20. Magnetic Fields

20.3 Force on a moving charge

Paper 4

Question Paper

1 **(b)** Fig. 5.1 shows two parallel conducting plates that are in a vacuum. The plates are separated by a distance of 6.7 cm and have a potential difference (p.d.) of 430 V between them.

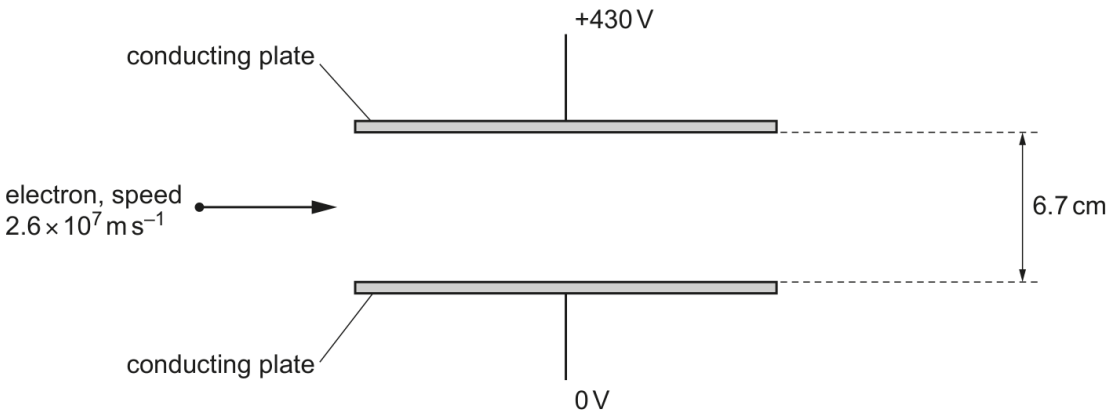


Fig. 5.1

(iii) An electron travels at a speed of 2.6×10^7 m s^{-1} towards the region between the plates, as shown in Fig. 5.1.

(c) A uniform magnetic field is now applied in the region of the electric field in Fig. 5.1, so that the electron in **(b)(iii)** travels undeviated through the region.

(i) Determine the direction of the uniform magnetic field.

..... [1]

(ii) Explain, with reference to the forces exerted by the two fields on the electron, why the path of the electron is undeviated.

.....

.....

..... [2]

(iii) Determine the flux density *B* of the uniform magnetic field. Give a unit with your answer.

B = ... unit ..... [2]

2 **(b)** Electrons are moving in a vacuum with speed $1.7 \times 10^7\,\text{m s}^{-1}$. The electrons enter a uniform magnetic field of flux density 4.8 mT. Fig. 6.1 shows the path of the electrons.

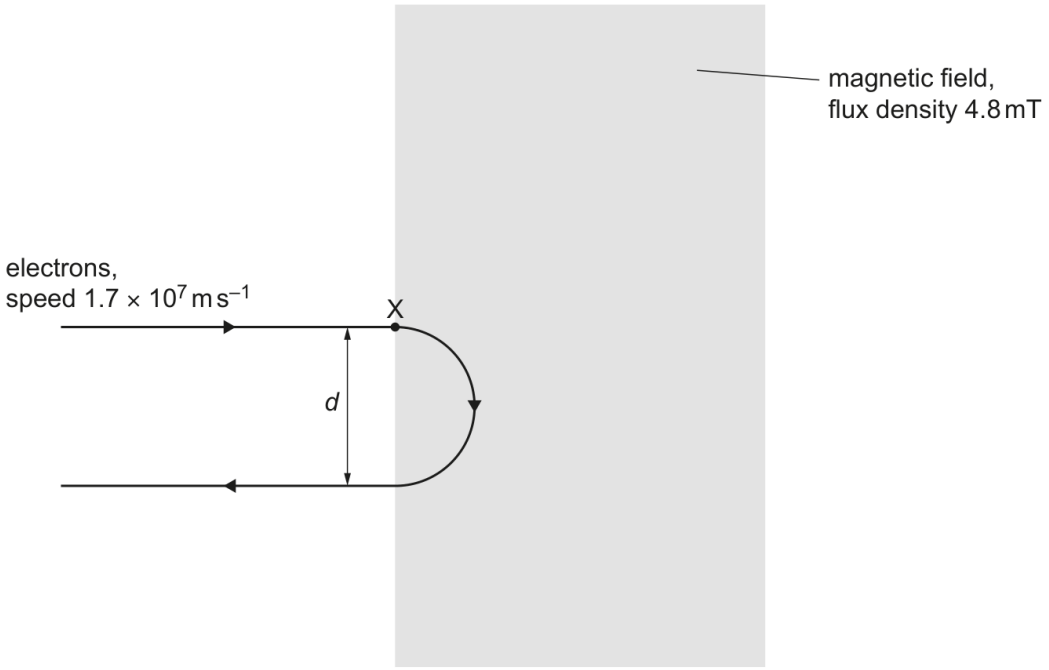


Fig. 6.1

The path of the electrons remains in the plane of the page.

(i) State the direction of the magnetic field.

.....

..... [1]

(ii) Show that the magnitude of the force exerted on each electron by the magnetic field is $1.3 \times 10^{-14}\,\text{N}$.

