MAGNETIC FIELDS
WORKSHEET
A-Level Physics 9702

1 **(a)** State Faraday's law of electromagnetic induction. **MJ24/42/Q7**

....

....

.... [2]

(b) Fig. 7.1 shows a coil at rest in a uniform magnetic field that is parallel to the axis of the coil.

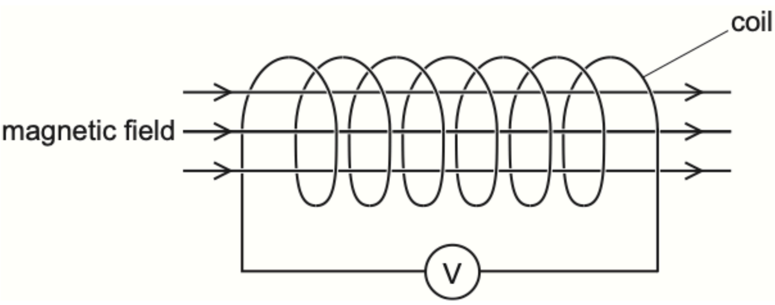

Fig. 7.1

The coil is connected to a centre-zero voltmeter.

The flux density *B* of the uniform magnetic field varies with time *t* as shown in Fig. 7.2.

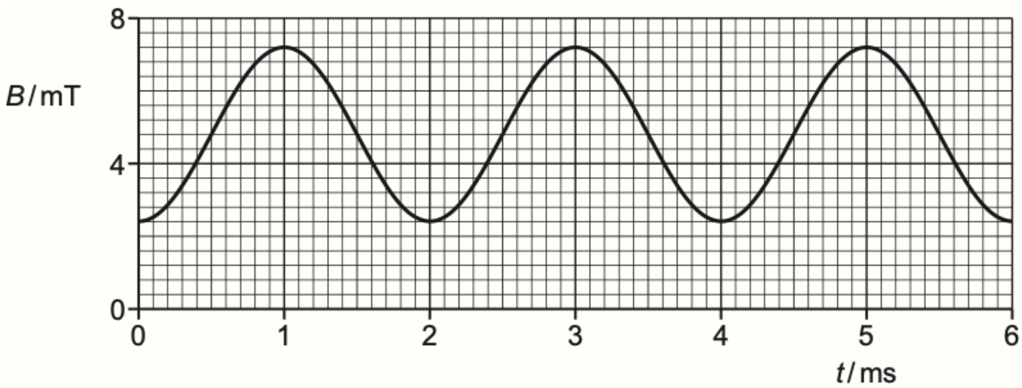

Fig. 7.2

The coil consists of 340 turns, each of cross-sectional area $3.2 \times 10^{-4}\,m^2$.

(i) Calculate the maximum magnetic flux through **one** turn of the coil.

maximum magnetic flux = ... Wb [2]

(ii) Determine the maximum rate of change of magnetic flux linkage in the coil.

maximum rate of change of flux linkage = ... $Wb\,s^{-1}$ [3]

(iii) State the maximum electromotive force (e.m.f.) V_0 induced across the coil.

V_0 = ... V [1]

(iv) On Fig. 7.3, sketch the variation of the e.m.f. V induced across the coil with t from $t = 0$ to $t = 6.0$ ms.

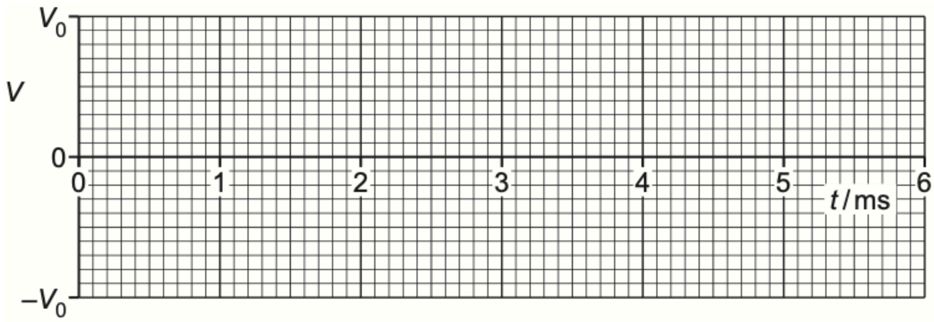

Fig. 7.3

[3]

(v) The variation of V with t can be described by

$$V = A \sin Bt$$

where A and B are constants.

Determine the values of A and B. Give units with your answers.

A = ... unit ....

B = ... unit ....

[3]

[Total: 14]

2 **(a)** An object travels in a circle at constant speed. **March24/42/Q5**

State the names of **two** quantities that vary during the motion of the object.

1 ....

2 ....
[2]

(b) A charged particle of mass *m* and with charge *q* enters a region of uniform magnetic field, perpendicular to the field lines. The magnetic flux density is *B*.

The particle travels in a circle with period *T* and radius *r*.

(i) By considering the magnetic force acting on the particle, show that

$$B = \frac{2\pi m}{qT}.$$

[3]

(ii) The particle is an alpha particle. The period of the circular motion is 2.5 μs.

Calculate *B*.

B = ...T [2]

(iii) A second alpha particle is in the same uniform field. It travels in a circle of radius 2*r*.

State and explain how the periods of the motion of the two particles compare.

....

....

.... [1]

(iv) The speed of the alpha particle in **(b)(ii)** is $1.1 \times 10^6\,m\,s^{-1}$. An electric field is applied so that this particle now moves with constant velocity.

Use your answer in **(b)(ii)** to calculate the electric field strength E. Give the unit with your answer.

E = ... unit .... [2]

[Total: 10]

3 **(a)** Define magnetic flux density. **ON23/41/Q6**

....

....

....

.... [2]

