7 Read the following article and then answer the questions that follow.

Solar Impulse – the future of flight?

Solar Impulse is the name of the project intending to achieve the first circumnavigation of the Earth by a piloted fixed-wing aircraft using only solar power. In March 2015 the project began a circumnavigation using the aircraft Solar Impulse 2. The circumnavigation will be completed in 12 separate stages. During each stage the aircraft undergoes continuous flight through both the day and the night.

On 3rd July 2015 the plane completed the longest stage, from Japan to Hawaii. This consisted of an unbroken flight time of 117 hours 52 minutes and covered a distance of 7212 km.

The cruising altitude (height above sea-level) of Solar Impulse 2 is 8500 m, and it can attain a maximum altitude of 12 000 m. At night-time, the altitude decreases to 1500 m to save energy.

Gliding occurs when the engines of an aircraft are not in use. It is possible to find a *glide ratio* for airborne bodies. This is the ratio of the distance the body travels horizontally to its vertical drop when gliding. The glide ratio is also the lift to drag ratio (the ratio of the vertically upward force on the aircraft to the resistive force on the aircraft) for an aircraft in horizontal flight at constant speed. For Solar Impulse 2, the value of the glide ratio is 40, which is greater than for birds and other aircraft and similar to the best gliders.

Solar Impulse 2 has a wing span of 71.9 m and a mass of 2300 kg. The top of the aircraft has 17 248 photovoltaic cells, covering an area of 270 m^2. These cells together can develop a combined peak power of 66 kW.

The electrical energy from the photovoltaic cells is stored in four Lithium-ion batteries. Each battery is able to store 41 kWh of energy when fully charged. The batteries supply power to four electric motors. Each motor is supplied with 13 kW of power when operating normally. The batteries have a total mass of 633 kg and an energy density of 0.260 kWh kg^{-1}. The amount of energy the photovoltaic cells capture depends upon many variables including geographic location (angle of latitude), time of day, time of year, altitude and the weather. During daylight hours the aircraft needs to collect more energy than it uses.

The intensity I (in kW m^{-2}) of the sunlight incident on the photovoltaic cells is given by

$$I = 1.353 \times 0.700^k$$

where $k = M^{0.678}$ and M is the 'air mass', a variable that represents the attenuation of the solar radiation due to the geographic location.

(a) **(i)** Calculate the horizontal distance travelled by Solar Impulse 2 when gliding from cruising altitude to night-time altitude.

distance = ... m [1]

(ii) Suggest two design features that may enable Solar Impulse 2 to have a large glide ratio.

1. ....

....

2. ....

....
[2]

(iii) Use the concept of glide ratio to deduce the drag force acting on Solar Impulse 2 whilst in horizontal flight at constant speed.

drag force = ... N [2]

(b) **(i)** Use the unit $kWh\,kg^{-1}$ to deduce what is meant by the phrase *energy density*.

....

....[1]

(ii) Calculate the total energy, in J, stored in the fully charged batteries.

energy = ... J [1]

(iii) Use your answers to **(a)(iii)** and **(b)(ii)** to determine the maximum distance travelled by Solar Impulse 2 in horizontal flight at constant speed.

distance = ... m [2]

(c) Suggest why the energy collected by the photovoltaic cells depends on the altitude of the aircraft.

....

....

....[1]

(d) Explain why, during daylight hours, the aircraft must collect more energy than it uses.

....

....[1]

(e) The symbol for a photovoltaic (solar) cell is given in Fig. 7.1.

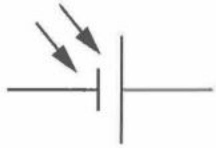

Fig. 7.1

The cell supplies a current I_s at an e.m.f. E_s.

Draw a diagram to suggest how two of these photovoltaic cells may be connected so that the combination supplies

1. a total current greater than I_s at the same e.m.f.,

2. a total e.m.f. greater than E_s.

[2]

(f) The graph in Fig. 7.2 shows the variation with area of the photovoltaic cells of the power collected by the cells for one part of one stage.

The light is incident on the area of the cells and the aircraft is at an altitude of 8500 m over Japan.