[2]

(iii) On Fig. 6.1, draw an arrow to indicate the direction of the centripetal acceleration of the electron where it enters the magnetic field at point X. [1]

(iv) Use the information in **(b)(ii)** to calculate the distance *d* between the path of the electrons entering the magnetic field and the path of the electrons leaving it.

d = ... m [3]

(c) The electrons in **(b)** are replaced with positrons that are moving with speed $3.4 \times 10^7\,\text{m s}^{-1}$ along the same initial path as the electrons.
The positrons enter the magnetic field at point X on Fig. 6.1.

On Fig. 6.1, draw a line to show the path of the positrons through the magnetic field. [3]

3 **(a)** A Hall probe containing a thin slice of semiconducting material is placed in a uniform magnetic field of flux density *B*. The largest faces of the slice are perpendicular to the magnetic field, as shown in Fig. 7.1.

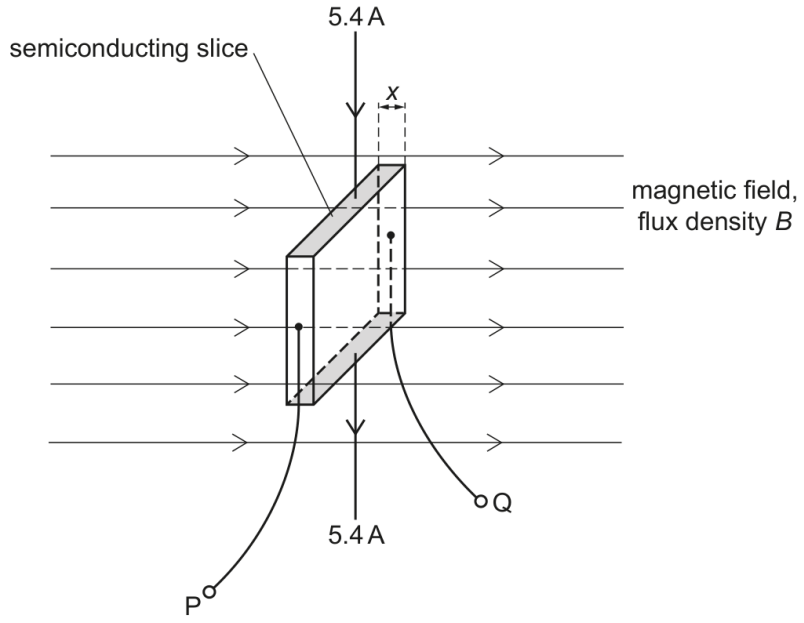


Fig. 7.1

The thickness *x* of the slice is 1.8 mm. The number density of charge carriers in the semiconducting material is $1.5 \times 10^{16}\,m^{-3}$.
A constant current of 5.4 A is passed through the slice between the shaded faces.
The Hall voltage V_H that is developed between the terminals PQ is recorded.

Fig. 7.2 shows the variation with time *t* of *B*.

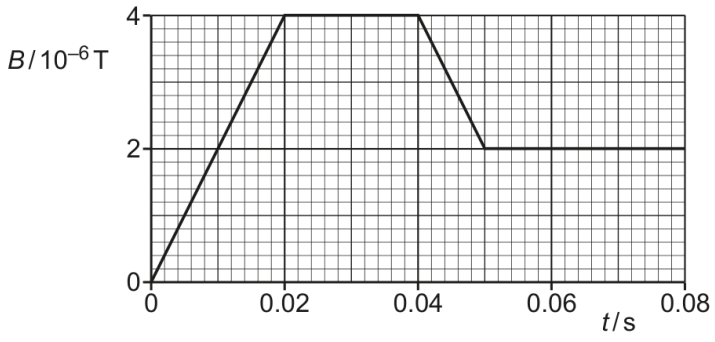


Fig. 7.2

(i) Show that, when *B* is equal to 4.0×10^{-6} T, the magnitude of V_H is 5.0 V.

[1]

(ii) On Fig. 7.3, sketch the variation of V_H with t between $t = 0$ and $t = 0.080\,s$.

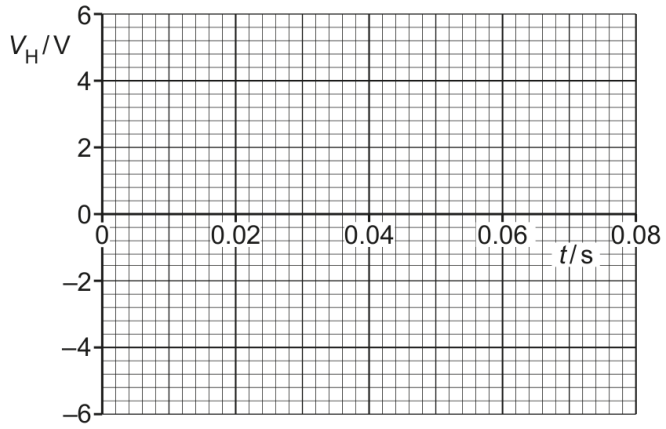


Fig. 7.3

[3]

4 A sphere of mass 1.6×10^{-10} kg has a charge of +0.27 nC. The sphere is in a uniform electric field that acts vertically upwards, as shown in the side view in Fig. 2.1.