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

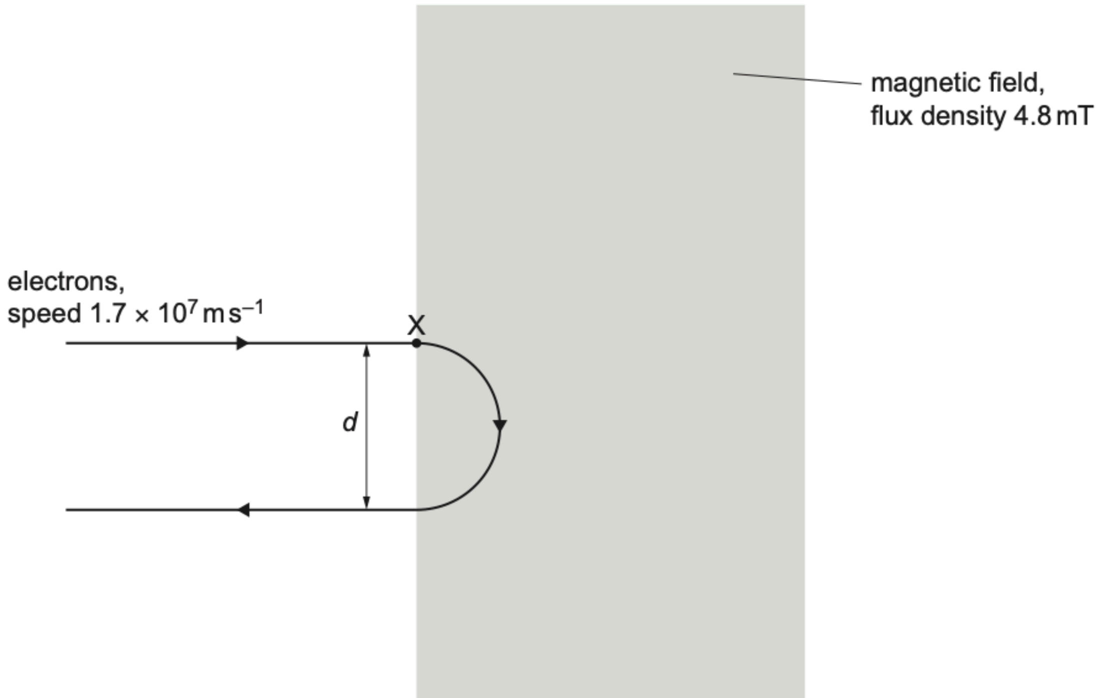

Fig. 6.1

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 1.3×10^{-14} 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 $3.4 \times 10^{7}\,\mathrm{m\,s^{-1}}$ 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]

[Total: 12]

4 **(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.

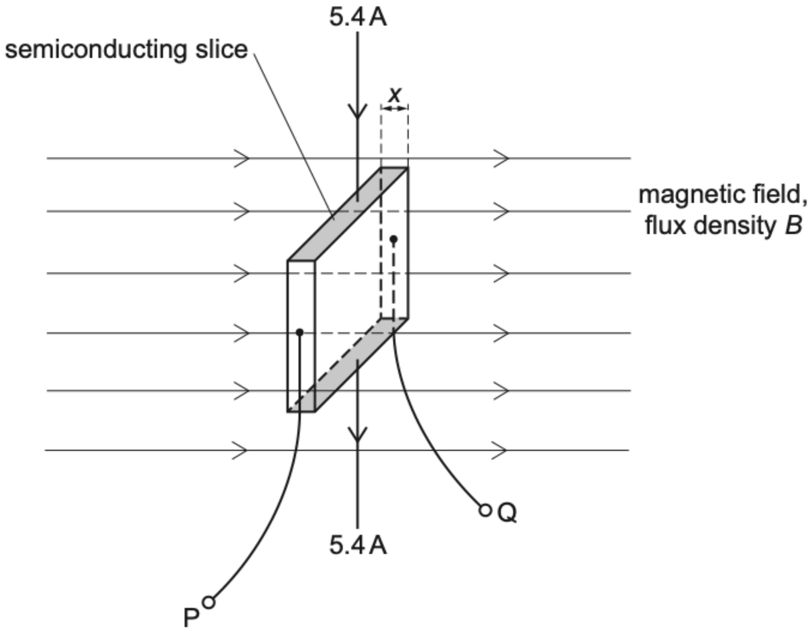

Fig. 7.1

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.

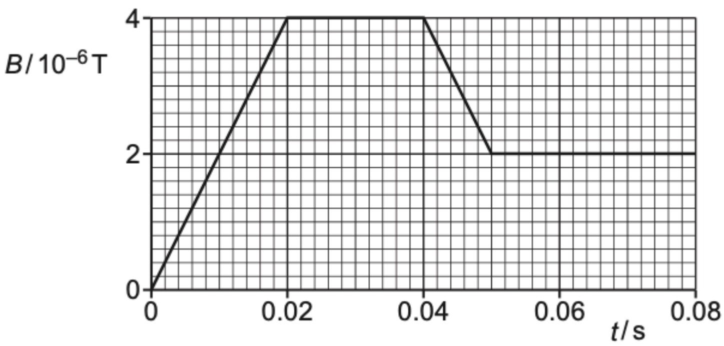

Fig. 7.2

(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 $t = 0.080\,s$.

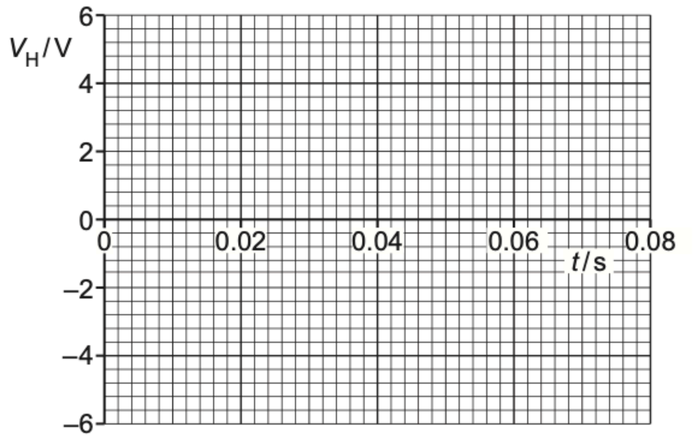

Fig. 7.3

[3]

(b) The Hall probe in **(a)** is replaced with a small flat coil that has 3000 turns. The cross-sectional area of the coil is $3.4 \times 10^{-4}\,m^2$.
The plane of the coil is perpendicular to the magnetic field. The electromotive force (e.m.f.) E induced between the terminals of the coil is recorded as B varies as shown in Fig. 7.2.

(i) Show that the magnitude of E at time $t = 0.010\,s$ is $2.0 \times 10^{-4}\,V$.

[3]

(ii) On Fig. 7.4, sketch the variation of E with t between $t = 0$ and $t = 0.080\,s$.

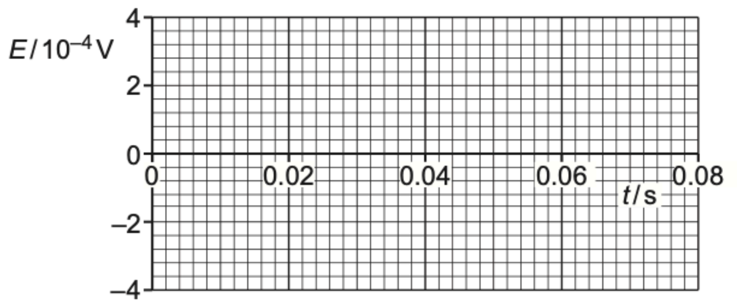

Fig. 7.4

[4]

[Total: 11]

5 **(a)** State what is meant by a magnetic field. **MJ23/41/Q6**

....

....

.... [2]

(b) A long, straight wire P carries a current into the page, as shown in Fig. 6.1.

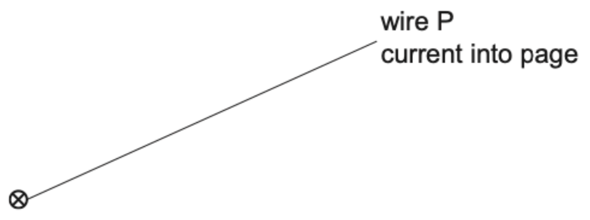

Fig. 6.1

On Fig. 6.1, draw four field lines to represent the magnetic field around wire P due to the current in the wire. [3]

(c) A second long, straight wire Q, carrying a current of 5.0 A out of the page, is placed parallel to wire P, as shown in Fig. 6.2.

