6 Thermal conduction is the transfer of thermal energy (heat) through a substance with no overall movement of the substance.

(a) Fig. 6.1 shows a solid metal rod of length about 50 cm that has one end maintained at a temperature of 100 °C using a bath of water.

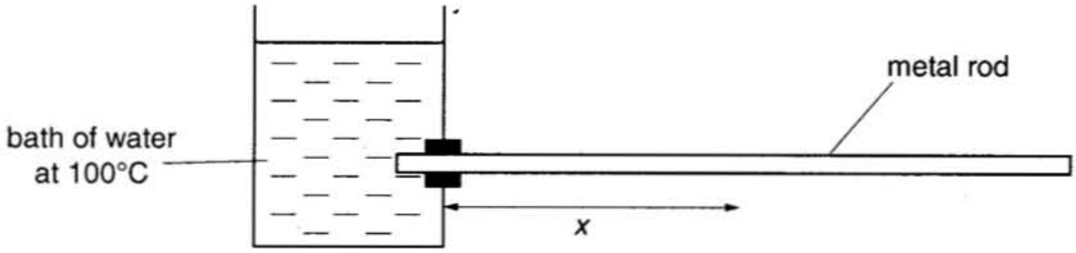

Fig. 6.1

The rod is in a draught-free room. The apparatus is left until the temperature at any point along the rod does not change. Fig. 6.2 shows the variation of the temperature θ of the rod with distance x from the bath of water.

