8 A research facility located in the northern hemisphere is used to study the effects of the solar wind from the Sun. At its location, the Earth's magnetic field is found to have a magnetic flux density of 5.2×10^{-5} T at an angle of $70°$ below the horizontal.

(a) A vertical window at the research facility has an aluminium frame ABCD with length 80 cm and width 55 cm, as shown in Fig. 8.1.

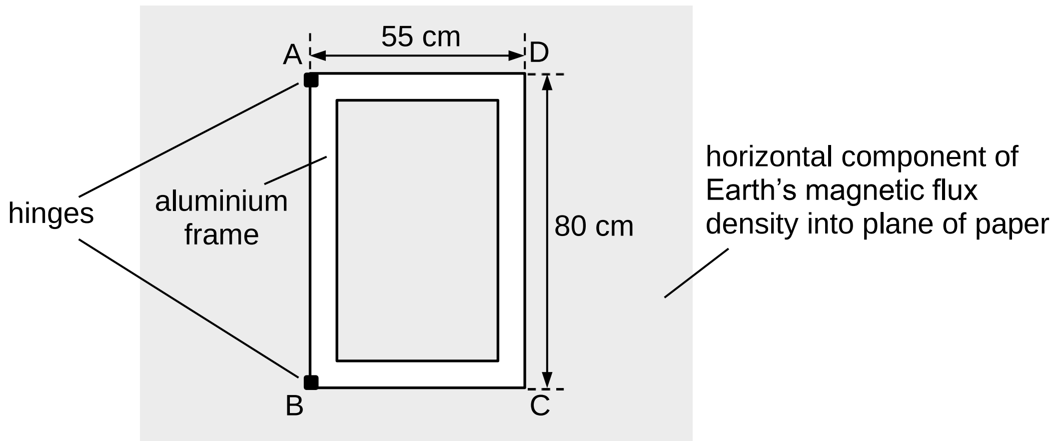

Fig. 8.1

The window is hinged along the side AB. When the window is closed as in Fig. 8.1, the horizontal component of the Earth's magnetic flux density is directed normally into the plane of the window.

(i) Calculate the magnetic flux through the window when it is closed.

magnetic flux = ... Wb [2]

(ii) The window is opened by pushing it into the plane of the paper in a time of 0.30 s. When fully opened, the plane of the window is parallel to the horizontal component of the Earth's magnetic flux density.

During the opening of the window,

1. use the laws of electromagnetic induction to explain why there is a current induced in the aluminium frame,

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.... [3]

2. determine the change in the magnetic flux through the window,

magnetic flux = ... Wb [1]

3. calculate the magnitude of the average e.m.f. induced in side CD of the frame.

e.m.f. = ... V [2]

(b) An electron and an alpha particle from the solar wind enter a region of uniform magnetic field. Both particles are travelling along the same path with the same speed just before they enter the uniform magnetic field, as shown in Fig. 8.2.

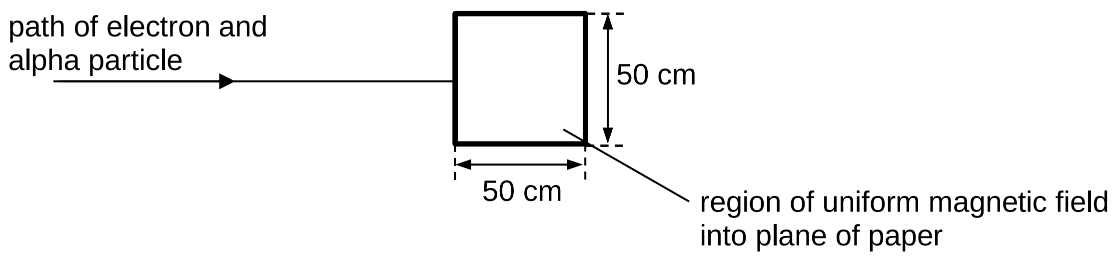

Fig. 8.2

The direction of the magnetic field is into the plane of the paper.