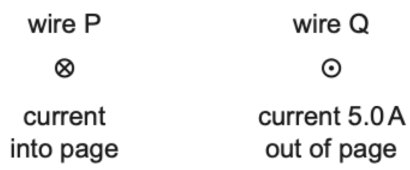

Fig. 6.2

The flux density of the magnetic field at wire Q due to the current in wire P is 2.6 mT.

(i) Calculate the magnetic force per unit length exerted on wire Q by wire P.

force per unit length = ... $N m^{-1}$ [2]

(ii) State the direction of the force exerted on wire Q by wire P.

.... [1]

(iii) The flux density of the magnetic field at wire P due to the current in wire Q is 1.5 mT.

Determine the magnitude of the current in wire P. Explain your reasoning.

current = ... A [2]

[Total: 10]

MJ23/42/Q6

6 A heavy aluminium disc has a radius of 0.36 m. The disc rotates with the wheels of a vehicle and forms part of an electromagnetic braking system on the vehicle.

In order to activate the braking system, a uniform magnetic field of flux density 0.17 T is switched on. This magnetic field is perpendicular to the plane of rotation of the disc, as shown in Fig. 6.1.

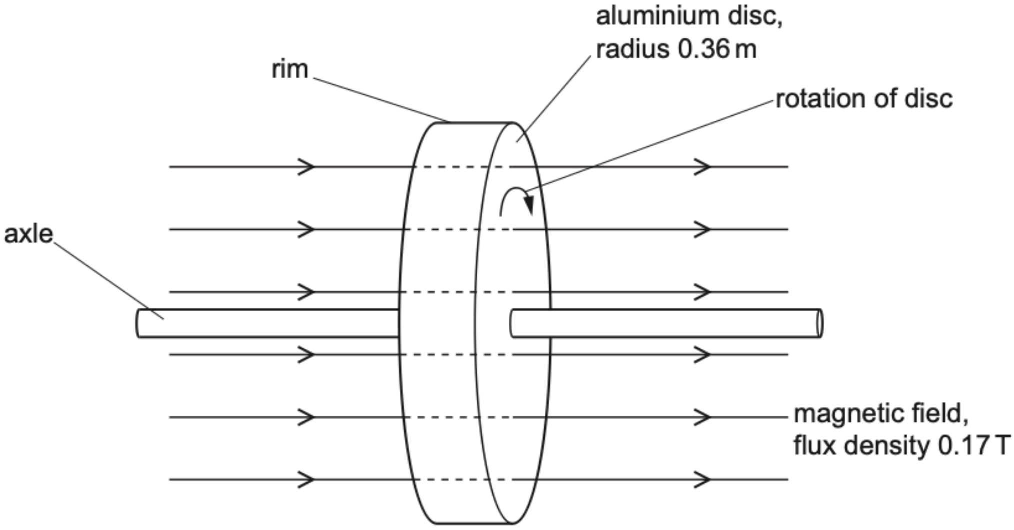

Fig. 6.1

(a) (i) Define magnetic flux.

....

....

.... [2]

(ii) Calculate the magnetic flux through the disc. Give a unit with your answer.

magnetic flux = ... unit .... [2]

(b) The disc is rotating at a rate of 25 revolutions per second.

Calculate the magnitude of the electromotive force (e.m.f.) induced between the axle and the rim of the disc.

e.m.f. = ... V [3]

(c) The axle and the rim are connected into an external circuit that enables the energy of the rotation of the disc to be stored for future use. The direction of rotation is shown in Fig. 6.1.

Use Lenz's law of electromagnetic induction to determine whether the current in the disc is from the rim to the axle or from the axle to the rim. Explain your reasoning.

....

....

....

....

.... [3]

[Total: 10]

7 **(a)** A Hall probe is placed in a magnetic field. The Hall voltage is zero. The Hall probe is rotated to a new position in the magnetic field. The Hall voltage is now maximum.

Explain these observations.

....

....

.... [2]

(b) The formula for calculating the Hall voltage V_H as measured by a Hall probe is

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

Table 6.1 shows the value of *n* for two materials.

Table 6.1

material	n / m^{-3}
silicon	9.65×10^{15}
copper	8.49×10^{28}

(i) State the meaning of *n*.

....

.... [1]

(ii) Explain why a Hall probe is made from silicon rather than copper.

....

.... [1]

(c) A Hall probe gives a maximum reading of 24 mV when placed in a uniform magnetic field of flux density 32 mT.

The same Hall probe is then placed in a magnetic field of fixed direction and varying flux density. The Hall probe is in a fixed position so that the angle between the Hall probe and the magnetic field is the same as when the Hall voltage was 24 mV.

The variation of the reading V_H on the Hall probe with time t from time $t = 0$ to time $t = 8.6$ s is shown in Fig. 6.1.

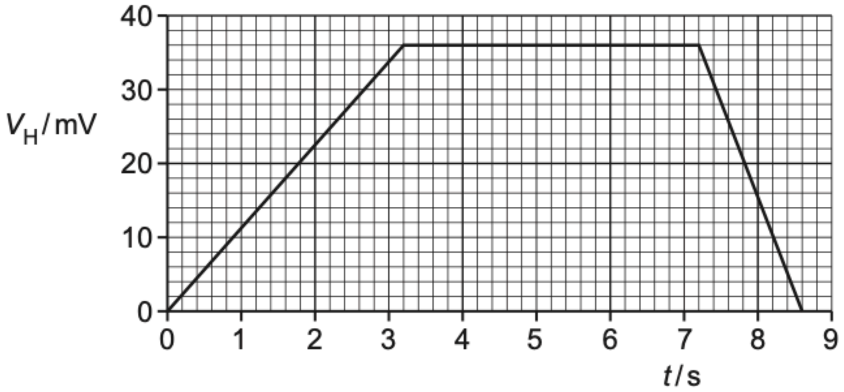

Fig. 6.1

A coil with 780 turns and a diameter of 3.6 cm is placed in this varying magnetic field. The plane of the coil is perpendicular to the field lines.

Calculate the magnitude of the maximum electromotive force (e.m.f.) induced in the coil in the time between $t = 0$ and $t = 8.6$ s.

e.m.f. = ... V [4]

[Total: 8]

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

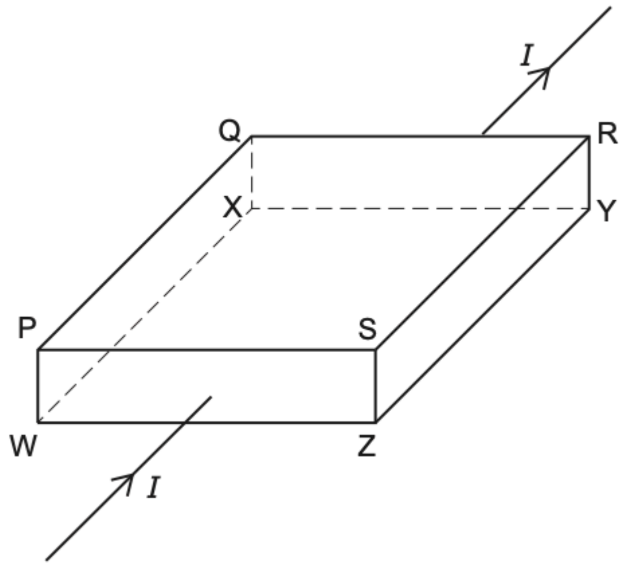

Fig. 6.1 (not to scale)

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]

[Total: 9]

ON22/42/Q7

9 **(a)** Define magnetic flux density.