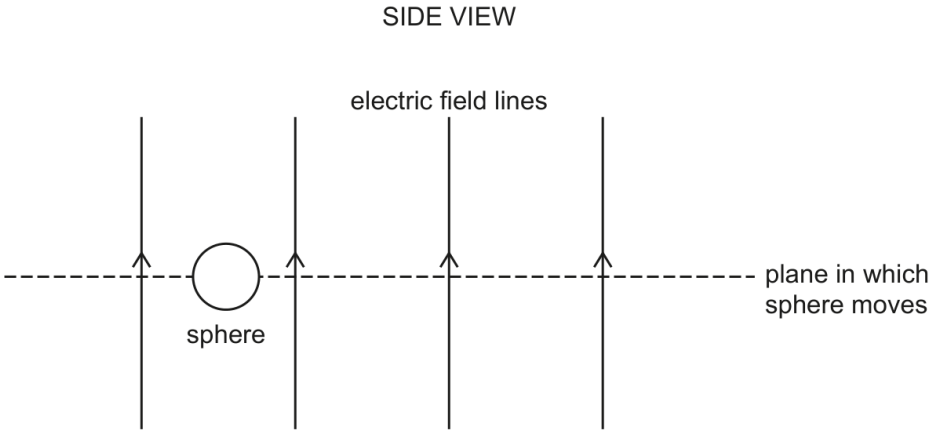


Fig. 2.1

The force exerted on the sphere by the electric field causes the sphere to remain at a fixed vertical height in a horizontal plane.

There is a uniform magnetic field in the region of the electric field. The sphere moves at a speed of $0.78\,m\,s^{-1}$ in the horizontal plane. The magnetic field causes the sphere to move in a circular path of radius 3.4 m, as shown in the view from above in Fig. 2.2.

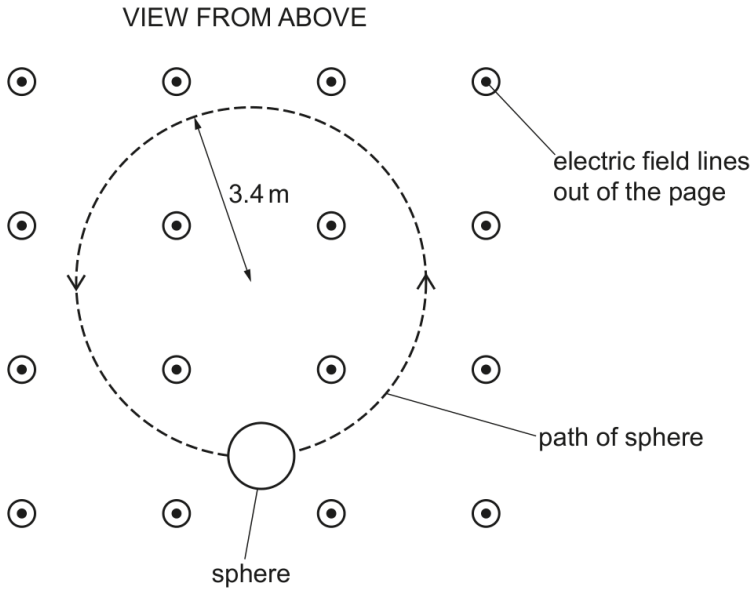


Fig. 2.2

(a) (i) Determine the direction of the uniform magnetic field.

..... [1]

(ii) Explain why the motion of the sphere in the horizontal plane is circular.

.....

.....

..... [2]

(c) By considering the magnetic force on the sphere, show that the flux density of the uniform magnetic field is 0.14 T.

[3]

5 Fig. 6.1 shows a thin slice of semiconducting material used in a Hall probe.

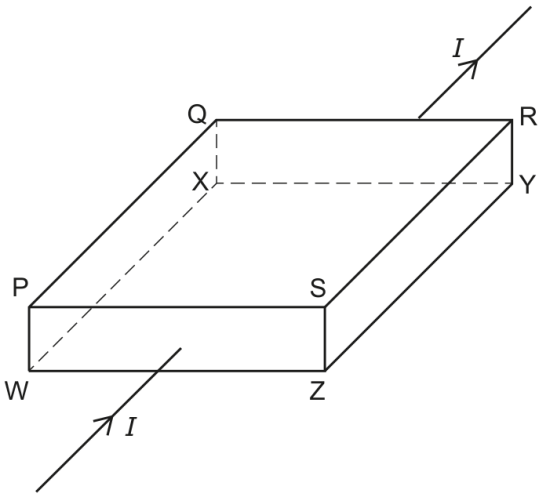


Fig. 6.1 (not to scale)

Current I passes through the slice in the direction shown.

The slice is placed in a uniform magnetic field of flux density B, so that two of its faces are perpendicular to the magnetic field.

A steady Hall voltage V_H is developed between face PQXW and face SRYZ.

(a) (i) Use the letters in Fig. 6.1 to identify the faces that are perpendicular to the magnetic field.

..... and ..... [1]

(ii) Explain how the steady Hall voltage V_H is developed between faces PQXW and SRYZ.

.....

.....

.....

.....

..... [3]

(b) The magnitude of V_H is given by the equation

$$V_H = \frac{BI}{ntq}.$$

(i) State the meaning of the symbols n, t and q. You may refer to the letters in Fig. 6.1.

n: .....

t: .....

q: .....

[3]

(ii) Suggest, with reference to the equation, why the slice of the material used in a Hall probe is thin.

.....

.....

..... [2]

6 **(b)** A rectangular piece of aluminium foil is situated in a uniform magnetic field of flux density *B*, as shown in Fig. 9.1.

