Experiment 5: Calorimetry (Specific Heat Capacity)

Determination of the specific heat capacity of a metal block including a cooling correction based on Newton's law of cooling

APPARATUS REQUIRED

- solid aluminium block (or calorimeter)
- insulating board (to protect bench)
- 50 W, 12 V immersion heater to fit the block
- mercury-in-glass thermometer for 0–100 °C (preferably reading to 0.5 °C)
- glycerol
- power supply 0–12 V d.c.
- voltmeter 0–10 V d.c.
- ammeter 0–5 A d.c.
- rheostat 0–10 Ω (at least 5 A maximum current)
- switch
- connecting wires
- stopwatch or stopclock
- hair dryer (set to blow cool air)
- clamp, boss and stand to support hair dryer

PRINCIPLES INVOLVED

a The specific heat capacity c of a solid of mass m is normally determined by measuring its temperature rise θ when a quantity of energy Q is supplied to the solid. In this experiment Q is supplied electrically using an immersion heater switched on for a time t:

$$IVt = mc\theta \qquad [9.4]$$

where I is the current flowing and V is the potential difference across the heater.

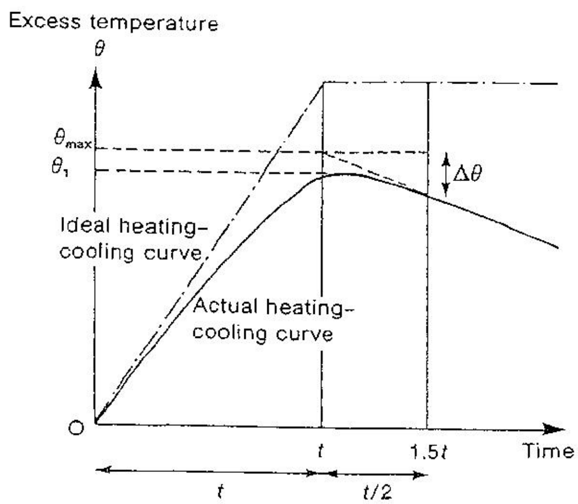

Fig. 9.1 The heating and cooling curve for a metal block, and the calculation of the cooling correction $\Delta\theta$.

b Equation [9.4] represents the perfect situation assuming no heat losses to the surroundings. The ideal heating curve corresponds to the dashed line (— · — ·) shown in Fig. 9.1. The actual heating curve will correspond to the continuous line. Thus the measured temperature rise θ_1 after time t will be too low and the calculated value of c too high.

c The metal block will usually reach its maximum temperature (as registered by a thermometer) after the electrical heating has been switched off. The maximum temperature rise θ_{max} at the time t, when the electrical heating has been switched off, can be obtained by extrapolating back the cooling curve to time t as shown in Fig. 9.1.

d The correction $\Delta\theta$ to the temperature θ_{max} for energy losses to the surroundings can also be found from the heating–cooling curve assuming Newton's law of cooling is valid. At a constant rate of heating it can be assumed that the average rate of energy loss is proportional to the average excess temperature, $\frac{1}{2}\theta_{max}$. After the electrical heating has been switched off the rate loss of energy is proportional to θ_{max} initially. Thus in a time $t/2$ the block will lose approximately the same amount of energy as it lost in a time t during the heating period. Thus the temperature fall from θ_{max} in a time $t/2$ will give a value for the cooling correction $\Delta\theta$.

THE HEATING-COOLING CURVE OF A METAL BLOCK

e Measure the mass m of the metal block using a balance.

f Connect the electrical circuit as shown in Fig. 9.2. Before inserting the immersion heater into the block, close the switch and adjust the power supply and the rheostat to give a potential difference V of about 10 V. Open the switch.

g Place the heater and thermometer in the block as shown in Fig. 9.2. A few drops of glycerol should be used in the thermometer hole to improve thermal contact; it is not usually necessary to do this for the immersion heater, which should be a fairly tight fit with good metal to metal contact.

h Place the hair dryer a few metres from the block, so that a steady stream of cool air is blown towards the block. If you do not have access to a hair dryer you

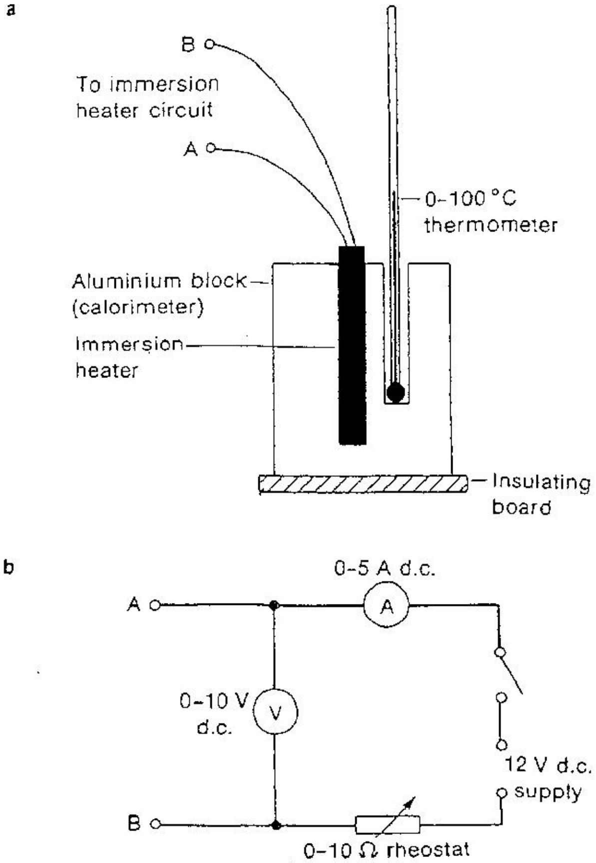

Fig. 9.2 Measurement of the specific heat capacity of an aluminium block: **a** apparatus and **b** circuit diagram.

should carry out the experiment in the best draught available, and assume that Newton's law of cooling is valid.

i Measure the initial temperature θ_R of the block. This temperature should be subtracted from all subsequent measurements to give the excess temperature θ.

j Close the switch and start timing. Record V and I. Record the temperature of the block at 1 minute intervals. Continue heating until the temperature rise is about 40 K (about 20 minutes). Observe the voltmeter and if necessary adjust the rheostat so as to keep V constant.

k Open the switch and continue to record the temperature every minute. If you only wish to calculate the cooling correction you will only need the cooling curve for $t/2$ (about 10 minutes). If you wish to check the validity of Newton's law of cooling (see Further work section) you should record the cooling curve until the temperature has fallen to at least 20 K below the maximum temperature of the block.

l Plot a graph of the excess temperature θ (ordinate) against t (abscissa).

CALCULATION OF THE SPECIFIC HEAT CAPACITY

m An approximate value for c can be calculated using equation [9.4] and the value of θ_{max} determined from your graph (see (c)).

n A more accurate value of c can be obtained by adding to θ_{max} the cooling correction $\Delta\theta$ as described in (d).

o You can also calculate the average rate of energy loss from the block during heating. It is approximately equal to half the value of the rate of energy loss during the initial cooling period, $-mc(d\theta/dt)_{\theta_{max}}$; $(d\theta/dt)_{\theta_{max}}$ is the slope of the $\theta - t$ cooling curve at $\theta = \theta_{max}$. Since the graph is nearly linear, you can estimate this slope and hence calculate the average rate of energy loss. What fraction of the total energy supplied to the block does this represent?

NOTES

p Your account should include a brief description of the experiment, the heating–cooling curve, the calculation of c with and without the cooling correction, and your estimate of the average rate of energy loss during heating.