....

....

....

.... [3]

(b) An insulated rectangular coil of wire, consisting of 40 turns, is suspended in a cradle from a newton meter, as shown in Fig. 7.1.

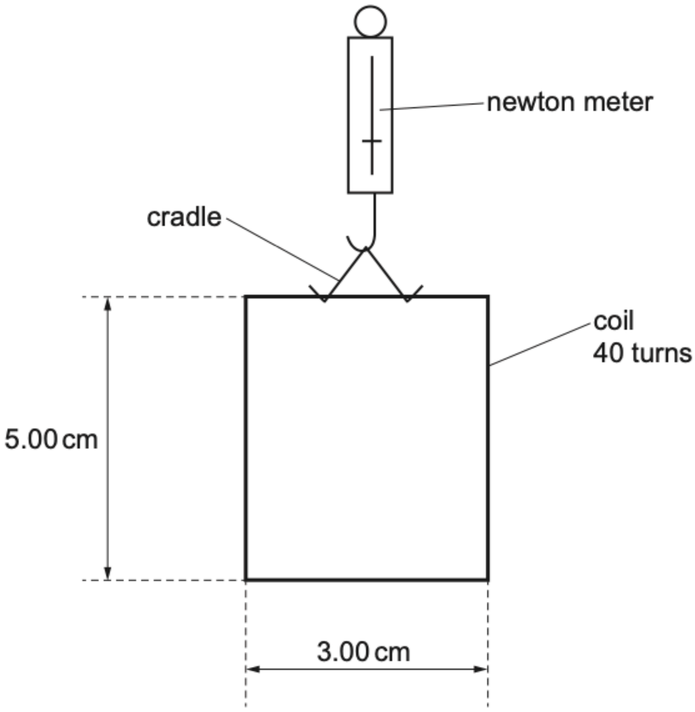

Fig. 7.1

The vertical sides of the coil have a length of 5.00 cm and the horizontal sides have a length of 3.00 cm. The initial reading on the newton meter is 0.563 N.

A U-shaped magnet rests on a top-pan balance that is set to a reading of 0.00 g.
The lower edge of the coil is lowered into the region between the poles of the U-shaped magnet, as shown in the side view in Fig. 7.2.

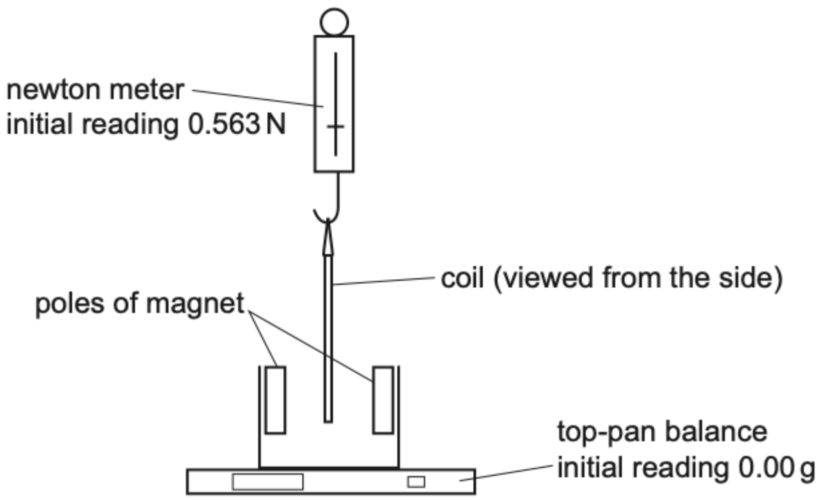

Fig. 7.2

The magnetic field in the region between the poles is uniform.
The lower edge of the coil is entirely within the uniform magnetic field.

A current of 3.94 A is now passed through the coil. This causes the reading on the top-pan balance to change to 2.16 g.

(i) Explain why the current causes a vertical force to act on the coil.

....

....

.... [2]

(ii) Determine, to three significant figures, the flux density B of the uniform magnetic field.

B = ... T [3]

(iii) Determine what is now the reading on the newton meter. Explain your reasoning.

reading = ... N [2]

[Total: 10]

MJ22/41/Q6

10 **(a)** Define magnetic flux.

....

....

.... [2]

(b) A square coil of wire of side length 12 cm consists of 8 insulated turns. The coil is stationary in a uniform magnetic field. The plane of the coil is perpendicular to the magnetic field, as shown in Fig. 6.1.

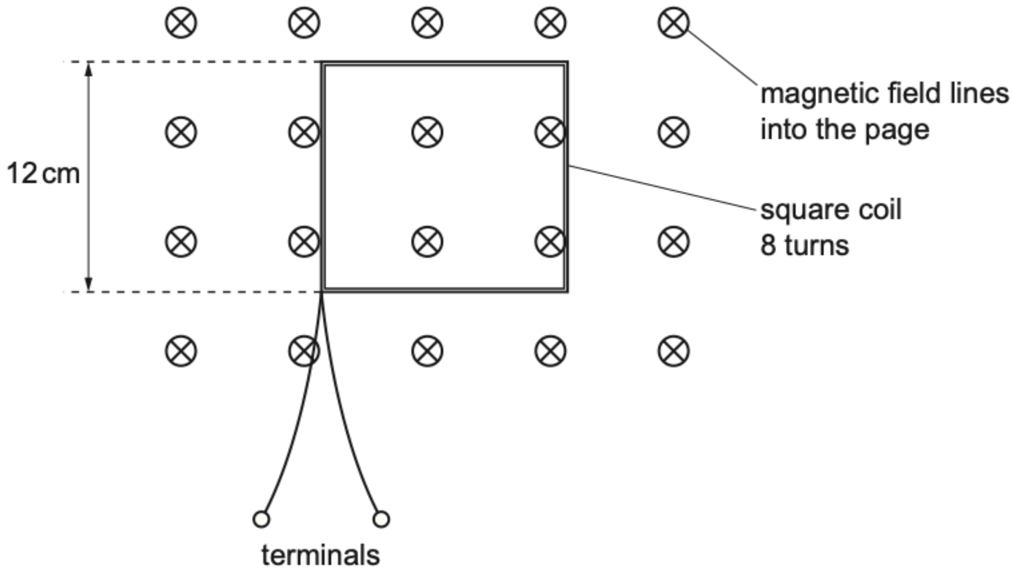

Fig. 6.1

The flux density *B* of the magnetic field varies with time *t* as shown in Fig. 6.2.