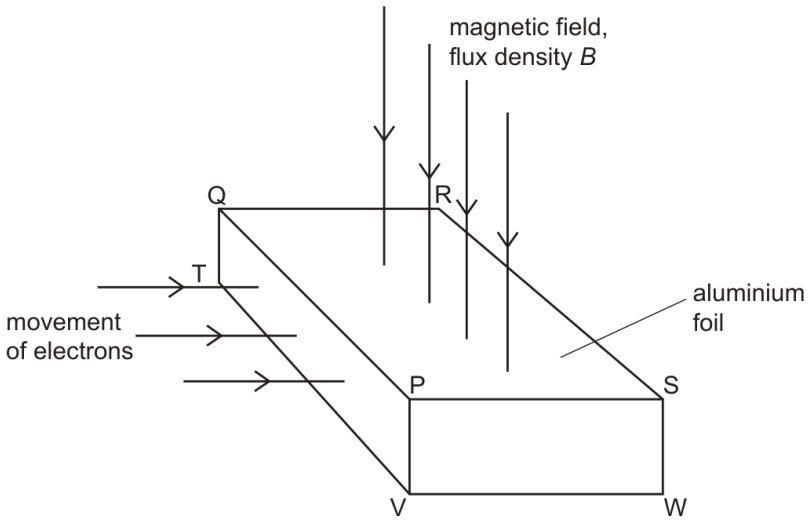


Fig. 9.1

The magnetic field is normal to the face PQRS of the foil.

Electrons, each of charge $-q$, enter the foil at right angles to the face PQTV.

(i) On Fig. 9.1, shade the face of the foil on which electrons initially accumulate. [1]

(ii) Explain why electrons do not continuously accumulate on the face you have shaded.

.....

.....

.....

..... [3]

(c) The Hall voltage V_H developed across the foil in **(b)** is given by the expression

$$V_H = \frac{BI}{ntq}$$

where I is the current in the foil.

(i) State the meaning of the quantity *n*.

.....

..... [1]

(ii) Using the letters on Fig. 9.1, identify the distance *t*.

..... [1]

(d) Suggest why, in practice, Hall probes are usually made using a semiconductor material rather than a metal.

.....

..... [1]

7 **(c)** The accelerated electrons in **(b)** are injected at point S into a region of uniform magnetic field of flux density *B*, as illustrated in Fig. 8.1.

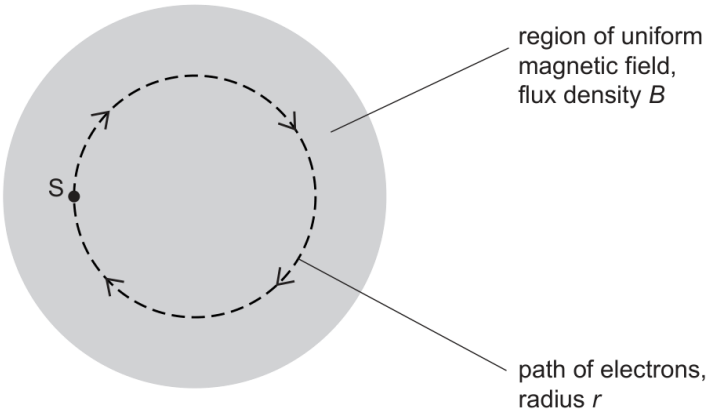


Fig. 8.1

The electrons move at right angles to the direction of the magnetic field. The path of the electrons is a circle of radius *r*.

(i) Show that the specific charge $\frac{q}{m}$ of the electrons is given by the expression

$$\frac{q}{m} = \frac{2V}{B^2 r^2}.$$

Explain your working.

[2]

(ii) Electrons are accelerated through a potential difference *V* of 230 V. The electrons are injected normally into the magnetic field of flux density 0.38 mT.
The radius *r* of the circular orbit of the electrons is 14 cm.

Use this information to calculate a value for the specific charge of an electron.

specific charge = ... $C\,kg^{-1}$ [2]

(iii) Suggest why the arrangement outlined in **(ii)**, using the same values of B and V, is not practical for the determination of the specific charge of α-particles.

.....

.....

..... [2]

8 **(a)** State **two** situations in which a charged particle in a magnetic field does **not** experience a force.

1. .....

.....

2. .....

.....
[2]

9 **(a)** An electron is travelling at speed v in a straight line in a vacuum. It enters a uniform magnetic field of flux density 8.0×10^{-4} T. Initially, the electron is travelling at right angles to the magnetic field, as illustrated in Fig. 9.1.

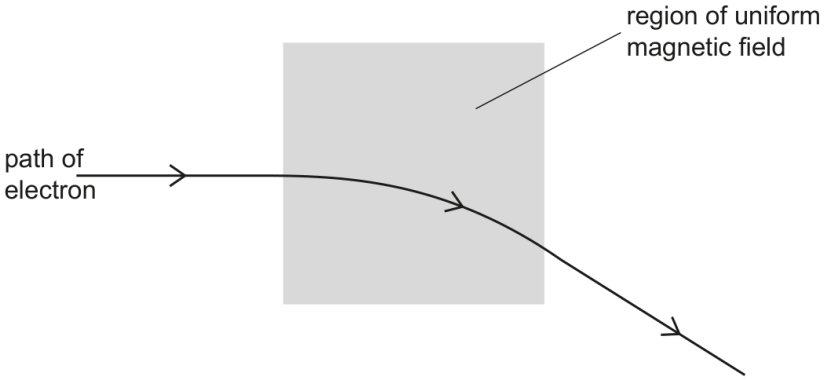


Fig. 9.1

The path of the electron in the magnetic field is an arc of a circle of radius 6.4 cm.

(i) State and explain the direction of the magnetic field.

.....

.....

..... [2]

(ii) Show that the speed v of the electron is $9.0 \times 10^{6}\,\text{m s}^{-1}$.

