HEAT CAPACITY

REFERENCE Noakes, *Textbook of Heat.* Copies of the relevant sections are available at the Resource Centre.

INTRODUCTION

Definitions

The purpose of this experiment is to determine the specific heat of two metal blocks.
In one of these measurements you will also investigate the use of ***Newton's Law of Cooling*** to calculate a cooling correction.

When a body of mass M at temperature T_1 receives an amount of heat (or energy) Q, its temperature may increase from T_1 to T_2.

The ***heat capacity C*** of a body is the amount of heat required to raise its temperature by one (Kelvin) degree:

$$C = \frac{Q}{(T_2 - T_1)} \qquad (1)$$

By dividing out the mass, one gets ***the specific heat capacity c*** or simply ***the specific heat***:

$$c = \frac{C}{M} = \frac{Q}{M(T_2 - T_1)} \qquad (1')$$

The units of specific heat in SI are J / kg ˚C.
Historically, "specific" means "referred to water" and the measurements done in this experiment are referred to the specific heat of water. Thus, in this experiment we use as the unit of heat, not the conventional SI unit of energy, but rather **the calorie**. The calorie is defined as the heat required to increase the temperature of 1 gram of water from 14.5°C to 15.5°C. This definition makes the specific heat capacity of water equal to unity.

THE METHOD

To determine the specific heat capacity of a substance, ***the method of mixtures*** is often used. A vessel, called **calorimeter**, of known specific heat capacity S_c and mass m_c is partially filled with a mass m_w of water at a temperature T_1 and then mounted in a suitable manner so that it is thermally insulated from the outside world.
A mass M of the substance of unknown specific heat capacity c is heated to a higher temperature T_b (usually in boiling water) and then quickly transferred to the calorimeter. The temperature of the calorimeter and the water contained quickly rises to a value T_2. It then slowly begins to fall as heat is lost to the room. If all the masses are measured in grams, the temperatures in degrees

Celsius and the specific heat capacities in calories per gram per degree Celsius, the block of substance has thus given $Mc(T_b - T_2)$ calories of heat to the calorimeter and the contained water. If no losses occur, this must be equal to the heat gained by them, which is $(m_cS_c + m_w)(T_2 - T_1)$.

Thus:

$$Mc(T_b - T_2) = (m_cS_c + m_w)(T_2 - T_1) \qquad (2)$$

and the specific heat c can be determined.
The calorimeter is made of copper and $S_c = 0.093$ cal g^{-1} °C^{-1}.

Experiment 1

Arrange the calorimeter with the inner vessel filled with enough water to cover the metal block. Try it before you heat the block. Measure the initial temperature T_1. Do not add anything between the inner and the outer vessels. The outer vessel acts as a thermal shield. The air between the two is the insulator.
Heat a metal block in boiling water (temperature T_b) and transfer it quickly to the calorimeter. The final temperature will be T_2.
Consider carefully the systematic errors present in this experiment.
Determine the specific heat of one of the metal blocks, using Equation 2.
What temperature, or temperature range, does your value correspond to?

Experiment 2 - The cooling correction

In the second part of the experiment you will measure the specific heat of the second block by using the same method, but this time you will allow the cooling effect to be large enough to study. The derivation in (2) above neglects the heat lost to the surroundings when the temperature of the calorimeter + water + metal block rises above room temperature.
The method is based on Newton's Law of Cooling, which assumes that the rate of loss of heat to the surroundings is proportional to the temperature excess above the surroundings:

$$\frac{dQ}{dt} = k\,(T - T_{room}) \qquad (3)$$

where Q is the quantity of heat,
t is the time,
dQ/dt is the rate of heat loss (how much heat is lost per unit time),
T and T_{room} are the temperatures of the cooling body and of the surroundings, and
k is a constant of proportionality.

The experiment should be performed using the method of mixtures, under conditions where *heat exchange with the room is deliberately made large*, so that the cooling correction will be fairly conspicuous. This is achieved by placing the inner part of the calorimeter out in the open to increase heat losses to the air around it.
Measure the temperature of the calorimeter at the time of transfer, t_1.
Read the temperature at frequent intervals; regular 15 sec intervals are recommended. These measurements should be continued until a maximum in the temperature has been passed and the temperature has fallen again about 1°C.

Plot **temperature** *vs.* **time** on graph paper. On the graph (indicated in Figure 1), select a time t_2 at which you would expect the metal block and the liquid in the calorimeter to have more or less reached thermal equilibrium so that the whole system is then cooling as a unit.

The amount of heat loss between t_2 and t_3 ($t_3 > t_2$) can be determined by integrating Equation (3) to yield:

$$Q = k \int_{t_2}^{t_3} (T - T_{room})\, dt \tag{4}$$

The right hand side of this equation is just the area under the curve of (T - T_{room}) *versus t,* denoted by A_2 in Figure 1.

The left hand side (Q), the heat lost by cooling in the interval $(t_3 - t_2)$, is proportional to ΔT_3 , the drop in temperature during this time interval. Remember that Q is equal to the product of the specific heat capacity of the cooling body, its mass, and the drop in temperature.

Thus we obtain $\Delta T_3 = k' A_2$, where k' is another constant.