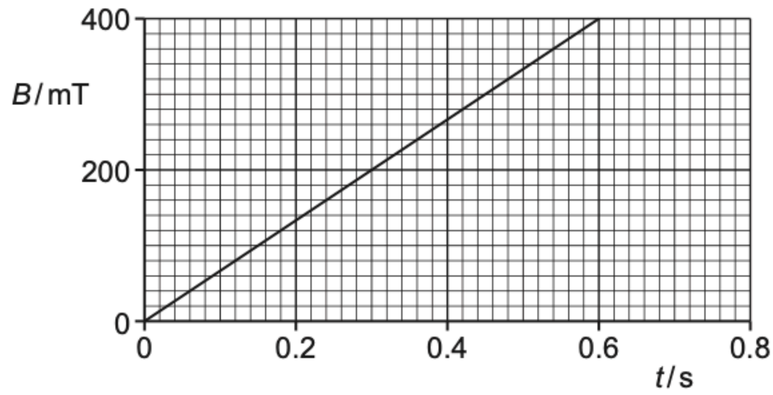

Fig. 6.2

(i) Determine the magnetic flux linkage inside the coil at time t = 0.60 s. Give a unit with your answer.

magnetic flux linkage = ... unit .... [3]

(ii) State how Fig. 6.2 shows that the electromotive force (e.m.f.) E induced across the terminals between $t = 0$ and $t = 0.60\,s$ is constant.

.... [1]

(iii) Calculate the magnitude of E.

E = ... V [2]

(c) The procedure in **(b)** is repeated, but this time the terminals of the coil are connected together.

State and explain the effect on the coil of connecting the terminals together during the change of magnetic flux density shown in Fig. 6.2.

....

....

....

.... [3]

[Total: 11]

11 **(a)** State the **two** conditions that must be satisfied for a copper wire, placed in a magnetic field, to experience a magnetic force.

1 ....

....

2 ....

.... [2]

(b) A long air-cored solenoid is connected to a power supply, so that the solenoid creates a magnetic field. Fig. 6.1 shows a cross-section through the middle of the solenoid.

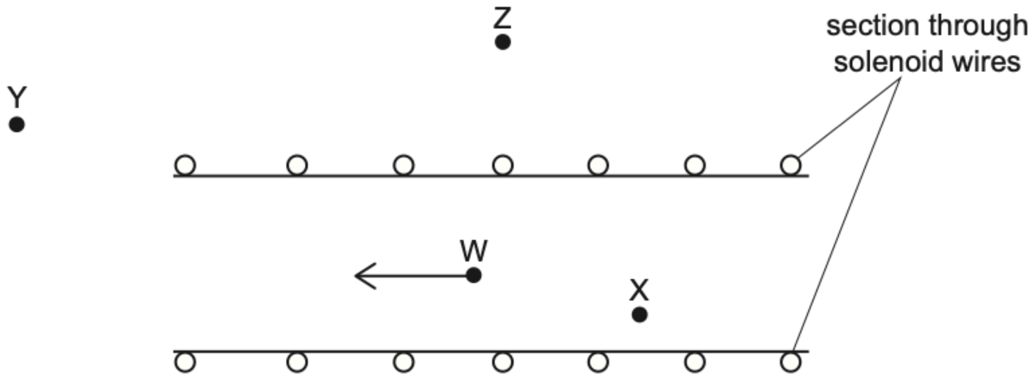

Fig. 6.1

The direction of the magnetic field at point W is indicated by the arrow. Three other points are labelled X, Y and Z.

(i) On Fig. 6.1, draw arrows to indicate the direction of the magnetic field at each of the points X, Y and Z. [3]

(ii) Compare the magnitude of the flux density of the magnetic field:

- at X and at W ....

....

- at Y and at Z. ....

.... [2]

(c) Two long parallel current-carrying wires are placed near to each other in a vacuum.

Explain why these wires exert a magnetic force on each other. You may draw a labelled diagram if you wish.

....

....

....

.... [3]

[Total: 10]

March22/42/Q6

12 A small solenoid of area of cross section $1.6 \times 10^{-3}\,m^2$ is placed inside a larger solenoid of area of cross-section $6.4 \times 10^{-3}\,m^2$, as shown in Fig. 6.1.

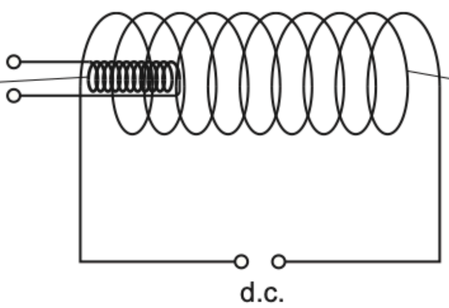

Fig. 6.1 (not to scale)

The larger solenoid has 600 turns and is attached to a d.c. power supply to create a magnetic field.

The smaller solenoid has 3000 turns.

(a) Compare the magnetic flux in the two solenoids.

....

....

.... [1]

(b) Compare the magnetic flux linkage in the two solenoids.

....

....

.... [1]

(c) **(i)** State Lenz's law of electromagnetic induction.

....

....

.... [2]

(ii) The terminals of the smaller solenoid are connected together. The smaller solenoid is then removed from inside the larger solenoid.

With reference to magnetic fields, explain why a force is needed to remove the smaller solenoid.

....

....

....

....

....

.... [3]

[Total: 7]

13 **(a)** Define the *tesla*.

....

....

.... [2]

(b) A stiff metal wire is used to form a rectangular frame measuring 8.0 cm × 6.0 cm. The frame is open at the top, and is suspended from a sensitive newton meter, as shown in Fig. 8.1.

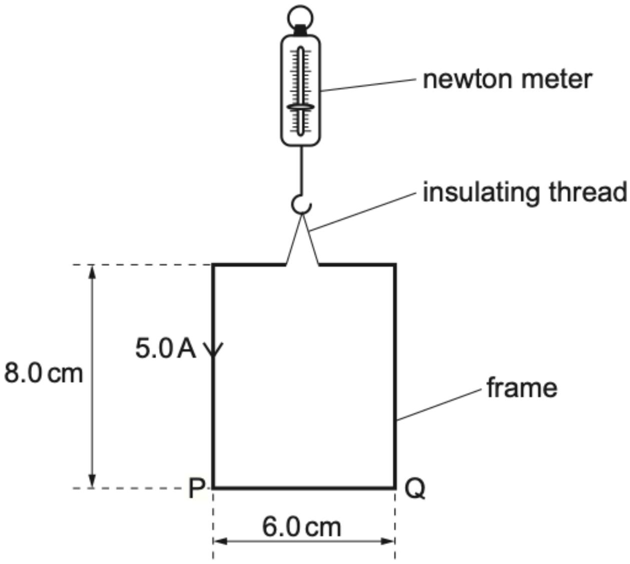

Fig. 8.1

The open ends of the frame are connected to a power supply so that there is a current of 5.0 A in the frame in the direction indicated in Fig. 8.1.

The frame is slowly lowered into a uniform magnetic field of flux density *B* so that all of side PQ is in the field. The magnetic field lines are horizontal and at an angle of 50° to PQ, as shown in Fig. 8.2.

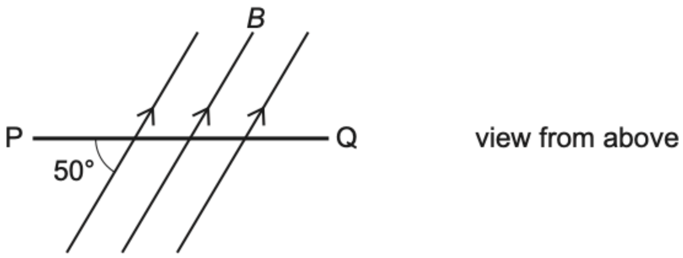

Fig. 8.2

When side PQ of the frame first enters the magnetic field, the reading on the newton meter changes by 1.0 mN.

