8 Read the article and then answer the questions that follow.

Photovoltaic (PV) Efficiency: The Temperature Effect

A photovoltaic (PV) cell absorbs light energy and converts this into electrical energy. A PV panel consists of a large number of photovoltaic cells. A PV system consists of a PV panel and the rest of the circuit to which it is connected.

Temperature generally affects current in an electrical circuit by changing the speed at which the electrons travel. In metals, this is due to an increase in resistance of the circuit that results from an increase in temperature. The opposite effect is seen in semiconductor materials where an increased temperature results in a decrease in resistance due to a change in the number density of charge carriers.

It is important that the equipment associated with a PV panel is appropriate for the context in which it will be used. The current and voltage output of a PV cell is affected by changing weather conditions. A PV system at a higher temperature will have a lower maximum voltage, lower efficiency and lower power output than the same system at a lower temperature.

Engineers must carefully choose the PV system for different temperature environments to ensure that the output voltage is not too high, which could damage the equipment. It is also important to consider the average operating voltage and current of a PV system for safety concerns, equipment capabilities and choices, and to minimize the amount of wire required for construction.

Since PV panels are more efficient at lower temperatures, engineers design systems with active and passive cooling. An example of active cooling is to pump water behind the panels to remove the heat. An example of passive cooling is to let the system be cooled by convection currents in the air.

While it is important to know the temperature of a solar PV panel to predict its power output, it is also important to know the PV panel materials because the efficiencies of different materials have varied levels of dependence on temperature. Therefore, a PV system must be engineered not only according to the maximum, minimum and average environmental temperatures at each location, but also with an understanding of the materials used.

The temperature dependence of a material is described with a temperature coefficient. For monocrystalline PV panels, if the temperature decreases by 1 °C, the voltage increases by 0.48 V, so the temperature coefficient is 0.48 V°C^{-1}. The general equation for estimating the open circuit voltage V of a material at the temperature T of the panel is

$$V = \mu(T_R - T) + V_R$$

where μ is the temperature coefficient, T_R is a reference temperature and V_R is the open circuit voltage at the reference temperature. The temperatures are in degree Celsius.

The variation with voltage of current at two different temperatures for one cell of the panel is shown in Fig. 8.1