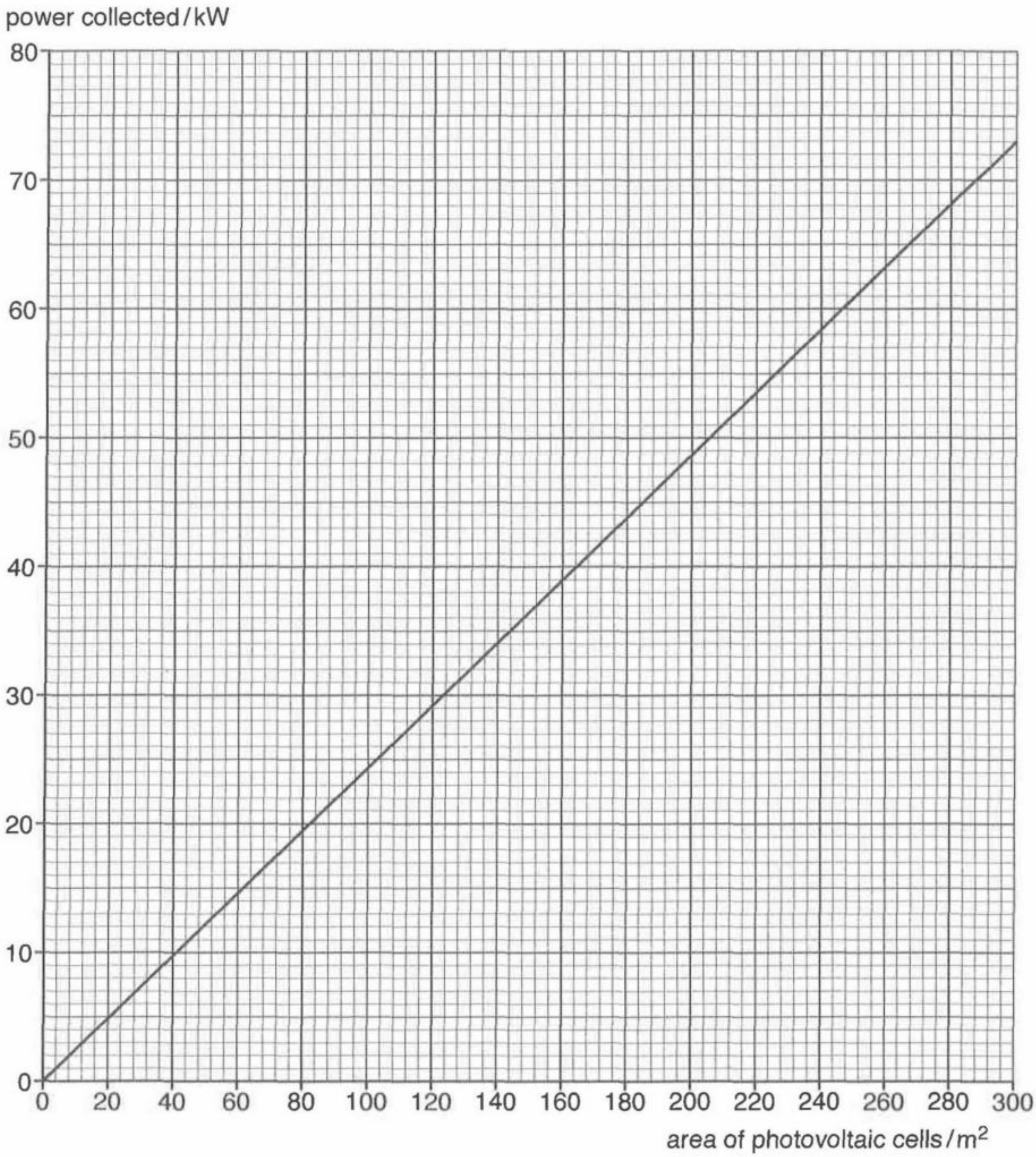

Fig. 7.2

Use Fig. 7.2 to

(i) state the relationship between power and area,

....

....[1]

(ii) state what is represented by the gradient of the graph,

....

....[1]

(iii) calculate the intensity I_c of the collected sunlight.

I_c = ... $W m^{-2}$ [1]

(g) Data for angle of latitude θ and the intensity I_i of incident solar radiation at an altitude of 8500 m are given in Fig. 7.3. Values of M are also given.

angle of latitude θ / °	$M = 1/\cos\theta$	I_i / $kW m^{-2}$
0	1.000	0.947
10	1.015	0.944
20	1.064	0.933
30	1.155	0.913
40	1.305	0.883
50		
60	2.000	0.765
70	2.924	0.647
80	5.759	0.420

Fig. 7.3

The variation with θ of I_i is shown in Fig. 7.4.