(i) Determine the magnetic flux density B, in mT.

B = ... mT [2]

(ii) State, with a reason, whether the change in the reading on the newton meter is an increase or a decrease.

....

....

.... [1]

(iii) The frame is lowered further so that the vertical sides start to enter the magnetic field.

Suggest what effect this will have on the frame.

....

....

.... [1]

[Total: 6]

14 Two long straight parallel wires P and Q carry currents into the plane of the paper, as shown in Fig. 8.1.

Fig. 8.1

The current in P is I and the current in Q is $2I$.

(a) **(i)** On Fig. 8.1, draw an arrow to show the direction of the magnetic field at wire Q due to the current in wire P. Label this arrow B. [1]

(ii) On Fig. 8.1, draw another arrow to show the direction of the force acting on wire Q due to the current in wire P. Label this arrow F. [1]

(b) **(i)** State, with a reason, how the magnitude of the force acting on wire P compares with the magnitude of the force acting on wire Q.

....

....

....

.... [2]

(ii) State how the direction of the force on wire P compares with the direction of the force on wire Q.

....

.... [1]

[Total: 5]

15 **(a)** State what is meant by a *magnetic field*. **MJ21/41/Q9**

....

....

.... [2]

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

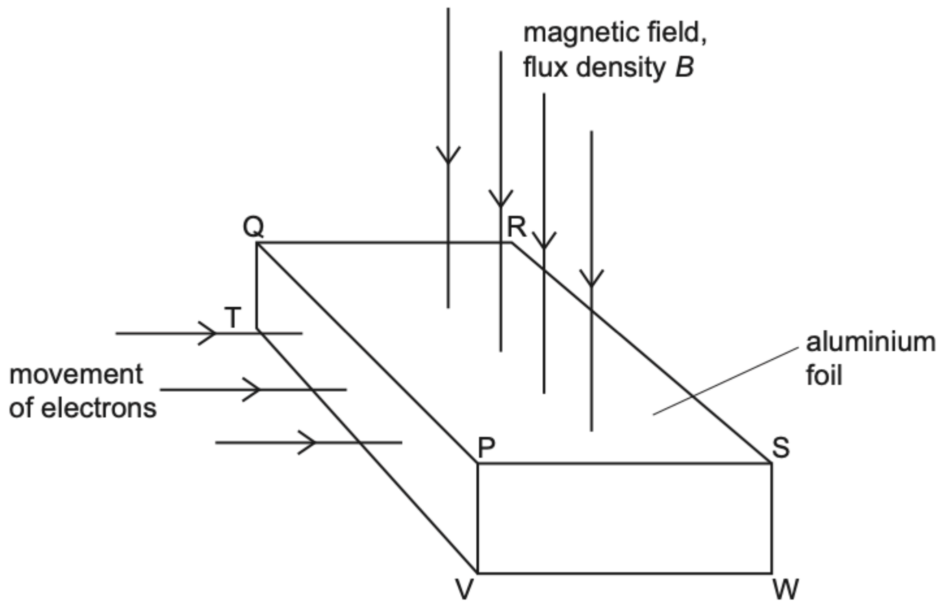

Fig. 9.1

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]

[Total: 9]

16 **(a)** Define *magnetic flux density*. **MJ21/42/Q8**

....

....

.... [2]

(b) Electrons, each of mass m and charge q, are accelerated from rest in a vacuum through a potential difference V.

Derive an expression, in terms of m, q and V, for the final speed v of the electrons. Explain your working.

[2]

(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.

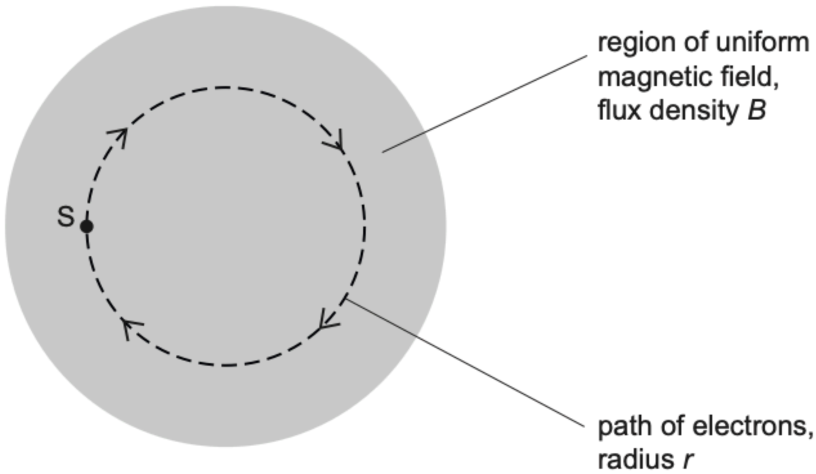

Fig. 8.1

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

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

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]

[Total: 10]

March21/42/Q8

17 **(a)** Two long straight wires P and Q are parallel to each other, as shown in Fig. 8.1. There is a current in each wire in the direction shown.

The pattern of the magnetic field lines in a plane normal to wire P due to the current in the wire is also shown.

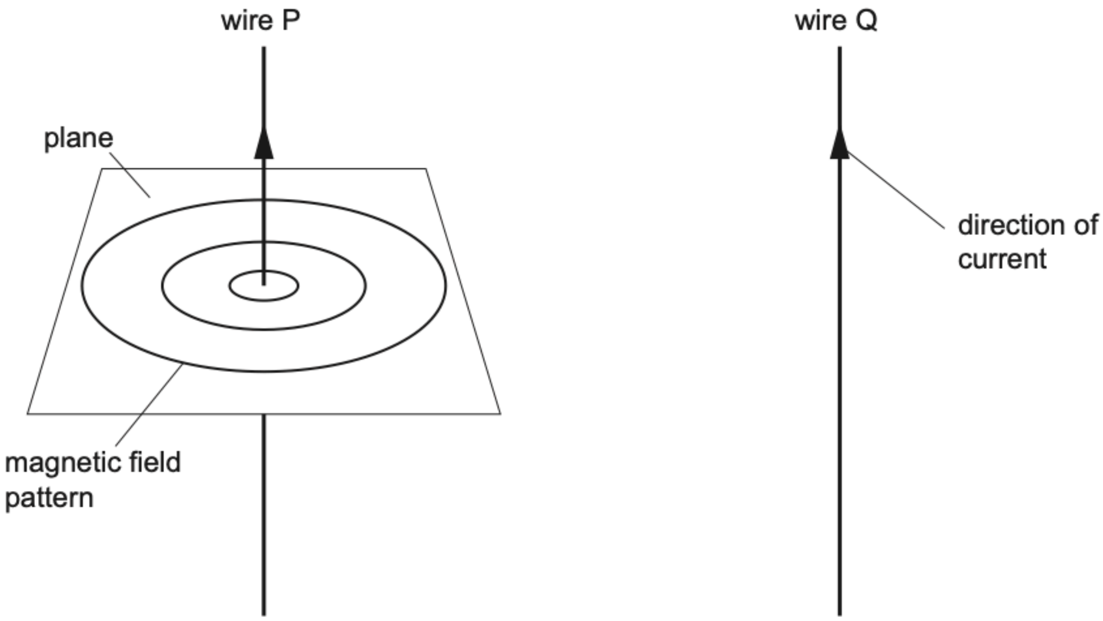

Fig. 8.1

(i) Draw arrows on the magnetic field lines in Fig. 8.1 around wire P to show the direction of the field. [1]

(ii) Determine the direction of the force on wire Q due to the magnetic field from wire P.