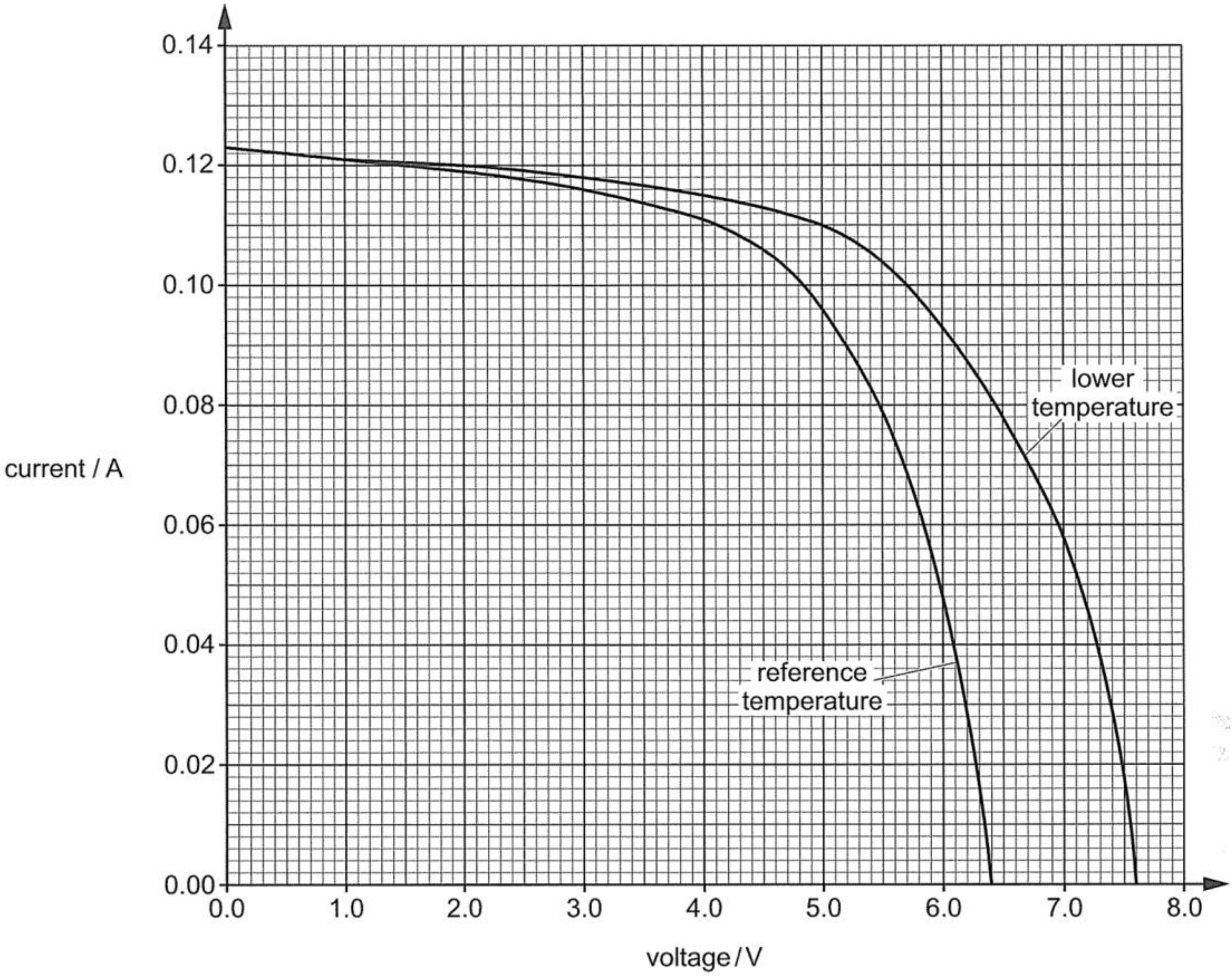

Fig. 8.1

(a) State and explain why the resistance of metals increases with temperature.

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

(b) The panel produces a much larger voltage or current than an individual cell. State how the cells are connected in a panel so that

(i) the voltage is increased,

…………………………………………………………………………………………… [1]

(ii) the current is increased.

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(c) Suggest why engineers do not design systems with active cooling alone.

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(d) Suggest how passive air cooling may be enhanced for a PV panel.

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(e) **(i)** Use Fig. 8.1 to state the open circuit voltage (e.m.f.) of the PV cell at both the reference temperature and the lower temperature.

V_R = ... V

V = ... V [1]

(ii) Use Fig. 8.1 to describe qualitatively the variation with temperature of the current in the cell.

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

(iii) Fig. 8.2 shows the variation with temperature T of the open circuit voltage V. Draw the line of best fit. [1]

