Experiment VIII: Specific Heat and Calorimetry

Goals

- Learn the experimental method of calorimetry
- Determine the specific heat of aluminum, brass, and steel with calorimetry

Introduction and Background

***Heat and Specific Heat*:** The amount of heat required to raise the temperature of a solid body depends on its change in temperature (ΔT), its mass (m), and an intrinsic characteristic of the material forming the body called specific heat (c). The heat is calculated from the equation

$$Q = cm\Delta T \tag{8-1}$$

The unit for c is thus heat per unit mass per unit temperature. The value of c does depend on the temperature. However, for the small temperature range we are interested in, it is a good approximation to regard c as temperature independent.

Historically, heat Q is measured in terms of calories. The calorie was defined as the amount of heat required to raise the temperature of 1 gram of water by 1 ^{o}C from 14.5 ^{o}C to 15.5 ^{o}C at 1 atmosphere pressure. With this definition, the specific heat of water is 1.00 cal/g ^{o}C. The use of calorie began before it was established that heat is a form of energy and 1 calorie is equivalent to 4.18 J. Thus the standard unit for c in the SI system is J/kg^{o}K. However, since so much work involving heat has used the calorie and since the specific heat for water is unity when it is used, it remains a common unit today and we will use it in this lab.

***Calorimetry*:** When two bodies in an isolated system, initially at different temperatures, are placed in intimate contact with each other, in time they will come to equilibrium at some common intermediate temperature. Because of energy conservation, the quantity of heat lost by the hot object is equal to that gained by the cold object provided that no heat is lost to the surroundings. This is the basis for the method of calorimetry through mixture: A metal sample whose specific heat is to be determined is heated in boiling water to 100 ^{o}C. It is then quickly transferred to an aluminum calorimeter cup which contains some cold water of known temperature. When the metal specimen and the calorimeter (including the water) come to equilibrium, the final temperature is measured with a thermometer. It is assumed that the heat loss to the thermometer is negligible and if the heat exchange with the environment is kept small, then the heat lost by the metal sample is equal to the total heat gained by the calorimeter cup and the water.

Set up an equation describing the energy conservation in the above process based on the masses M_s, M_c, and M_w for the sample, cup and water respectively, the specific heat c_s, c_c, and c_w, and the initial temperatures T_s, T_w and the final temperature T_f.

Experimental Setup

***Equipment*:** Calorimeter, aluminum, brass, and steel samples, stainless steel beaker, 3-leg support, thermometer, Bunsen burner, balance

Setup**:** The calorimeter consists of two aluminum cups separated by a plastic top. The inner cup is suspended in air to minimize heat transfer to the environment. The plastic top and the outer cup are assumed to be unaffected by changes in the temperature of the inner cup during the course of the experiment. Therefore, the system under consideration is the sample, the inner cup and the water in the inner cup.

Experimental Procedure and Data Analysis

A. Aluminum

Since the calorimeter cup is made of aluminum and we need to determine the specific heat of aluminum, we have to measure the aluminum sample first.

1. Weigh the aluminum sample and the inner calorimeter cup when it is fully dry.
   Fill a stainless steel beaker with enough water so that when the sample is suspended with a string and a wooden rod it is fully submerged. Make sure that the sample does not touch the side or the bottom of the beaker. Heat up the water bath to boil with a Bunsen burner.

2. While the water bath is being heated up, fill the inner calorimeter cup to about ½ full of cool water. You may use ice to cool down the water. Weigh the inner cup with the water. Care should be taken so that the water is not so cold as to cause condensation on the outside. If condensation does occur, dry the outside of the inner cup before proceeding.

   Adjust the temperature of the calorimeter so that when you are ready to transfer the aluminum sample it is about 3 ^{o}C below room temperature.

   Place the thermometer in the boiling water near the sample, not touching the side or the bottom of the beaker. When equilibrium is reached, record the sample temperature (T_s). Remove the thermometer, cool it with tap water and wipe it dry and then place it in the calorimeter cup. Record the temperature when it is reasonably steady and it is about 3 ^{o}C below room temperature.

   Now transfer the aluminum sample from the boiling water bath to the calorimeter. It is extremely important to do this quickly so that the temperature of the sample does not drop much during transfer. On the other hand, you have to make sure that the sample does not carry with any hot water and it does not splash any water out of the calorimeter cup. Stir the water in the calorimeter cup with the thermometer gently and observe the temperature. When equilibrium is reached, record the temperature (T_f). Always read the thermometer as accurately as you can, interpolating between the marks. You should end up with a final temperature that is the same few degrees above the room temperature as the starting temperature below room temperature.

3. Calculate the specific heat of aluminum using the equation you derived in the last section. Note that both the sample and the cup are made of aluminum. If the result you obtain falls outside the range of 0.19 to 0.25 cal/g ^{o}C, repeat the experiment to improve your technique.

***B. Brass*:**

Repeat the experiment with the brass sample and calculate the specific heat of brass. Use for the specific heat of the cup the value you calculated for aluminum in Part A.

***C. Steel*:**

Repeat the experiment with the steel sample and calculate the specific heat of steel. Use for the specific heat of the cup the value you calculated for aluminum in Part A.

Discussions and 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 sample were to cool down 3 ^{o}C during transfer.

   Calculate the effect if the uncertainty in $T_f - T_w$ is ± 0.2 ^{o}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 for brass and steel if the value you use for the specific heat of the calorimeter cup is off by as much as 20%?

3. How would your results be affected if some boiling water were carried over with the sample?

4. How would your results be affected if some water originally in the calorimeter cup is splashed out during the sample transfer? How would water condensation on the outside of the inner cup affect your results?

5. Why is it desired to have a starting temperature of the calorimeter lower than the room temperature and end with a final temperature above the room temperature by the same amount?

Conclusions

Briefly discuss whether you have accomplished the goals listed at the beginning.