[3]

(b) A uniform electric field is now applied in the same region as the magnetic field.

The electron passes undeviated through the region of the two fields, as illustrated in Fig. 9.2.

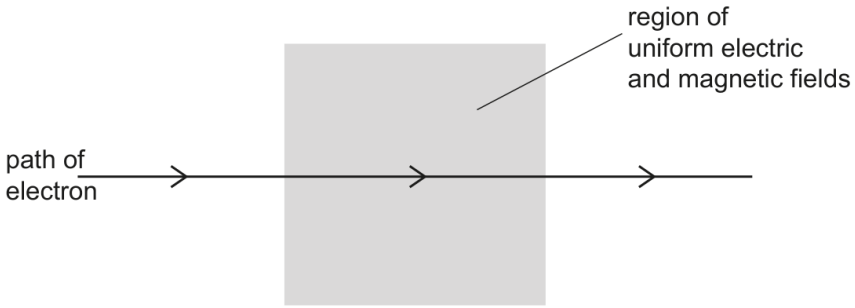


Fig. 9.2

(ii) Use data from **(a)** to calculate the magnitude of the electric field strength.

field strength = ... NC^{-1} [2]

(c) The electron in **(b)** is now replaced by an α-particle travelling at the same speed v along the same initial path as the electron.

Describe and explain the shape of the path in the region of the magnetic and electric fields.

.....

.....

..... [2]

10 A slice of a conducting material has its face QRLK normal to a uniform magnetic field of flux density *B*, as illustrated in Fig. 8.1.

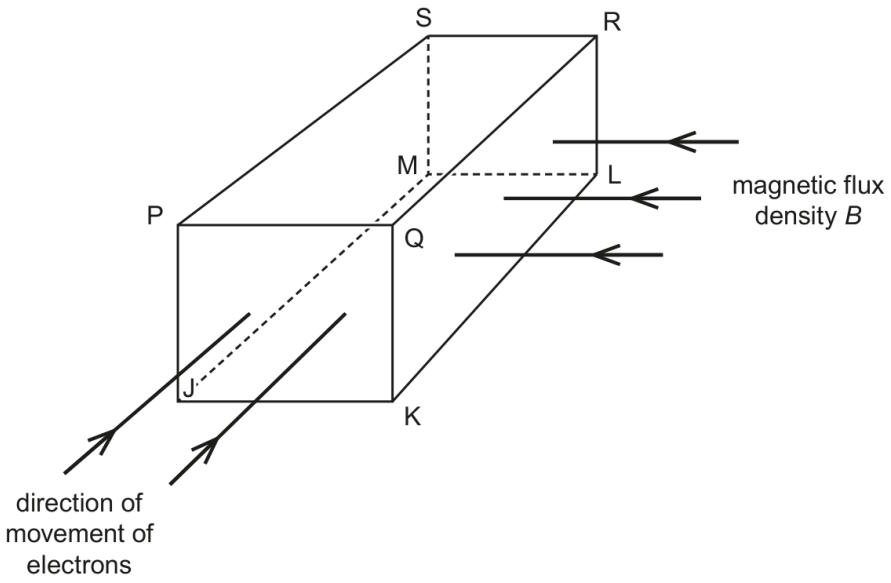


Fig. 8.1

Electrons enter the slice travelling perpendicular to face PQKJ.

(a) For the free electrons moving in the slice:

(i) state the direction of the force on an electron due to movement of the electron in the magnetic field

.....

..... [1]

(ii) identify the faces, using the letters on Fig. 8.1, between which a potential difference is developed.

face ..... and face ..... [1]

(b) Explain why the potential difference in **(a)(ii)** reaches a maximum value.

.....

.....

..... [2]

(c) The number of free electrons per unit volume in the slice of material is $1.3 \times 10^{29}\,m^{-3}$.
The thickness PQ of the slice is 0.10 mm.
The magnetic flux density B is 4.6×10^{-3} T.

Calculate the potential difference across the slice for a current of 6.3×10^{-4} A.

potential difference = ... V [2]

(d) The slice in **(c)** is a metal.

By reference to your answer in **(c)**, suggest why Hall probes are usually made using semiconductors rather than metals.

.....

.....

..... [2]

11 (a) A small coil is placed close to one end of a solenoid connected to a power supply. The plane of the small coil is normal to the axis of the solenoid, as illustrated in Fig. 9.1.

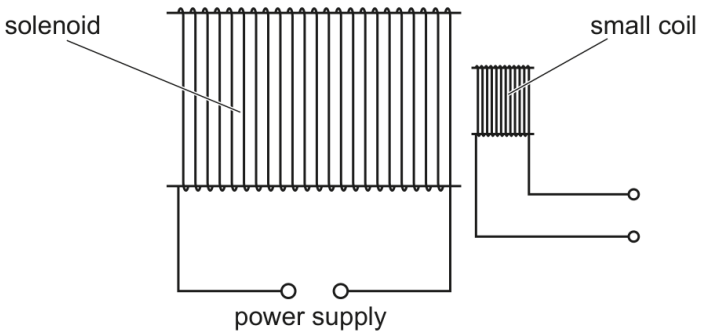


Fig. 9.1

The power supply causes the current I in the solenoid to vary with time t as shown in Fig. 9.2.