(i) Complete Fig. 7.3 for $\theta = 50°$. [1]

(ii) Plot the point for $\theta = 50°$ on Fig. 7.4. [1]

(iii) Complete Fig. 7.4 by drawing the best-fit line. [1]

(iv) Use Fig. 7.4 to determine the intensity of the incident radiation above Japan, at an angle of latitude of 36°.

incident intensity = ... $kW m^{-2}$ [1]

(v) Use your answers from **(f)** and **(g)** to calculate the efficiency of collection of solar power by the solar cells.

efficiency = ... % [1]

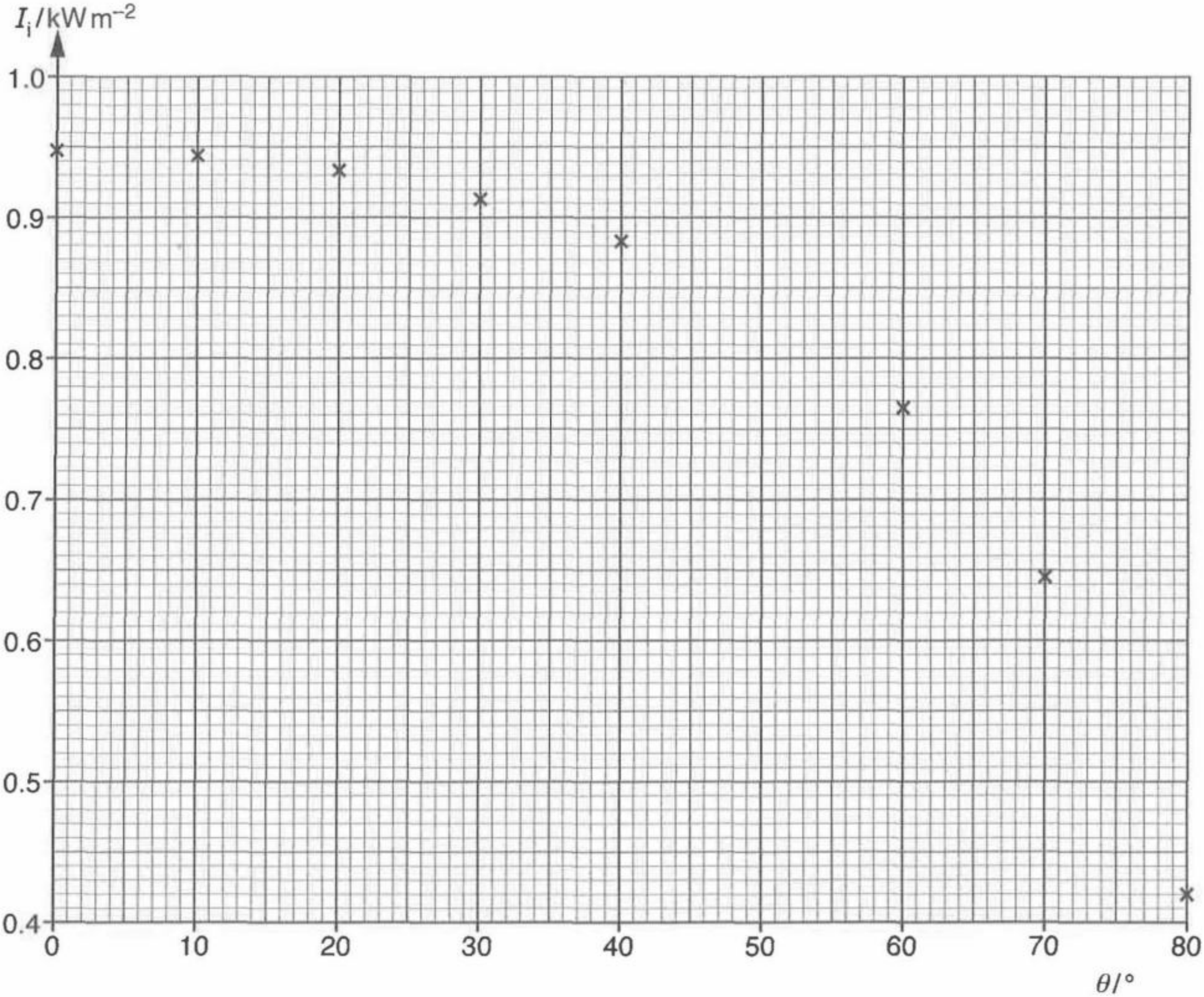

Fig. 7.4

(h) It is unlikely that there will be a purely solar powered passenger aircraft in the near future. Suggest two physics-related reasons for this.

1. ....

....

2. ....

....

[2]