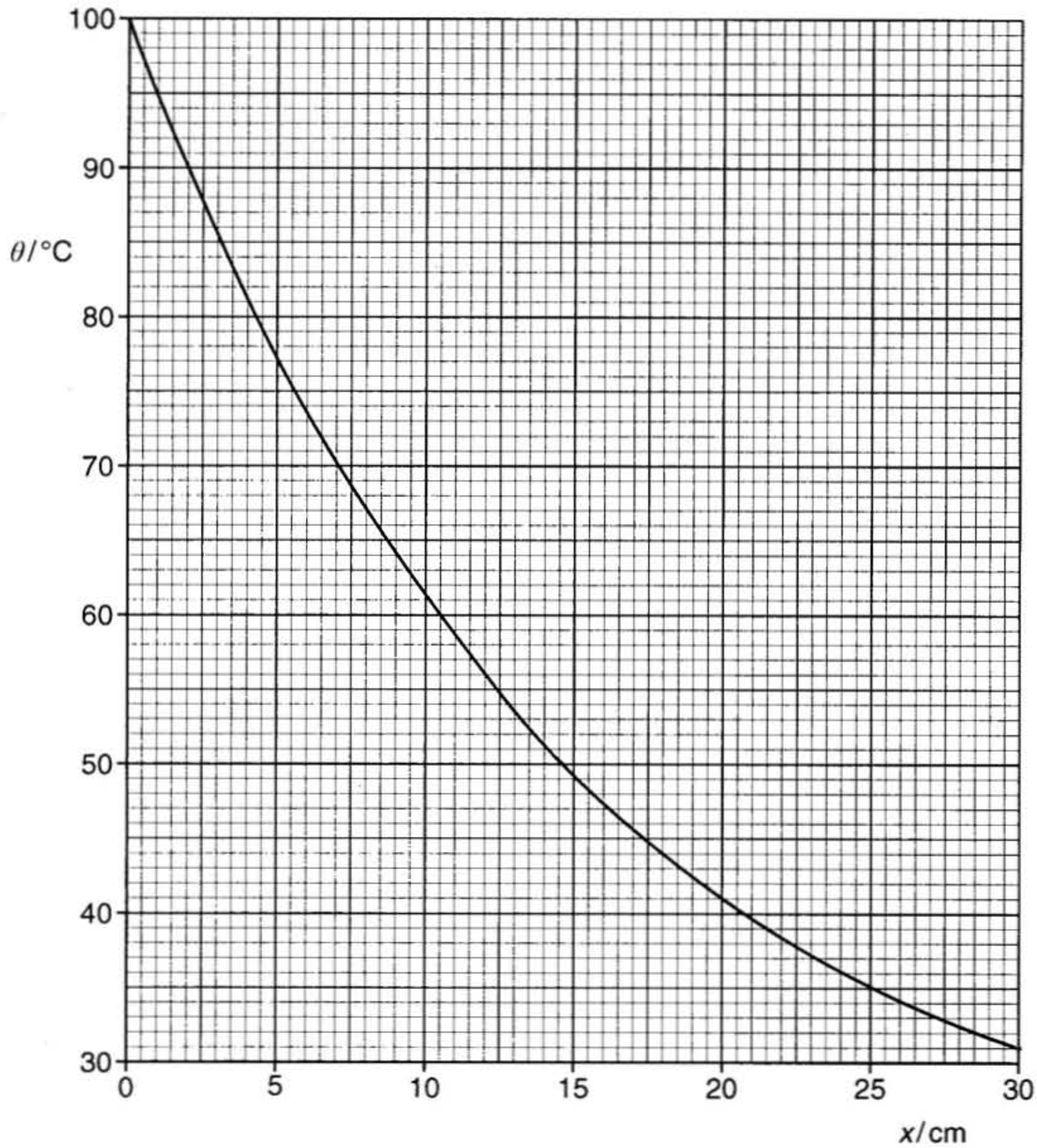

Fig. 6.2

Use Fig. 6.2 to determine the temperature of the rod at a distance x of 17.5 cm.

temperature = ...°C [1]

(b) The rod in **(a)** is shortened and placed between two baths of water, as shown in Fig. 6.3.

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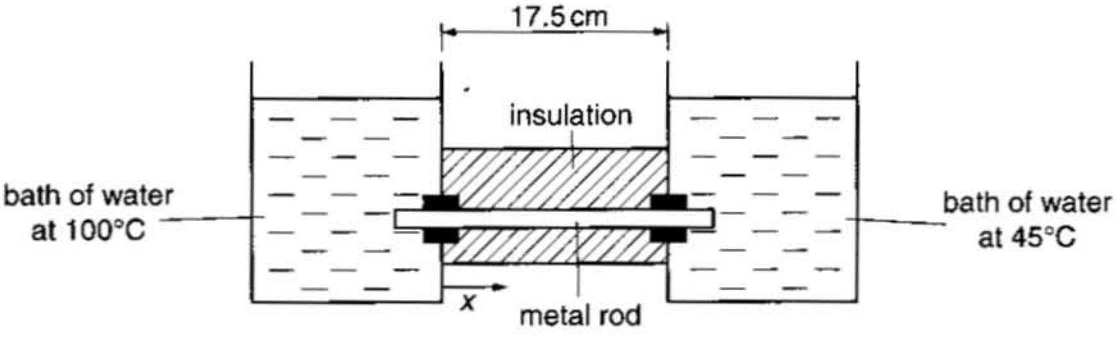

Fig. 6.3

The baths of water are maintained at temperatures of 100 °C and 45 °C. The length of the rod between the baths of water is 17.5 cm and the rod is surrounded by insulation. The apparatus is left until the temperature at any point along the rod does not change. Fig. 6.4 shows the variation of the temperature θ of the rod with the distance x from the hotter bath of water.