.... [1]

(iii) The current in wire Q is less than the current in wire P.

State and explain whether the magnitude of the force on wire P is less than, equal to, or greater than the magnitude of the force on wire Q.

....

....

.... [2]

ON20/42/Q9

18 **(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.

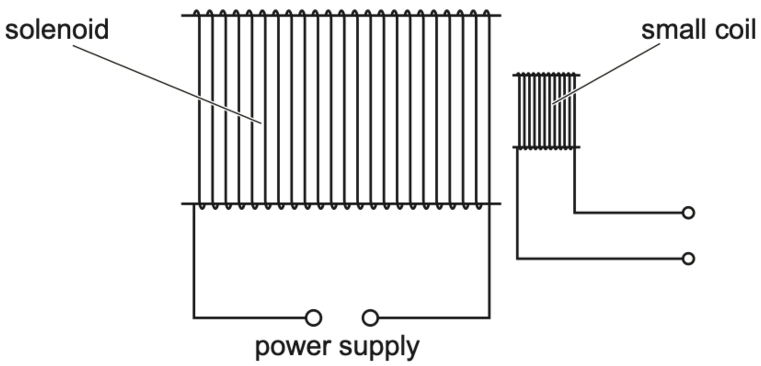

Fig. 9.1

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

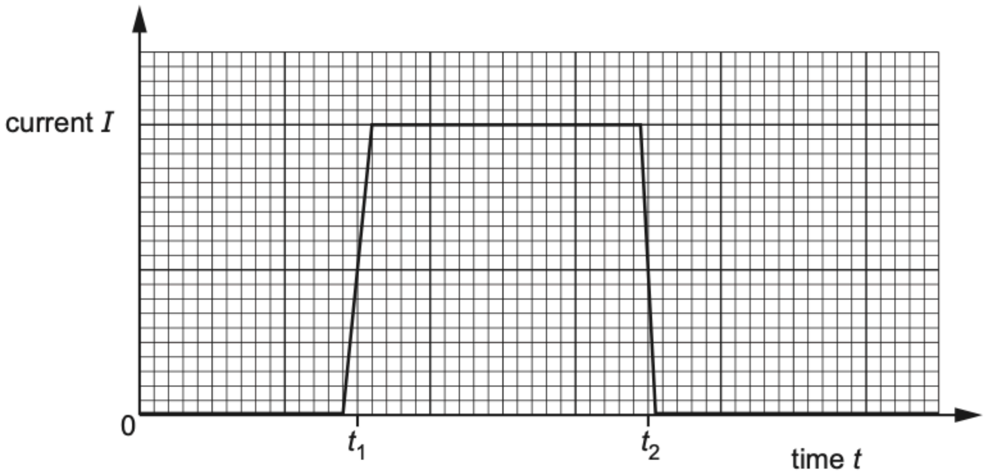

Fig. 9.2

(i) State Faraday's law of electromagnetic induction.

....

....

.... [2]

(ii) On the axes of Fig. 9.3, sketch a graph to show the variation with time t of the electromotive force (e.m.f.) induced in the small coil.

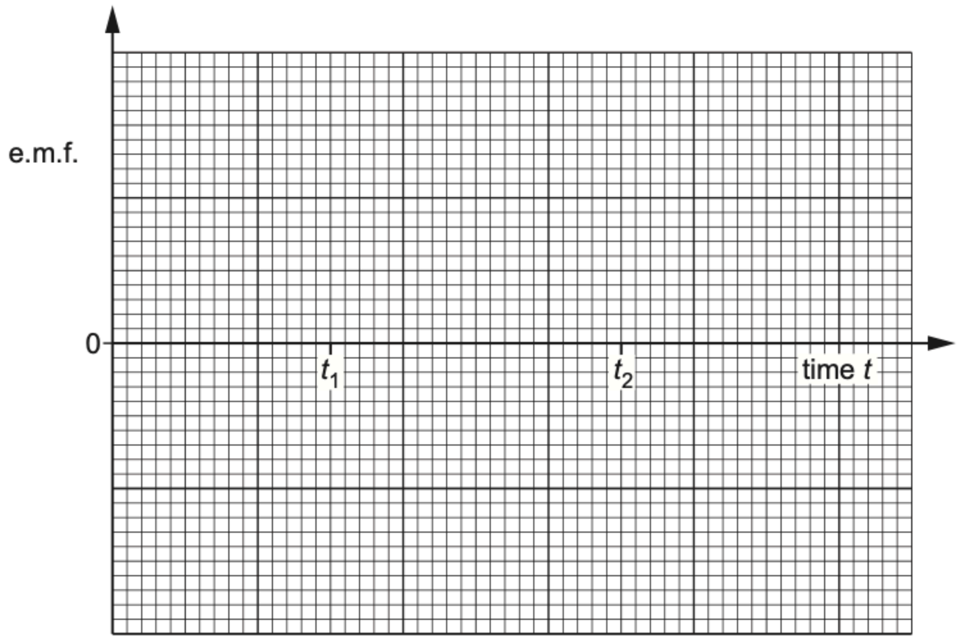

Fig. 9.3

[4]

(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.

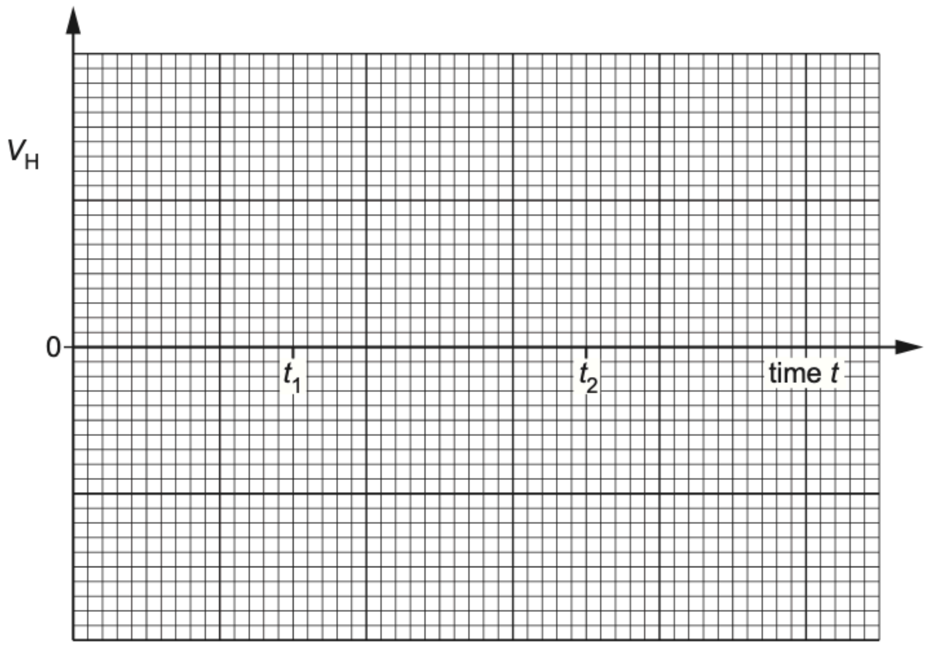

Fig. 9.4

[2]

[Total: 8]

ON20/42/Q10

19 **(a)** A long straight vertical wire A carries a current in an upward direction. The wire passes through the centre of a horizontal card, as illustrated in Fig. 10.1.