The particles enter the region of the magnetic field at right angles to the edge of the region. Both particles follow circular paths in the magnetic field.

(i) Explain why the charged particles follow circular paths in the magnetic field.

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.... [2]

(ii) Show that the radius r_α of the circular path of the alpha particle is related to the radius r_e of the circular path of the electron by the equation

$$r_\alpha = 3.6 \times 10^3 r_e .$$

Explain your working.

[2]

(iii) The radius of the circular path of the electron is observed to be about 7 mm.

On Fig. 8.2, draw a possible path for the alpha particle as it passes through and beyond the region of the magnetic field.

[1]

(iv) The uniform magnetic field in Fig. 8.2 is now replaced with a varying magnetic field. The variation with time t of the magnetic flux density B of this new magnetic field is shown in Fig. 8.3.

Positive values of B indicate that the magnetic field is directed into the plane of the paper.

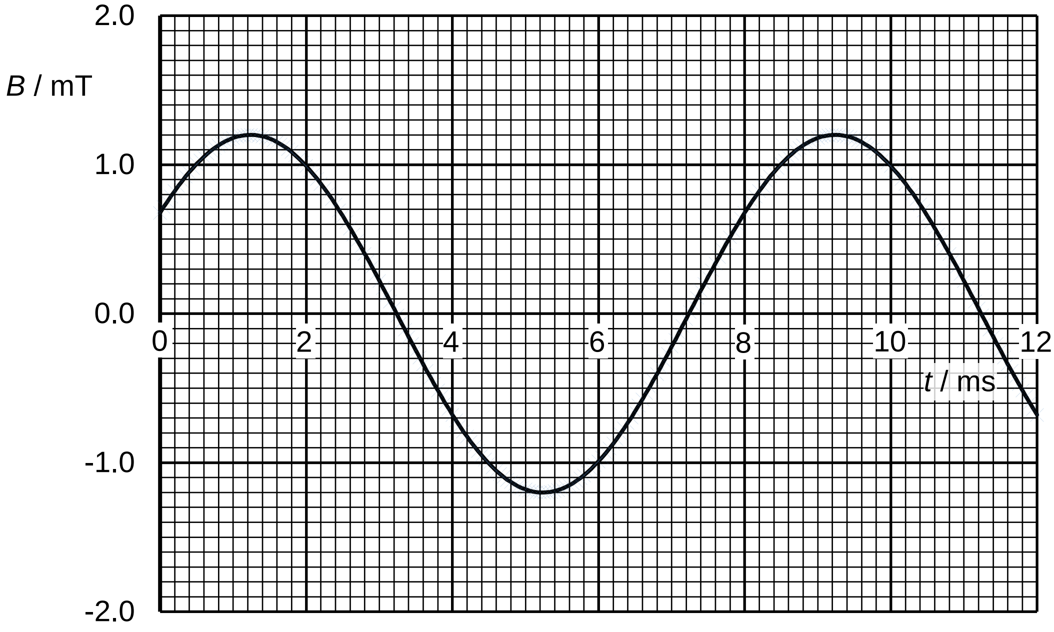

Fig. 8.3

Another electron travelling perpendicularly to the magnetic field and at a speed of 1.2×10^6 m s^{-1} enters the centre of the magnetic field at time $t = 0$ ms.

From Fig. 8.3, at $t = 0$ ms, $B = 0.70$ mT.

1. Show that the radius of curvature of the electron's path is 9.8 mm at $B = 0.70$ mT.

[1]

2. Calculate the period of the electron's motion at $B = 0.70$ mT .

T = ... s [2]

3. Describe the path of the electron in the magnetic field for the first 4.0 ms, assuming it stays in the magnetic field for the whole of this duration.

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.... [3]

4. In reality, the electron leaves the magnetic field before 4.0 ms.

Without any calculations, state a possible time when this occurs.

Explain your answer.

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.... [1]

[Total: 20]