8 The magnitude of the rate of flow of heat $\frac{dQ}{dt}$ through a length d of material from a higher temperature T_1 to a lower temperature T_2 can be modelled by the following equation:

$$\frac{dQ}{dt} = kA\frac{T_1 - T_2}{d}$$

where k is a constant called the thermal conductivity of the material, and A is the cross-sectional area of the material. A simple experimental setup shown in Fig. 8.1 can be used to verify the model, using a cylindrical metal bar as the material under test.

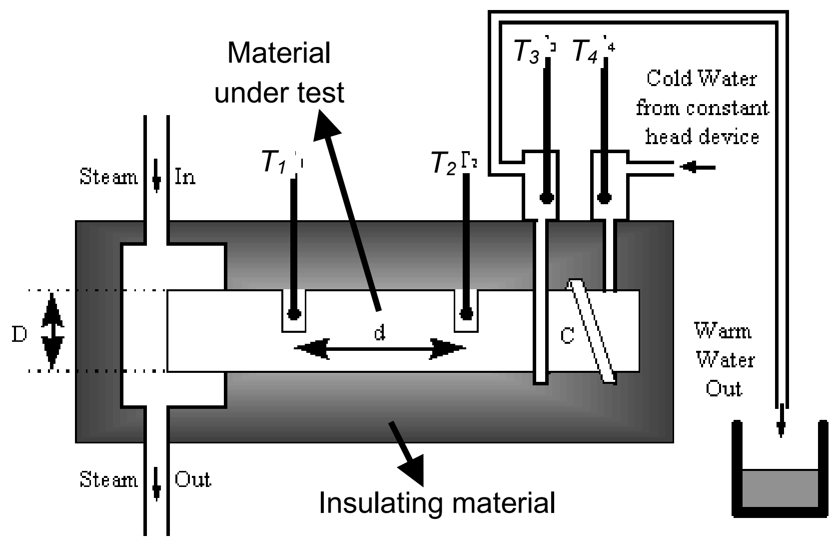


Fig. 8.1

Heat flows from the left end of the material at 100 °C, through the material and out from the right end, carried away by the flowing water. Cold water flows in at a temperature T_4 = 30.0 °C and flows out at a temperature T_3 = 32.5 °C at a rate of 0.186 kg min^{-1}. The specific heat capacity of water is 4200 J K^{-1} kg^{-1}.

When the temperatures have stabilized, the variation of temperature with distance from the hot end is shown in Fig. 8.2.

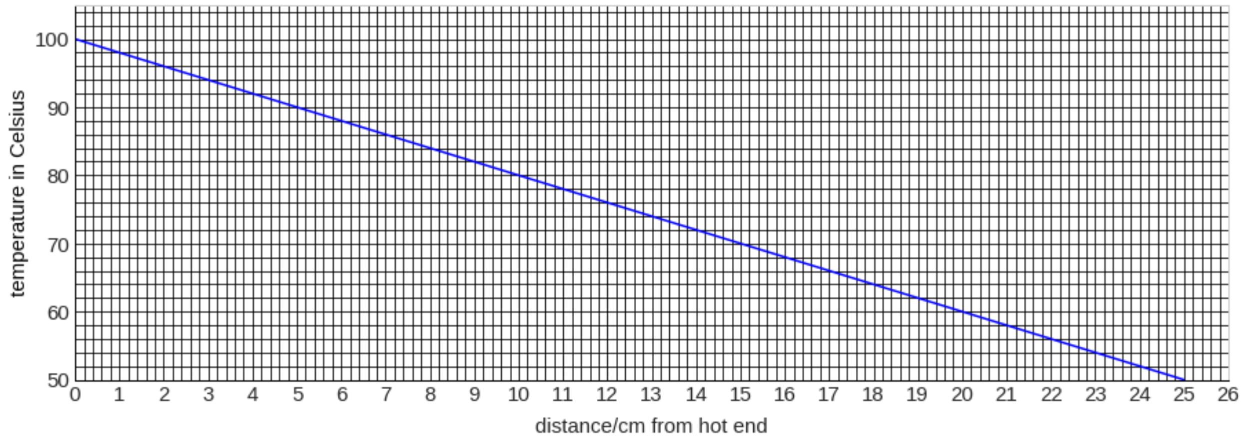


Fig. 8.2

(a) State the SI unit for k.

unit = ……………………… [1]

(b) Calculate the rate of heat flow through the metal bar.

rate of heat flow = ……………………… J s^{-1} [2]

(c) Given that the diameter of the cylindrical metal bar is 3.00 cm, calculate the thermal conductivity of the metal bar. Express your numerical answer in standard SI unit.

thermal conductivity = ……………………… SI unit [3]

(d) **(i)** Draw on Fig. 8.2 another graph if the cross-sectional area of the metal bar decreases with distance from the hot end to the cold end, as shown in Fig. 8.3.