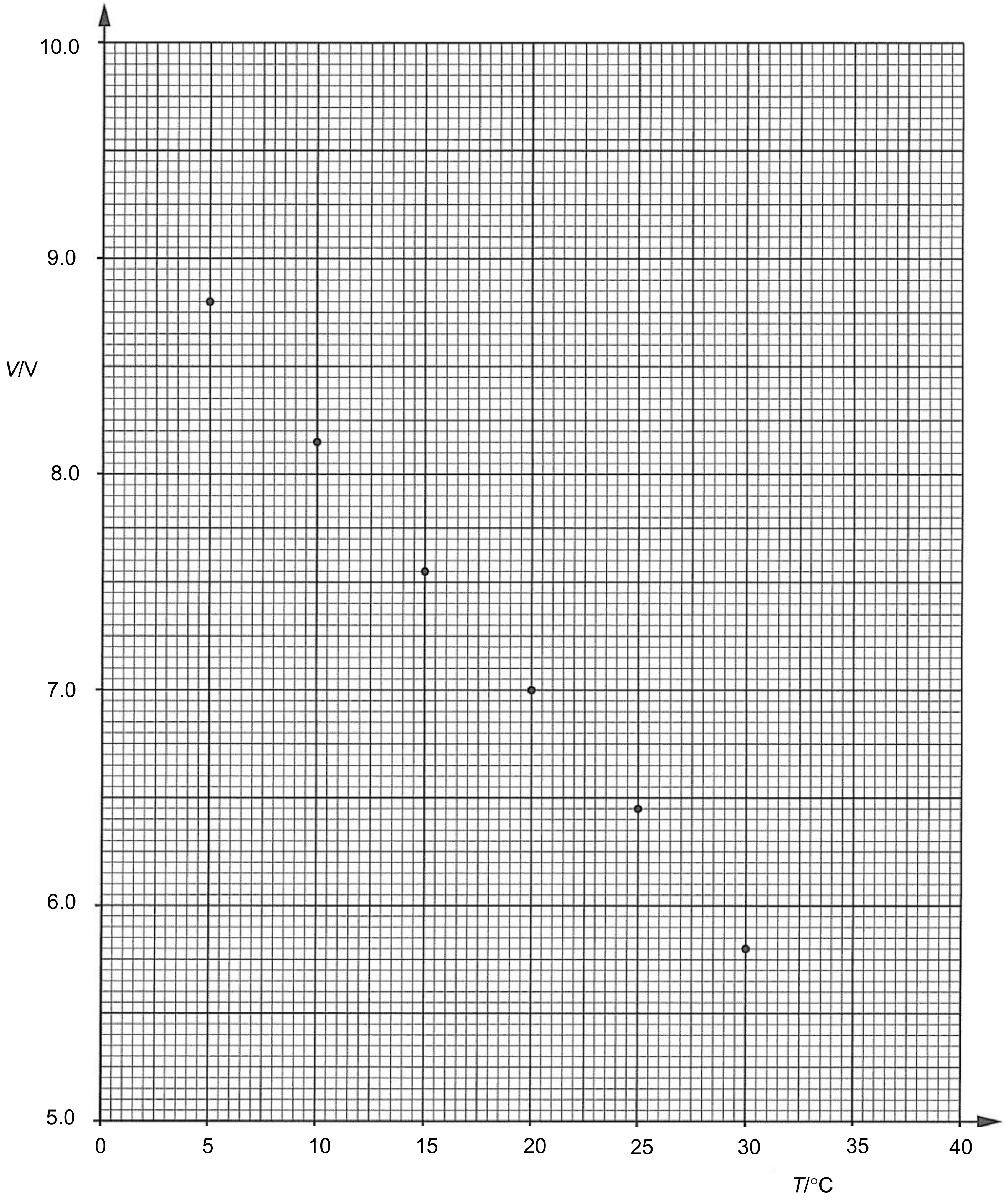

Fig. 8.2

(iv) Use Fig. 8.2 to determine the constants μ and T_R.

μ = ... V °C^{-1}

T_R = ... °C [4]

(v) Use your answers to **(e)(i)** and **e(iv)** to determine the lower temperature used to obtain the data for Fig. 8.1.

lower temperature = ... °C [1]

(vi) The PV cell is producing 6.0 V at the reference temperature.

On Fig. 8.1, indicate the area which represents the output power of the cell. [1]

(vii) Use Fig. 8.1 to estimate the maximum power output of the PV cell at the reference temperature.

maximum power output = ... W [2]

(f) **(i)** A PV cell may have multiple layers of different semi-conducting materials. As the number of layers increase, the efficiency of conversion of light energy to electrical energy increases.

Suggest a reason why the efficiency increases.

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(ii) Suggest how the angle between the PV panel and the incident sunlight affects the power output of the PV panel.

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[Total: 20]