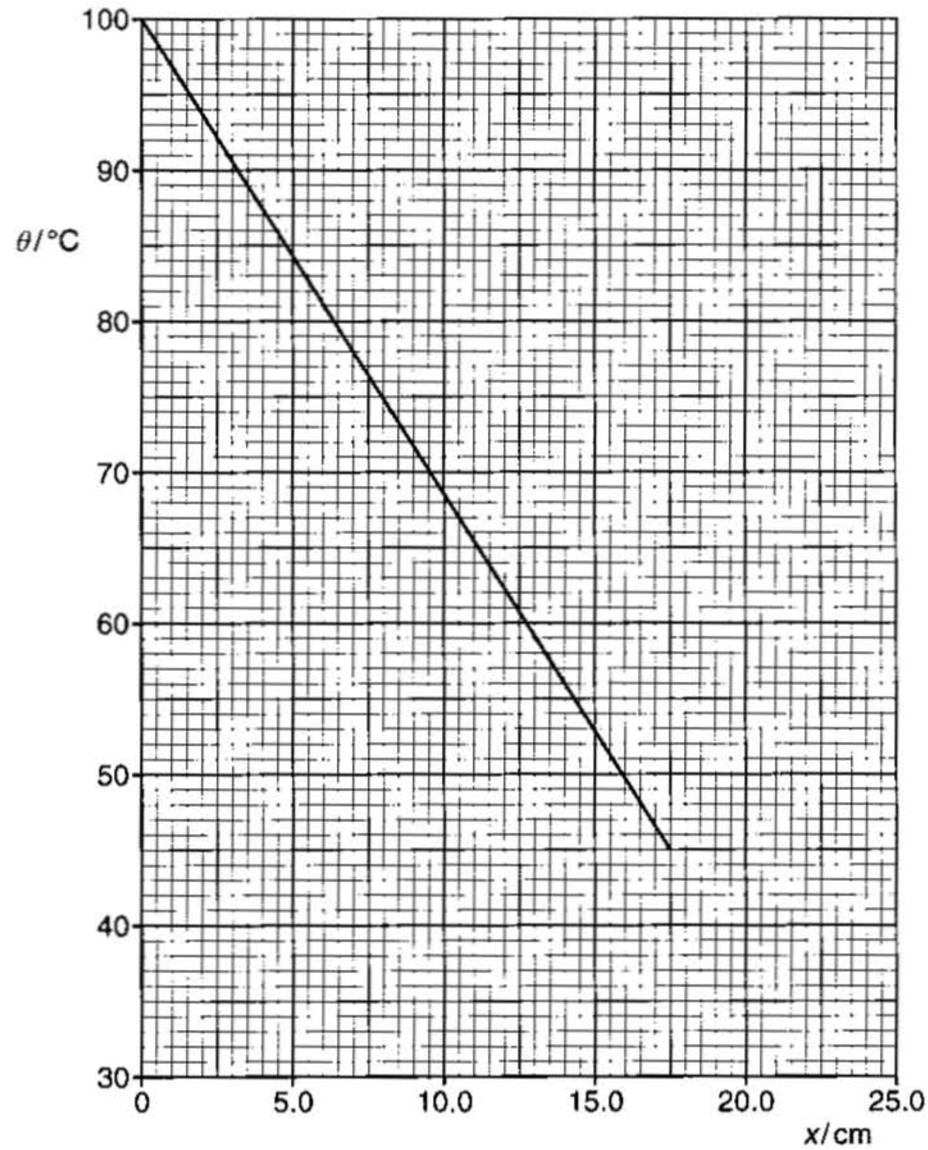

Fig. 6.4

(i) The insulation on the rod is perfect. State the relation between the rate at which thermal energy enters the rod at 100 °C and the rate at which it leaves the rod at 45 °C.

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....[1]

(ii) Use Fig. 6.4 to determine the rate of change of temperature with distance along the rod (the temperature gradient). Give your answer to an appropriate number of significant figures.

temperature gradient = ... $°C\,cm^{-1}$ [2]

(iii) State why, for any value of x between 0.5 cm and 17 cm, the temperature, as shown in Fig. 6.4, is higher than that shown in Fig. 6.2.

....

....[1]

(c) A student thinks that the temperature θ of the insulated rod in **(b)** may be inversely proportional to the distance x along the rod. Show, without drawing a graph, that this proposal is **not** correct.

[2]

(d) A second student thinks that the temperature θ of the non-insulated rod in **(a)** depends on the excess temperature of the rod above its surroundings.

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Furthermore, the student thinks that the excess temperature reduces exponentially with distance along the rod.

In order to test the proposal, the student measures room temperature and then calculates the excess temperature θ_E and $\ln(\theta_E/°C)$ for different values of x. Fig. 6.5 shows some data for x, θ, θ_E and $\ln(\theta_E/°C)$.

room temperature = 20 °C

x/cm	θ/°C	θ_E/°C	$\ln(\theta_E/°C)$
0	100	80	4.38
2.0	90	70	4.25
5.0	77	....	....
8.0	67	47	3.85
12.0	56	36	3.58
15.0	49	29	3.37
17.5	45	25	3.22
20.0	41	21	3.04
25.0	35	15	2.70

Fig. 6.5

(i) Complete Fig. 6.5 for the distance x = 5.0 cm. [1]

(ii) Fig. 6.6 is a graph of some of the data of Fig. 6.5.

