cal/gm· °C* to within better than 1%. The use of the calorie began before it was established that heat was a form of energy and that 1 *calorie* is the equivalent of about 4.18 *Joules*. Thus in the SI system of units specific heats, that is the values of C for particular materials, are expressed as *J/kg· °C* and there is no need for the *calorie*. However, since so much work involving heat has used the *calorie* and since the specific heat of water is unity when it is employed, it remains a common unit and will be used in this work. The food *Calorie*, with a capital C is 1000 of these *calories* or 1 *kilo-calorie*.

The process of measuring quantities of heat exchanged is called calorimetry. In this experiment your objective will be to determine the average specific heat of several metals over a certain temperature range by the calorimeter method of mixtures.

Theory:

We know that when two bodies, initially at different temperatures, are placed in intimate contact, in time they will come to equilibrium at some intermediate temperature. Provided no heat is lost to or gained from the surroundings, the quantity of heat lost by the hotter body is equal to that gained by the colder body. This is the process which occurs in the method of mixtures that you will use. The metal sample whose specific heat is to be measured is heated in boiling water to about 100 °C. It is then quickly transferred to an aluminum calorimeter cup which contains cold water of known temperature. When the metal sample and calorimeter cup come to equilibrium, the common temperature is measured with a thermometer. It is assumed that the transfer of heat between the thermometer and the system is small enough to be neglected. If the net heat exchange with the surroundings can be kept small, then the heat lost by the metal sample equals the heat gained by the water and the calorimeter cup.

Let M_s be the mass of the sample whose specific heat is C_s.. Let T_s be its temperature before it is placed in the calorimeter. Let M_w and C_w be the mass and specific heat of the water and let M_c and C_c the mass and specific heat of the calorimeter cup. Denote the temperature of the water and calorimeter cup before the sample is added by T_w and the final temperature of the mixture by T_f.. Now use these symbols to express mathematically the situation when a hot object (the sample) is placed in contact with a cooler one (the water and the calorimeter cup) and the two are allowed to exchange heat until they reach a common temperature. From this equation derive an expression for the specific heat of the sample in terms of the other quantities.

Procedure:

Fill a beaker with enough water so that the sample when placed in it will be covered with some to spare. Bring the water to a boil using a bunsen burner. Weigh the aluminum sample and the dry inner calorimeter cup. Note that the plastic top on the calorimeter is a thermal insulator whose temperature like that of the outer cup is assumed to be unaffected by changes in the temperature of the inner calorimeter cup during the course of experiment. Suspend the sample in the boiling water with string and a glass rod making sure not to touch the sides or bottom.

While the aluminum sample is reaching equilibrium, fill the calorimeter cup about $^2/_3$ full of cool water (about 5°C below room temperature). Cool water can be had from a water cooler. Ice is also available. Weigh the cup plus water. Care should be taken that the water is not so cold as to cause condensation on the outside of the calorimeter. If condensation does occur, dry the outside of the inner cup before proceeding.

Place the thermometer in the boiling water near the sample, not touching the bottom. When equilibrium is reached, record the sample temperature. Remove the thermometer, cool it with tap water, wipe it dry and then place it in the calorimeter cup. Record the temperature as soon as it is reasonably steady and then quickly transfer the sample from the boiling water to the calorimeter. Care must be taken not to carry any hot water over with the sample nor to splash any cold water out of the calorimeter. Stir the water in the calorimeter gently with the glass rod and observe the temperature. When equilibrium is reached, record the temperature. Always read the thermometer as accurately as you can, interpolating between the marks.

Calculate the average specific heat of your aluminum sample as determined by your experiment and specify the temperature range over which your value applies. Since the specific heat of the aluminum calorimeter cup is also an unknown, approximate its value by assuming it to be the same as the sample even though the cup and the sample are subject to different temperature ranges. (Later when you check the effect of this approximation you will see that it introduces little error.) If the value you obtain for the specific heat of your sample is not between 0.19 and 0.25 $cal/g \cdot {}^\circ C$, repeat the experiment to improve your technique. You may, for example, want to use a different temperature for the cool water. The objective is to have the cool water as far below room temperature initially as the final temperature of the mixture is above room temperature.

Perform the experiment for the other samples and determine their specific heats. Compare your results with the accepted values (which your instructor will furnish) and calculate the percentage error and estimate the uncertainty in your experimental technique.

Questions:

1. What do you see as the major sources of error in this experiment? Use your calculation for steel as an example and determine the effect on the measured specific heat if the sample were to cool down 3 °C during the transfer. Then calculate the effect if the net uncertainty in $T_f - T_w$ were ± 0.2 °C. These calculations will give you some idea of the sensitivity of the results to some of the measured variables.
2. How much difference does it make in your results if the value you use for the specific heat of the calorimeter cup is off by as much as 20%?
3. How would the measured value of the specific heat be affected if some boiling water were carried over with the sample?
4. How would the results be affected by splashing water out of the calorimeter, or by condensation taking place on the inner cup from water which is too cold?
5. Why is it desired to start with the temperature of the water lower than room temperature and end with the temperature about the same amount above room temperature?