11.2 Specific heat capacity

Learning objectives:

- What do we mean by 'heating up' and by 'cooling down'?
- Which materials heat and cool fastest?
- What is specific heat capacity? How do we measure it?

Specification reference: 3.5A.3

Table 1 *Some specific heat capacities*

substance	specific heat capacity / $J\,kg^{-1}\,K^{-1}$
aluminium	900
concrete	850
copper	390
iron	490
lead	130
oil	2100
water	4200

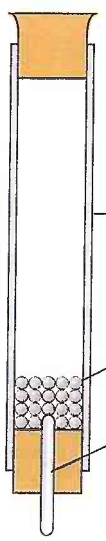

Figure 1 *The inversion tube experiment*

Heating and cooling

Sunbathers on the hot sandy beaches of the Mediterranean Sea dive into the sea to cool off. Sand heats up much more readily than water does. Even when the sand is almost too hot to walk barefoot across, the sea water is refreshingly cool. The temperature rise of an object when it is heated depends on:

- the mass of the object,
- the amount of energy supplied to it,
- the substance or substances from which the object is made.

The specific heat capacity, *c*, of a substance is the energy needed to raise the temperature of unit mass of the substance by 1 K without change of state. The unit of c is $J\,kg^{-1}\,K^{-1}$.

Specific heat capacities of some common substances are shown in Table 1.

To raise the temperature of mass m of a substance from temperature T_1 to temperature T_2,

$$\textbf{the energy needed } \Delta Q = mc(T_2 - T_1)$$

For example, to calculate the energy that must be supplied to raise the temperature of 5.0 kg of water from 20 °C to 100 °C, using the above formula gives $\Delta Q = 5.0 \times 4200 \times 80 = 1.7 \times 10^6$ J.

The inversion tube experiment

In this experiment, the gravitational potential energy of an object falling in a tube is converted into internal energy when it hits the bottom of a tube. Figure 1 shows the idea. The object is a collection of tiny lead spheres.

The tube is inverted each time the spheres hit the bottom of the tube. The temperature of the lead shot is measured initially and after a certain number of inversions.

Let m represent the mass of the lead shot.

For a tube of length L, the loss of gravitational potential energy for each inversion $= mgL$

Therefore, for n inversions, the loss of gravitational potential energy $= mgLn$

The gain of internal energy of the lead shot $= mc\Delta T$, where c is the specific heat capacity of lead and ΔT is the temperature rise of the lead shot.

Assuming all the gravitational potential energy lost is transferred to internal energy of the lead shot,

$$mc\Delta T = mgLn$$

$$\therefore\ c = \frac{gLn}{\Delta T}$$

The experiment can therefore be used to measure the specific heat capacity of lead with no other measurements than the length of the tube, the temperature rise of the lead and the number of inversions.

Specific heat capacity measurements using electrical methods

Measurement of the specific heat capacity of a metal

A block of the metal of known mass m in an insulated container is used. A 12 V electrical heater is inserted into a hole drilled in the metal and used to heat the metal by supplying a measured amount of electrical energy. A thermometer inserted into a second hole drilled in the metal is used to measure the temperature rise ΔT (= its final temperature – its initial temperature). A small amount of water or oil in the thermometer hole will improve the thermal contact between the thermometer and the metal.

The electrical energy supplied

$$= \text{heater current } I \times \text{heater pd } V \times \text{heating time } t$$

$\therefore$ assuming no heat loss to the surroundings, $mc\Delta T = IVt$

$$\therefore \; c = \frac{IVt}{m\Delta T}$$

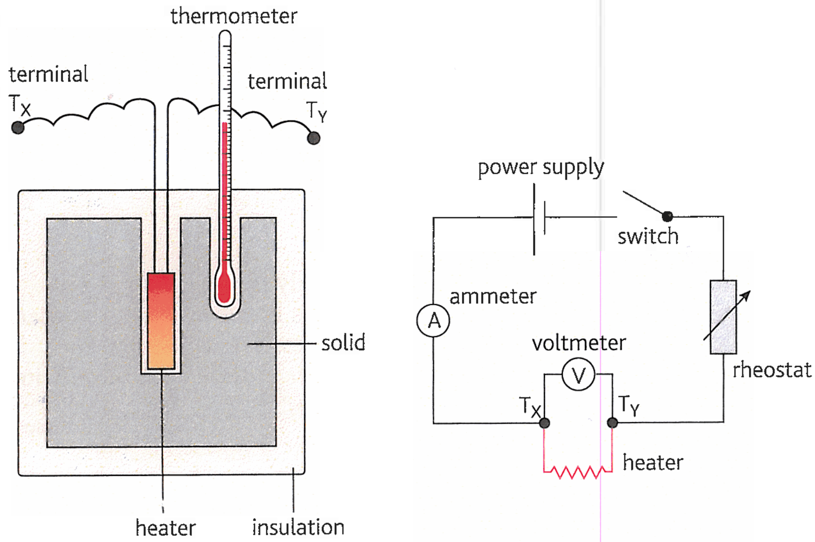

Figure 2 *Measuring c*

Measurement of the specific heat capacity of a liquid

A known mass of the liquid is used in an insulated calorimeter of known mass and known specific heat capacity. A 12 V electrical heater is placed in the liquid and used to heat it directly. A thermometer inserted into the liquid is used to measure the temperature rise, ΔT.