Similarly, the drop in temperature due to cooling in the time interval between $t = t_1$ and $t = t_2$, is given by $\Delta T_2 = k' A_1$ (note that, since the mechanism by which cooling takes place is the same for times between t_1 and t_2 and between t_2 and t_3 , the constant of proportionality will be the same for both regions).

Finally we have: $\Delta T_2 / \Delta T_3 = A_1 / A_2$.

Thus, if T_2 is the temperature observed at time t_2, the temperature which the calorimeter and its contents would have reached had no heat been lost by cooling is $T_2 + \Delta T_2$, and equation (2) should be correspondingly corrected. A_1 and A_2 are most conveniently measured by counting squares on graph paper.

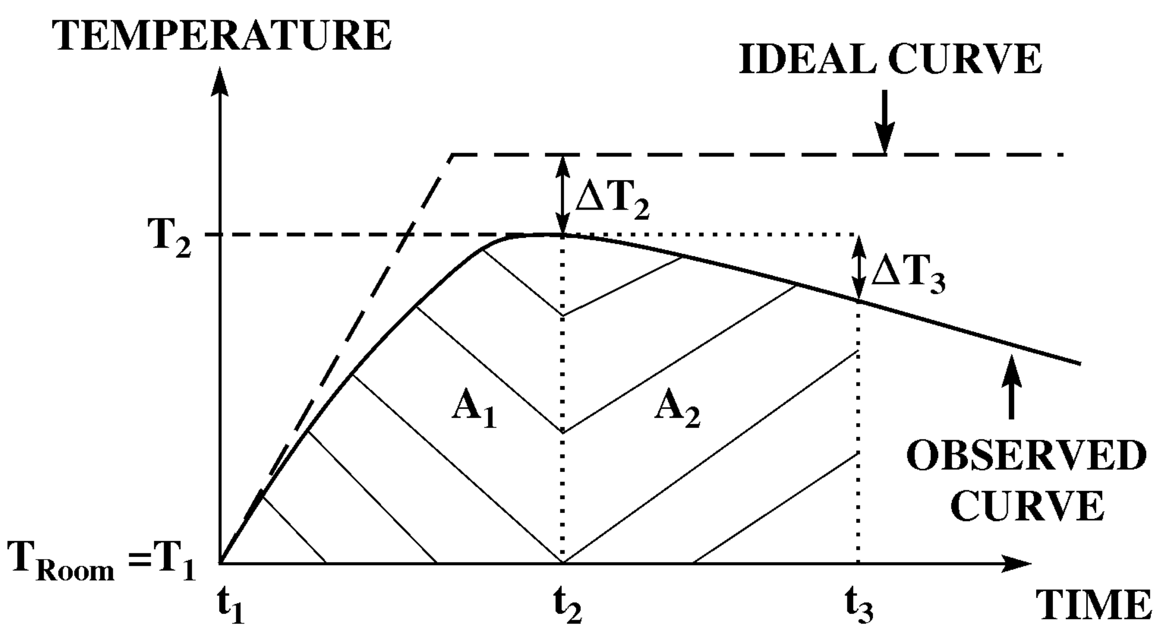

Figure 1

Correction for the heat capacity of the thermometer:
The thermometer you use in this experiment is a partial immersion model. Insert it exactly to the line. The liquid this thermometer uses is kerosene.
If the specific heat capacities of kerosene and of glass are expressed as calories per cm^3 per °C, they are: 0.57 cal/(cm^3°C) for kerosene and 0.45 cal/(cm^3°C) for glass.
Assume that the thermometer's bulb is mainly kerosene and has a volume V_1. The column (up to the line) is mainly glass and has a volume V_2.
Measure V_1 with the aid of a 10 cm^3 graduated cylinder, by measuring the water volume the bulb displaces.
Measure the column diameter and length (up to the line) and calculate V_2.
The amount of heat absorbed by the thermometer when immersed in the calorimeter can now be expressed as:

$$Q_t = 0.57V_1(T_2 - T_1) + 0.45V_2(T_2 - T_1) \quad (5)$$

This quantity of heat (Q_t) will also correct equation (2).

Please dispose of any water in the sink!

(Revised: Ruxandra M. Serbanescu – 2004. Previous versions of this guide sheet were written by Tony Key in 1995 -1998)

Preparatory Questions

Note: We hope that the following questions will guide you in your preparation for the experiment you are about to perform. They are not meant to be particularly testing, nor do they contain any "tricks". Once you have answered them, you should be in a good position to embark on the experiment.

1. The SI unit of heat is the Joule. How is that related to the calorie?
2. What is your best estimate of the reading error in the thermometer you will use?
3. You read on the package of your favorite junk food that it contains 250 calories per serving. Are these the same kind of calories that you will be measuring in this experiment?
4. The derivation of equation (2) assumes that there was no heat loss in the transfer of the heated block to the cooler water. If this equation were used to analyze the data from an experiment in which the heat losses were, in fact, significant, what would be the value of the specific heat obtained?
5. Two bodies, made of different materials and having different specific heats, but of equal mass and identical shape, are heated up. They are then allowed to cool down. Assuming that the constant *k* is independent of the material the bodies are made of, which body would you expect to cool down more quickly?