HEAT CAPACITY

REFERENCE Noakes, *Textbook of Heat* (copies of the relevant sections are available at the **R**esource **C**entre).

INTRODUCTION

Two large metal blocks, a calorimeter and a thermometer are provided. The purposes of the experiment are to determine the specific heat of each metal block; in one of these determinations, you can investigate the use of Newton's Law of Cooling to compute a cooling correction.

The heat capacity of a body is the amount of heat required to raise its temperature by one (Kelvin) degree. This is made a property of the substance by dividing by the body's mass to yield the *specific heat capacity* or simply the *specific heat*. Historically “specific” meant “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, the joule, but rather the calorie. The calorie is defined as the heat required to raise the temperature of 1 g of water from 14.5°C to 15.5°C. This definition makes the specific heat capacity of water equal to unity.

THE METHOD OF MIXTURES

To determine the specific heat capacity of a substance, the method of mixtures is often used. A vessel, called a calorimeter, of known specific heat capacity, S_c, and mass m_c is partially filled with 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 high 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 temperature 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, that is $(m_c S_c + m_w)(T_2 - T_1)$.
Thus: $MC(T_b - T_2) = (m_c S_c + m_w)(T_2 - T_1)$ (1)
and C can be determined. The calorimeter is made of copper and $S_c = 0.093$ cal g^{-1} °C^{-1}.

The experiment consists of adding a heated metal block to the calorimeter which has previously been filled with some water. If there is enough water to cover the metal block, an optimum heat exchange can be attained. The water is contained in the inner vessel and the outer one acts as a shield. Consider carefully which quantities need to be measured, and what systematic errors are present in this experiment (one source of error can be reduced by mixing some ice with the water so that T_1 is lower than the room temperature by an amount approximately equal to the amount by which the final temperature is above room temperature). Determine the specific heat of one of the metal blocks. What temperature, or temperature range, does your value correspond to?

COOLING CORRECTION

In the second part of the experiment you will measure the specific heat of the second block in exactly the same way, but this time you will allow the cooling effect to be large enough to study. The derivation in (1) above neglects, among other things, the heat lost to the surroundings when the temperature of the calorimeter + water + metal block rises above room temperature. (It is true that the systematic error is reduced if one begins with the calorimeter + water below room temperature, but usually some systematic error remains). To make a correction for this effect, which is rather small using the procedure outlined above, requires more precise thermometry and a longer time than is available in this introductory laboratory. However, the method of correction is interesting and worth learning, so it is suggested that you investigate how you would make a cooling correction while measuring the specific heat of the other block of metal in a situation where the cooling effect has been allowed to be artificially large.

The quantitative correction is achieved by a study of the rate of cooling after the calorimeter and contents have reached their maximum 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, i.e. $$\frac{dQ}{dt} = k\ (T - T_{room}) \qquad (2)$$
where Q is the quantity of heat, t is the time, T and T_{room} are the temperatures of the cooling body and the surroundings, respectively and k is a constant of proportionality.

In order to illustrate the method, 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. Now 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 the temperature against time on graph paper. On the graph (indicated in Figure 1), select a time t_2 at which you would expect that the metal block and the liquid in the calorimeter have more or less reached thermal equilibrium so that the whole system is then cooling as a unit. Then the amount of heat loss between t_2 and t_3 ($t_3 > t_2$) can be determined by integrating Equation (1) to yield:

$$Q = k \int_{t_2}^{t_3} (T - T_{room}) \, dt \qquad (3)$$

Now 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. And 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). So finally we have that $\Delta T_2 / \Delta T_3 = A_1 / A_2$. 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 (1) should be correspondingly corrected. A_1 and A_2 are most conveniently measured by measuring squares on graph paper.

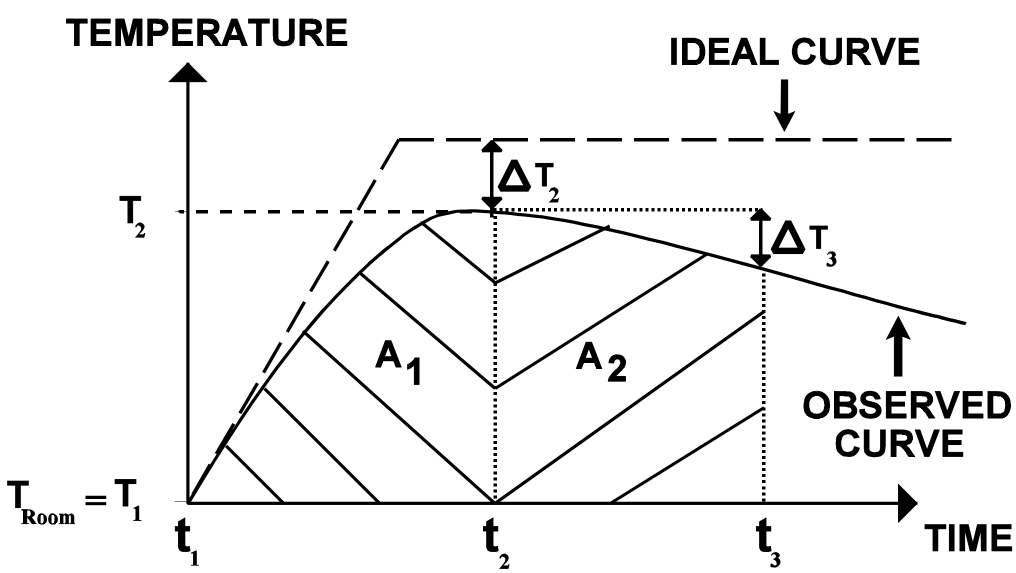

Figure 1

OTHER CORRECTIONS

(a) Correction for stem exposure of the thermometer: many thermometers are calibrated for total immersion, *i.e.*, they read the temperature correctly only when the whole length of the thermometer is at the indicated temperature. In many experiments such as this, only the lower part of the thermometer is immersed in the bath, the remainder being at some average temperature, T', between that of the bath, T°C, and room temperature. If n is the number of degrees of the mercury column *not immersed* in the bath, and a', the apparent coefficient of expansion of mercury in glass, is equal to $0.000155(°C)^{-1}$, then the correction to be applied to the temperature reading is $+a'n(T - T')$.

Discuss briefly what values should be assigned to T' and estimate the effect of neglecting this correction to your measured temperatures, and the resulting error in C.

(b) Correction for the heat capacity of the thermometer: If the specific heat capacities of mercury and of glass are expressed as calories per cm^3 per °C, it is found that they are very nearly the same and equal to 0.45 calories $(cm^3 °C)^{-1}$. Consequently, if a volume v of the thermometer is immersed in the calorimeter, it will absorb a quantity of heat equal to $0.45v\,(T_2 - T_1)$ calories. Measure v with the aid of a 10 cm^3 graduated cylinder, and determine the error introduced by the neglect of this effect.

Are corrections (a) and (b) sufficiently large in this experiment to make a significant difference to your answers, having regard to the other experimental errors (such as uncertainties arising from thermometer readings and weighings)?

(revised tk-1995,96,98)

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 favourite 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 (1) 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 of which the bodies are made, which body would you expect to cool down more quickly?