- The electrical energy supplied = current I × voltage V × heating time t
- The energy needed to heat the liquid =
  mass of liquid (m_l) × specific heat capacity of liquid (c_l) × temperature rise (ΔT)
- The energy needed to heat the calorimeter =
  mass of calorimeter (m_{cal}) × specific heat capacity of calorimeter (c_{cal}) × temperature rise (ΔT)

Notes

1 Notice that the unit of mass × the unit of c × the unit of temperature change gives the joule. In other words, $\text{kg} \times \text{J kg}^{-1}\text{K}^{-1} \times \text{K} = \text{J}$.

2 The **heat capacity, C,** of an object is the heat supplied to raise the temperature of the object by 1 K. Therefore, for an object of mass m made of a single substance of specific heat capacity c, its heat capacity $C = mc$. For example, the heat capacity of 5.0 kg of water is $21\,000\,\text{J K}^{-1} = 5.0\,\text{kg} \times 4200\,\text{J kg}^{-1}\text{K}^{-1}$.

AQA Examiner's tip

A temperature change is the same in °C as it is in K. If you are given the initial and final temperatures in °C, just calculate the temperature difference in °C.

AQA Examiner's tip

Stir a liquid in a heating experiment before you measure its temperature.

Assuming no heat loss to the surroundings,

$$\therefore IVt = m_l c_l \Delta T + m_{cal} c_{cal} \Delta T$$

Hence c can be calculated from this equation as all the other quantities are known.

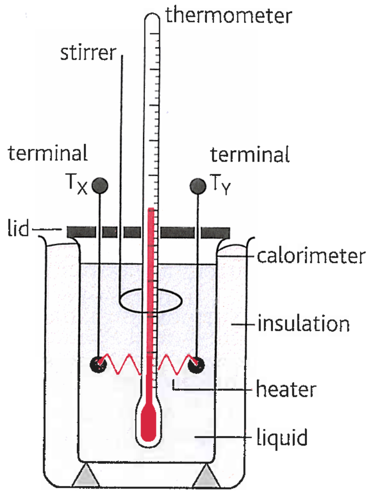

Figure 3 *Measurement of the specific heat capacity of a liquid*

Application

Continuous flow heating

In an electric shower, water passes steadily through copper coils heated by an electrical heater. The water is hotter at the outlet than at the inlet. This is an example of continuous flow heating. For mass m of fluid passing through the heater in time t at a steady flow rate, assuming no heat loss to the surroundings:

the electrical energy supplied per second $IV = mc\dfrac{\Delta T}{t}$

where ΔT is the temperature rise of the water.

Note that when the outflowing water has attained a steady temperature, the temperature of the copper coils does not change, so no '$mc\Delta T$' term is needed for the copper coils in the above equation.

For a solar heating panel, the heat energy gained per second by the liquid that flows through the panel $= mc\dfrac{\Delta T}{t}$

where m is the of liquid flowing through the panel in time t, c is the specific heat capacity of the liquid and ΔT is its temperature rise.

Note:

If the volume flow rate is given, you need to know the density of the fluid to calculate the rate of flow of mass (m/t). See *AS Physics* Topic 11.1.

Summary questions

Use the data in Table 1 for the following calculations.

1 Calculate:

a the energy needed to heat an aluminium pan of mass 0.30 kg from 15 °C to 100 °C,

b the energy needed to heat 1.50 kg of water from 15 °C to 100 °C.

2 a Calculate the time taken to heat the water and pan in Q1 from 15 °C to 100 °C using a 2.0 kW electric hot plate, assuming no heat transfer to the surroundings occurs.

b Calculate the energy needed to raise the temperature of 80 kg of water in an insulated copper tank of mass 20 kg from 20 °C to 50 °C.

3 In an inversion tube experiment, 0.50 kg of lead shot at an initial temperature of 18 °C was inverted fifty times in a tube of length 1.30 m. The final temperature of the lead shot was 23 °C. Calculate:

a the total gravitational potential energy released by the lead,

b the specific heat capacity of lead. Assume $g = 9.81\,\text{m}\,\text{s}^{-2}$.

4 An electric shower is capable of heating water from 10 °C to 40 °C when the flow rate is $0.025\,\text{kg}\,\text{s}^{-1}$. Calculate the minimum power of the heater.