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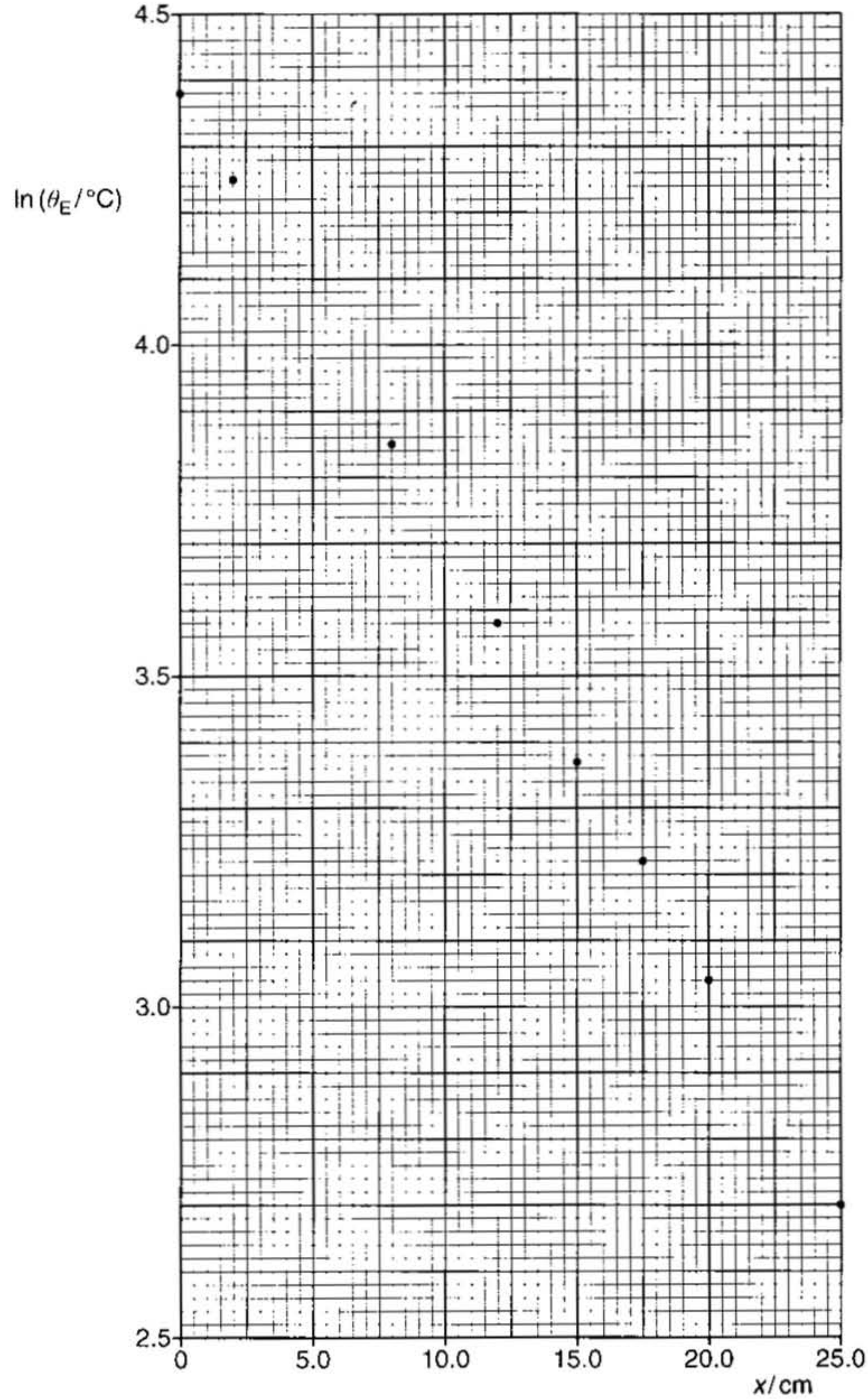

Fig. 6.6

1. Complete Fig. 6.6 using your data for the distance $x = 5.0\,\text{cm}$. [1]

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2. It is proposed that the excess temperature θ_E changes with distance x according to an expression of the form

$$\theta_E = \theta_0\, e^{-\mu x}$$

where θ_0 and μ are constants.

Explain why the graph of Fig. 6.6 supports this proposal.

....

....

....

.... [3]

3. Use Fig. 6.6 to determine the constants θ_0 and μ.

θ_0 = ... °C

μ = ... cm^{-1} [3]

(e) The material of the rod in **(a)** is a metal. A similar rod made of wood replaces the metal rod, under the same conditions.

On the axes of Fig. 6.2, sketch a graph to show a possible variation with distance x of the temperature θ of this wooden rod. [2]