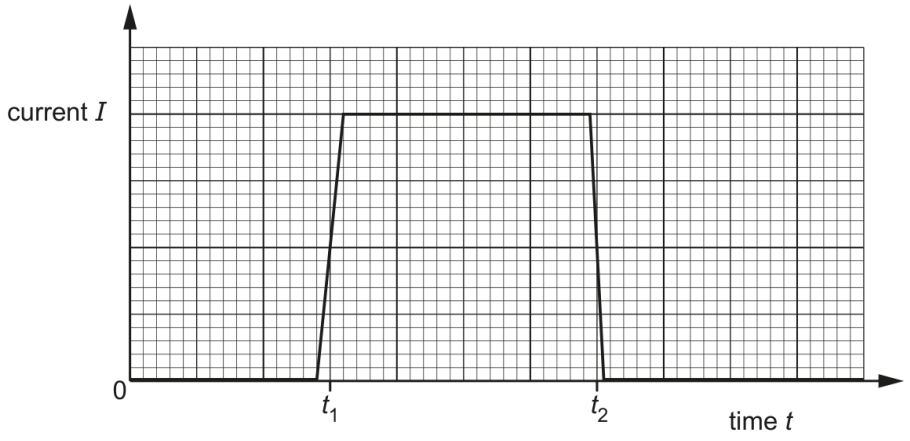


Fig. 9.2

(b) The small coil in **(a)** is now replaced by a Hall probe.

The Hall probe is positioned so that the reading for the probe is a maximum.

The current I in the solenoid varies again as shown in Fig. 9.2.

On the axes of Fig. 9.4, sketch a graph to show the variation with time t of the reading V_H of the probe.

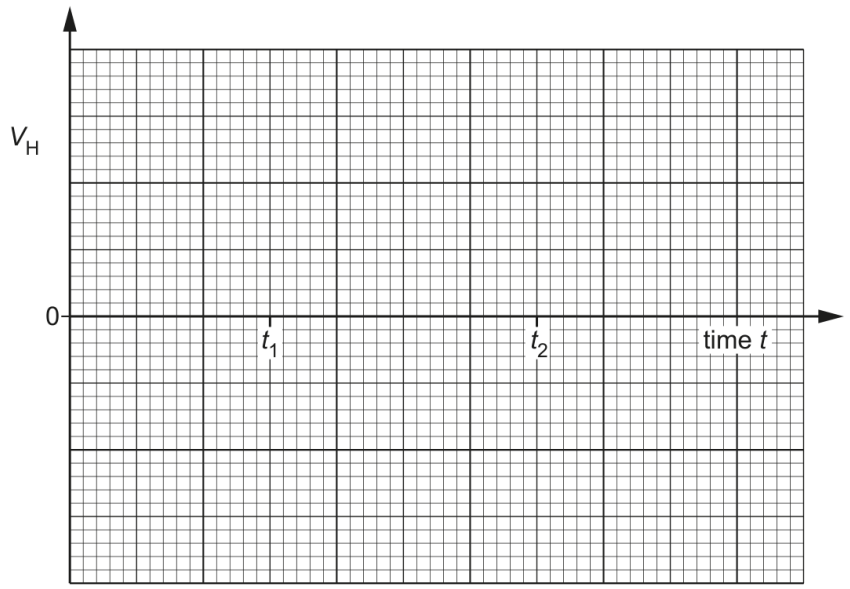


Fig. 9.4

[2]

12 An electron is travelling in a vacuum at a speed of $3.4 \times 10^7\,\text{m s}^{-1}$. The electron enters a region of uniform magnetic field of flux density 3.2 mT, as illustrated in Fig. 8.1.

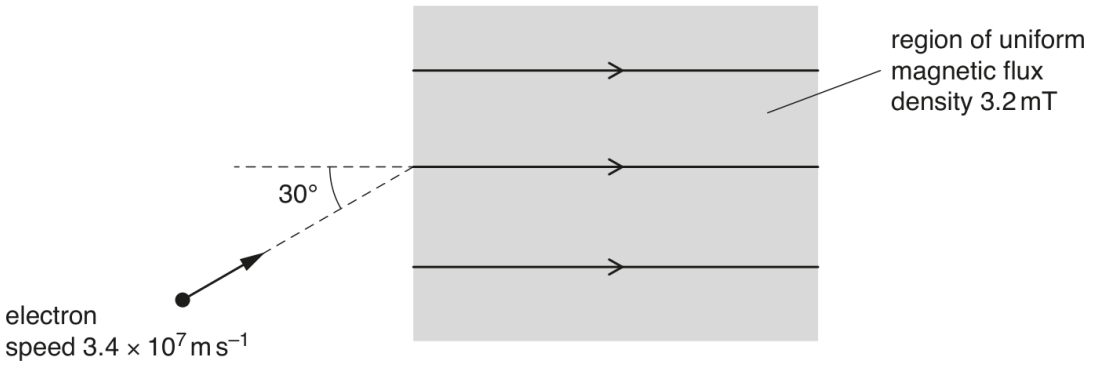


Fig. 8.1

The initial direction of the electron is at an angle of 30° to the direction of the magnetic field.

(a) When the electron enters the magnetic field, the component of its velocity v_N normal to the direction of the magnetic field causes the electron to begin to follow a circular path.

Calculate:

(i) v_N

v_N = ... m s^{-1} [1]

(ii) the radius of this circular path.

radius = ... m [3]

(b) State the magnitude of the force, if any, on the electron in the magnetic field due to the component of its velocity along the direction of the field.

.....[1]

(c) Use information from **(a)** and **(b)** to describe the resultant path of the electron in the magnetic field.

.....