Label this line (i). [1]

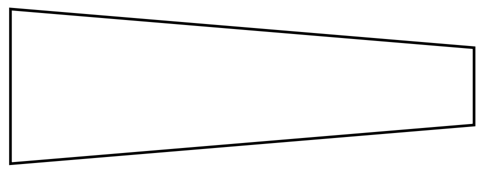


Fig. 8.3

(ii) The insulating material is now removed from the uniform metal bar in Fig. 8.1.

Draw another graph on Fig. 8.2 to show how the temperature varies with distance from the hot end to the cold end.

Label this line (ii). Explain the shape of your graph.

…………………………………………………………………………………………...

…………………………………………………………………………………………...

………………………………………………………………………………………… [2]

(iii) The same experimental setup cannot be used for an insulating material by directly substituting the metal bar with a wooden bar.

Explain why and suggest an improvement to allow the thermal conductivity of a piece of wood to be measured.

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

………………………………………………………………………………………… [2]

(e) Ice at 0 °C fills up the entire volume of a cylindrical container as shown in Fig. 8.4. The container is suspended from a support using insulating material.

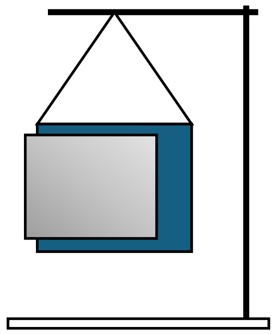


Fig. 8.4

Temperature of the room	= 30 °C
Internal diameter of container	= 20.0 cm
Height of ice in container	= 16.0 cm
Thickness of wall of container	= 2.00 cm
Density of ice	= 917 kg m^{-3}
Specific latent heat of ice	= 3.35×10^5 J kg^{-1}
Thermal conductivity of container wall	= 2.50 in standard SI unit

(i) Calculate the quantity of ice that has melted in the container in 120 s. State the assumption you have made in your calculations.

mass of ice melted = ………………………. kg [4]

(ii) Heat energy can also be absorbed by radiation from surrounding objects that are at higher temperatures.

The magnitude of the rate of heat absorbed by radiation is given by the formula

$$\frac{dQ}{dt} = (5.7 \times 10^{-8})(A)(T_{room}^4 - T_{ice}^4),$$

where A is the total area of the container and T_{room} and T_{ice} are the thermodynamic temperatures of the room and ice.

Calculate the rate of radiation energy absorption. Comment on your answer.

……………………………………………………………………………………………………

…………………………………………………………………………………………………... [3]

(iii) In order to reduce rate of heat lost to the surrounding, a double-glazed wall is used. The wall consists of 2 material layers with a layer of air in between. The thermal conductivity of air is 0.024 in standard SI unit.

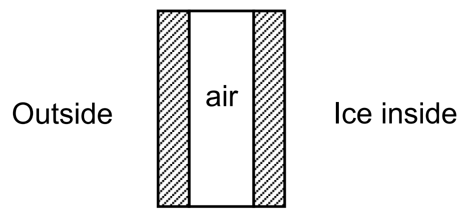
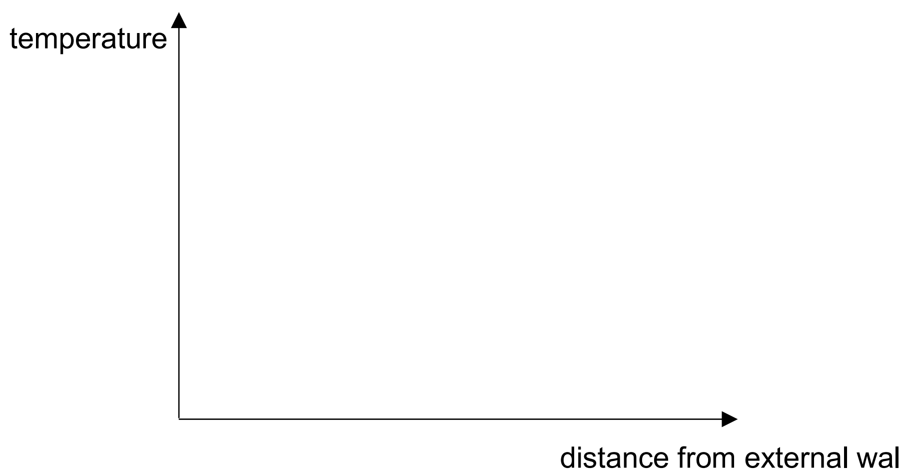


Fig. 8.5

Sketch a graph of temperature variation across the double-glazed wall. [2]



(iv) Increasing the thickness of the air layer can enhance the heat insulation up to a point. Suggest why this is the case.

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………… [2]

End of paper