Thermodynamics: Specific Heat

Experiment Type: Cookbook

Overview

In this experiment, students will find the specific heat of three "unknown" samples of metal. To do this, students will use their knowledge of thermodynamics to construct a calorimeter.

Key Concepts

Heat, specific heat, calorie, temperature

Objectives

On completion of this experiment, students should be able to:

1) determine the specific heat of a substance
2) explain how heat and temperature are related

Review of Concepts

Heat and Temperature

Temperature is a measure of the average translational kinetic energy of the atoms or molecules of a substance. I.e. the higher the temperature, the faster the molecules are moving around in the substance.

Heat, on the other hand, is a mechanism by which energy is transferred from one substance to another as a result of a temperature difference between them.

Transferring energy into (out of) a system as heat is one way to increase (decrease) the temperature of a substance. The relationship between the heat transferred, Q, and the temperature change, ΔT, is given in Eq. (11-1)

$$Q = mc(\Delta T) \tag{11-1}$$

In this equation, m is the mass of the substance (to which the heat is being transferred to or from). The value c is the specific heat of the substance. This equation *defines* the specific heat. The specific heat is not necessarily constant over the entire range of temperatures in a given phase of the substance, but in this lab, we will *assume* that the specific heats of the objects we are testing are constant over the temperature range that we will use.

Calorimetry

A process called Calorimetry is used to determine the specific heat of a substance. This process involves:

1) Raising the temperature of the substance to a known temperature
2) Placing this substance into a thermally-insulated container filled with water of known mass and at a known temperature
3) Allowing the two to reach equilibrium
4) Measuring the temperature of the two at equilibrium

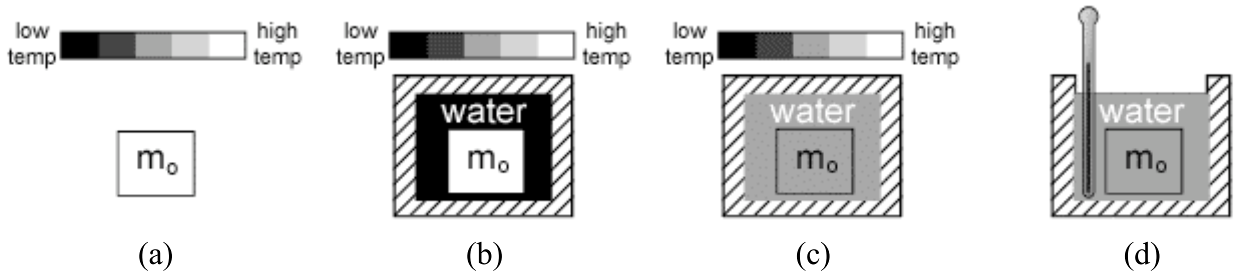

Figure 0-1 (a) Step 1: raise the temperature of the substance, (b) Step 2: Place the substance in a thermally-insulated container with water, (c) Step 3: Let them reach equilibrium, (d) Measure the temperature at equilibrium

Since the container is thermally-insulated, the heat can only be transferred to the water and not to the surrounding environment. Thus, the heat transferred out of the object is equal to the heat absorbed by the water, or:

$$-Q_{object} = Q_{water} \tag{11-2}$$

Then we can use Eq. (11-1) to write this heat transfer in terms of the mass of the object, m_o, the mass of the water, m_w, the specific heat of the object, c_o, the specific heat of the water, c_w, the temperature at equilibrium, T_{eq}, the initial temperature of the object, T_{hot}, and the initial temperature of the water, T_{cold}.

$$-m_o c_o \left(T_{eq} - T_{hot}\right) = m_w c_w \left(T_{eq} - T_{cold}\right) \tag{11-3}$$

This can be solved for the specific heat of the object:

$$c_o = \frac{m_w c_w \left(T_{eq} - T_{cold}\right)}{m_o \left(T_{hot} - T_{eq}\right)} \tag{11-4}$$

This general method will be employed to find the specific heat of three "unknown" metals.

Procedure

The three objects are aluminum, copper, and lead.

Hints:

- Make sure you use *boiling* water to heat the objects and use *ice* water (but *no* ice cubes) in the calorimeter. The greater the difference in temperature the more precisely we can determine the specific heat of the objects. This means that you need to dump out the water from the previous trial every time you start a new run!
- Use *just* enough water in the calorimeter to cover the object completely. Water has a high specific heat. (c_w = 1.0 cal/g·°C) This means that it takes a great deal of energy to raise the temperature just one degree. The hot object must transfer enough energy to the water to raise it several degrees (enough to see a difference)—so the less water the better!

1. Measure the weight of the calorimeter.
2. Measure the masses of the three objects.
3. Place the three objects into boiling water. Wait for a few minutes while the objects come into equilibrium with the boiling water. The temperature of the objects should be 100 °C.
4. Pour some ice water (T_{cold} = 0 °C) into the calorimeter from the thermos. Measure the weight of the container plus the water. Calculate the mass of the water, m_w.
5. Place one of the hot objects into the calorimeter.
6. Check the temperature of the water every minute or so. When the temperature stops changing (or when it reaches a maximum) this is the equilibrium temperature. Log this temperature, T_{eq}.
7. Throw out the water in your calorimeter and repeat the experiment for the other two objects.
8. You should run a few more trials of each metal to get a better idea of the uncertainties involved.
9. Determine the specific heats of the three objects.

Assignment

Make sure you compare your results with the "known" values from Tipler:

Al	0.215 cal/g·°C
Cu	0.0923 cal/g·°C
Pb	0.0305 cal/g·°C

Answer any assigned questions.

Questions

1. What are some of the assumptions we make in this lab? Are these valid assumptions to make? Explain.

2. Discuss the uncertainties inherent in the measurements you made in this experiment. Are there some measurements which could *realistically* be changed to improve the precision of our experiment? Explain.

3. Why don't we want to have ice cubes in the calorimeter?

4. Originally, the calorie was defined to be the amount of energy needed to raise the temperature of one gram of water by one degree Celsius. Now it is defined to be the amount of energy needed to raise the temperature of one gram of water *from 14.5 °C to 15.5°C*. This is because careful measurements of the energy transferred revealed that the specific heat of water was *not* constant for all temperature ranges. This is also true for the metals we have investigated in this experiment! Come up with an experiment (or modify this experiment) in which we could find these differences in specific heat. Do you think our present apparatus could measure these differences?

Reference

Tipler, Paul A., *Physics for Scientists and Engineers*, 3rd Ed., Vol. 1 (Worth Publishers, NY 1991), p. 519