.....[1]

13 Electrons enter a rectangular slice PQRSEFGH of a semiconductor material at right-angles to face PQFE, as shown in Fig. 8.1.

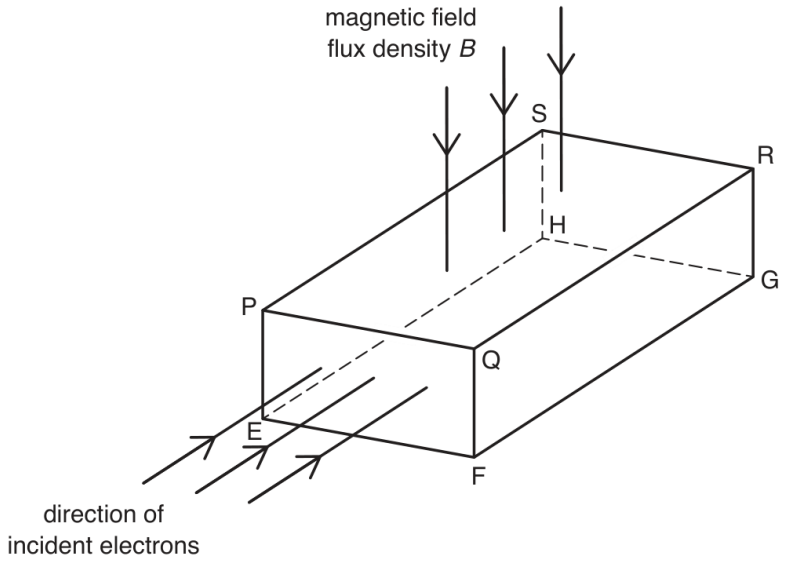


Fig. 8.1

A uniform magnetic field of flux density B is directed into the slice, at right-angles to face PQRS.

(a) The electrons each have charge $-q$ and drift speed v in the slice.

State the magnitude and the direction of the force due to the magnetic field on each electron as it enters the slice.

.....

.....

..... [2]

(b) The force on the electrons causes a voltage V_H to be established across the semiconductor slice given by the expression

$$V_H = \frac{BI}{ntq}$$

where I is the current in the slice.

(i) State the two faces between which the voltage V_H is established.

face ..... and face ..... [1]

(ii) Use letters from Fig. 8.1 to identify the distance t.

..... [1]

(c) Aluminium ($^{27}_{13}Al$) has a density of 2.7 g cm^{-3}. Assume that there is one free electron available to carry charge per atom of aluminium.

(i) Show that the number of charge carriers per unit volume in aluminium is 6.0×10^{28} m^{-3}.

[2]

(ii) A sample of aluminium foil has a thickness of 0.090 mm. The current in the foil is 4.6 A.

A uniform magnetic field of flux density 0.15 T acts at right-angles to the foil.

Use the value in **(i)** to calculate the voltage V_H that is generated.

V_H = ... V [2]

14 (a) Explain how a uniform magnetic field and a uniform electric field may be used as a velocity selector for charged particles.

.....

.....

.....

.....[3]

(b) Particles having mass m and charge $+1.6 \times 10^{-19}$ C pass through a velocity selector. They then enter a region of uniform magnetic field of magnetic flux density 94 mT with speed 3.4×10^{4} m s^{-1}, as shown in Fig. 8.1.

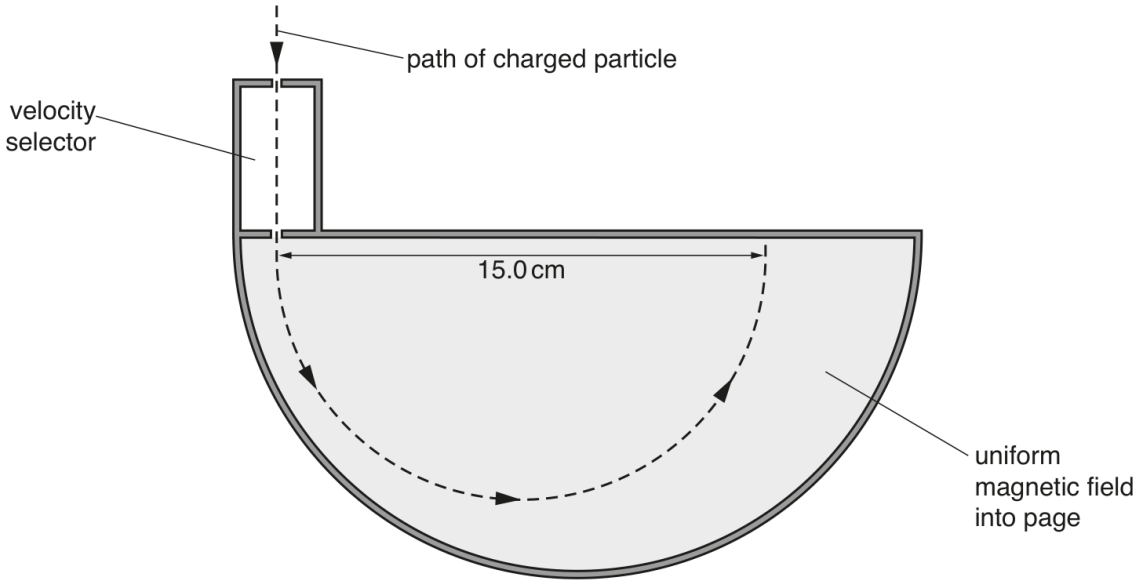


Fig. 8.1

The direction of the uniform magnetic field is into the page and normal to the direction in which the particles are moving.

The particles are moving in a vacuum in a circular arc of diameter 15.0 cm.

Show that the mass of one of the particles is 20 u.

[4]

(c) On Fig. 8.1, sketch the path in the uniform magnetic field of a particle of mass 22 u having the same charge and speed as the particle in **(b)**. [2]

15 (b) A particle has mass m, charge $+q$ and speed v.

The particle enters a uniform magnetic field of flux density B such that, on entry, it is moving normal to the magnetic field, as shown in Fig. 8.1.

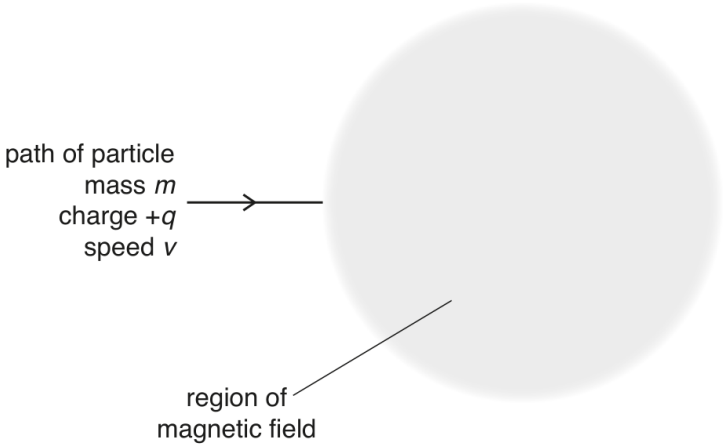


Fig. 8.1

The direction of the magnetic field is perpendicular to, and into, the plane of the paper.

(i) On Fig. 8.1, draw the path of the particle through, and beyond, the region of the magnetic field. [3]

(ii) There is a force acting on the particle, causing it to accelerate.
Explain why the speed of the particle on leaving the magnetic field is v.

.....

.....

.....[1]

(c) The particle in **(b)** loses an electron so that its charge becomes $+2q$. Its change in mass is negligible.

Determine, in terms of v, the initial speed of the particle such that its path through the magnetic field is unchanged. Explain your working.

speed = ... [3]

16 (a) A Hall probe is placed near one end of a solenoid that has been wound on a soft-iron core, as shown in Fig. 9.1.

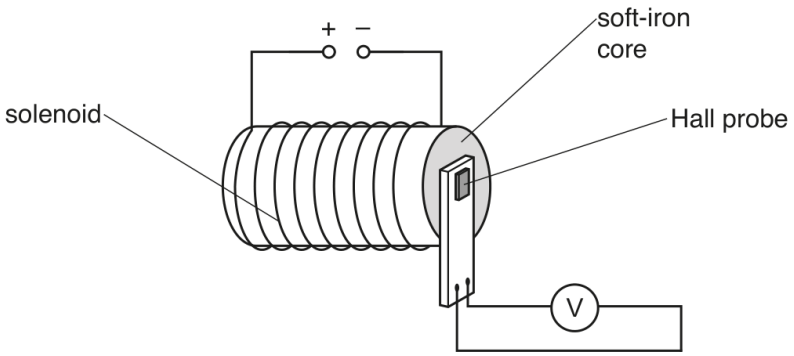


Fig. 9.1

The current in the solenoid is switched on.
The Hall probe is rotated until the reading V_H on the voltmeter is maximum.

The current in the solenoid is then varied, causing the magnetic flux density to change.
The variation with time t of the magnetic flux density B at the Hall probe is shown in Fig. 9.2.

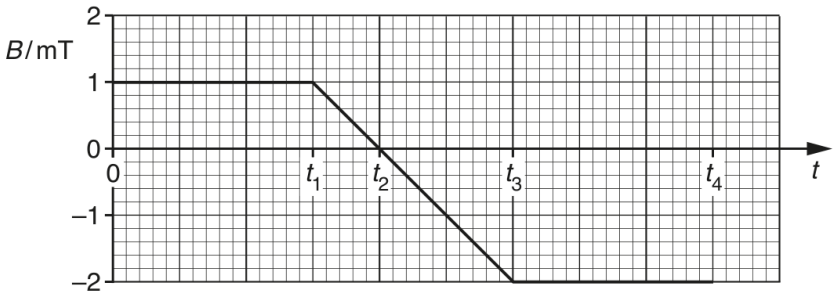


Fig. 9.2

At time $t = 0$, the Hall voltage is V_0.
On Fig. 9.3, draw a line to show the variation with time t of the Hall voltage V_H for time $t = 0$ to time $t = t_4$.

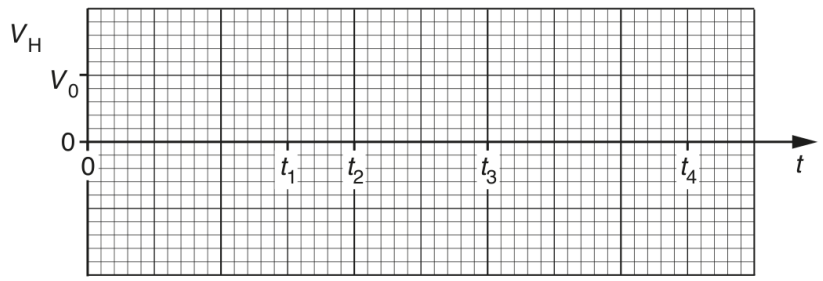


Fig. 9.3

[2]