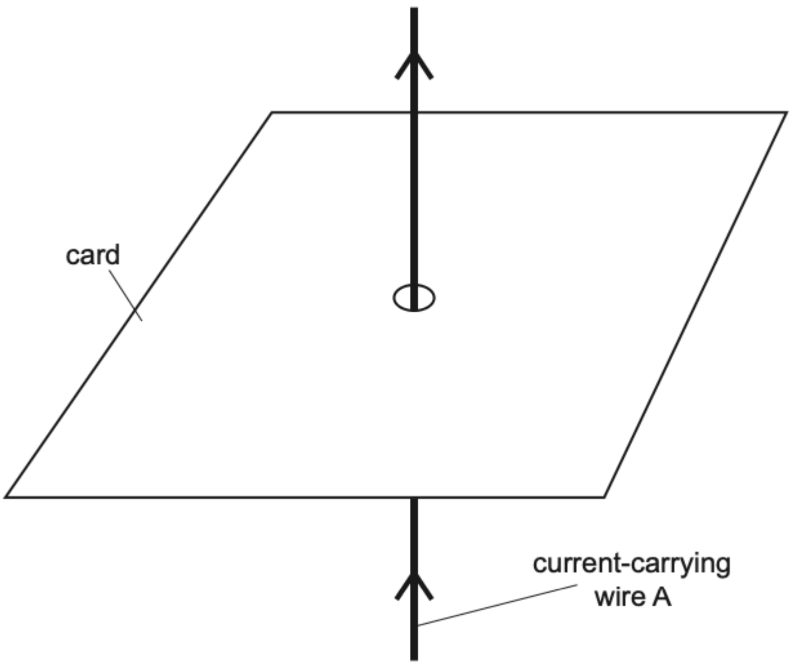

Fig. 10.1

The card is viewed from above. The card is shown from above in Fig. 10.2.

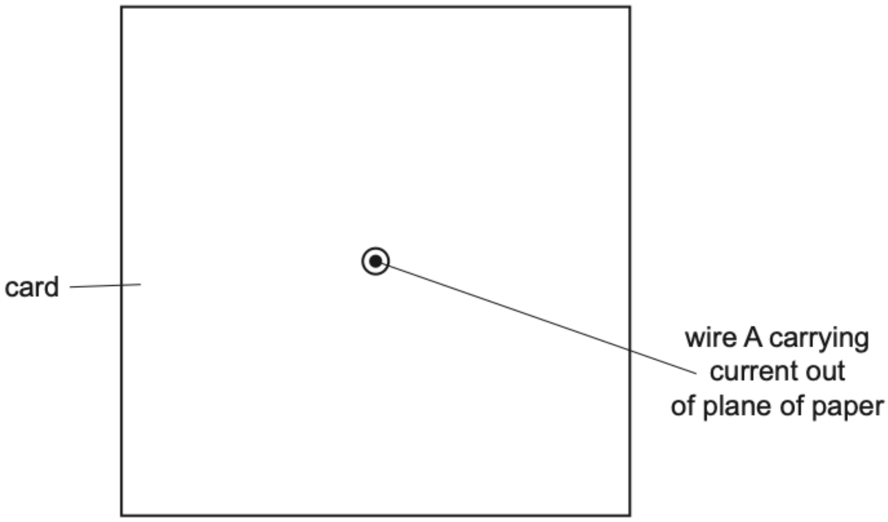

Fig. 10.2

On Fig. 10.2, draw four lines to represent the magnetic field produced by the current-carrying wire. [3]

(b) Two wires A and B are now placed through a card. The two wires are parallel and carrying currents in the same direction, as illustrated in Fig. 10.3.

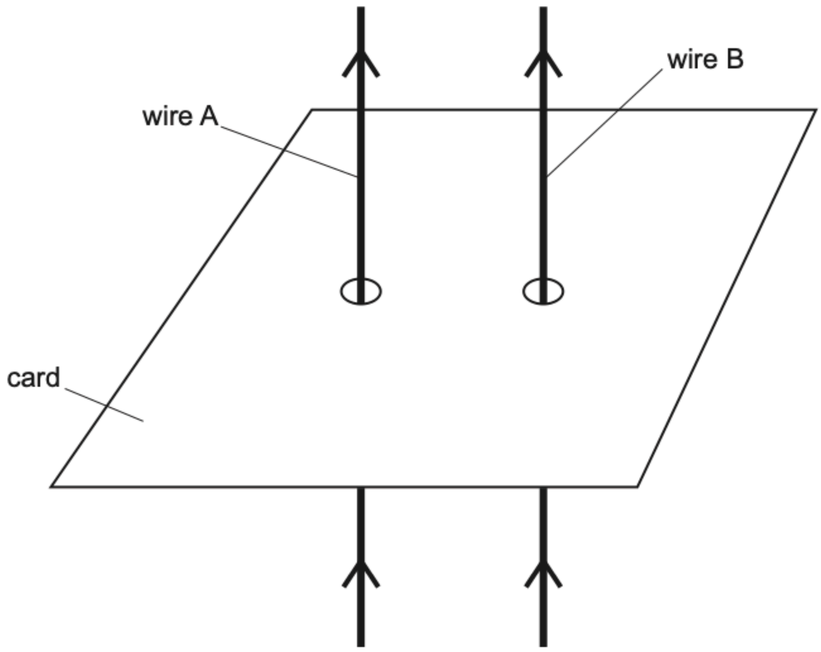

Fig. 10.3

(i) Explain why a magnetic force is exerted on each wire.

....

....

....

.... [2]

(ii) State the directions of the forces.

....

.... [1]

(c) The currents in the two wires are not equal.

Explain whether the magnetic forces on the two wires are equal in magnitude.

....

....

.... [1]

[Total: 7]

MJ20/41/Q8

20 **(a)** Define the *tesla*.

....

....

....

.... [3]

(b) A magnet produces a uniform magnetic field of flux density *B* in the space between its poles.

A rigid copper wire carrying a current is balanced on a pivot. Part PQLM of the wire is between the poles of the magnet, as illustrated in Fig. 8.1.

(b) A magnet produces a uniform magnetic field of flux density *B* in the space between its poles.

A rigid copper wire carrying a current is balanced on a pivot. Part PQLM of the wire is between the poles of the magnet, as illustrated in Fig. 8.1.

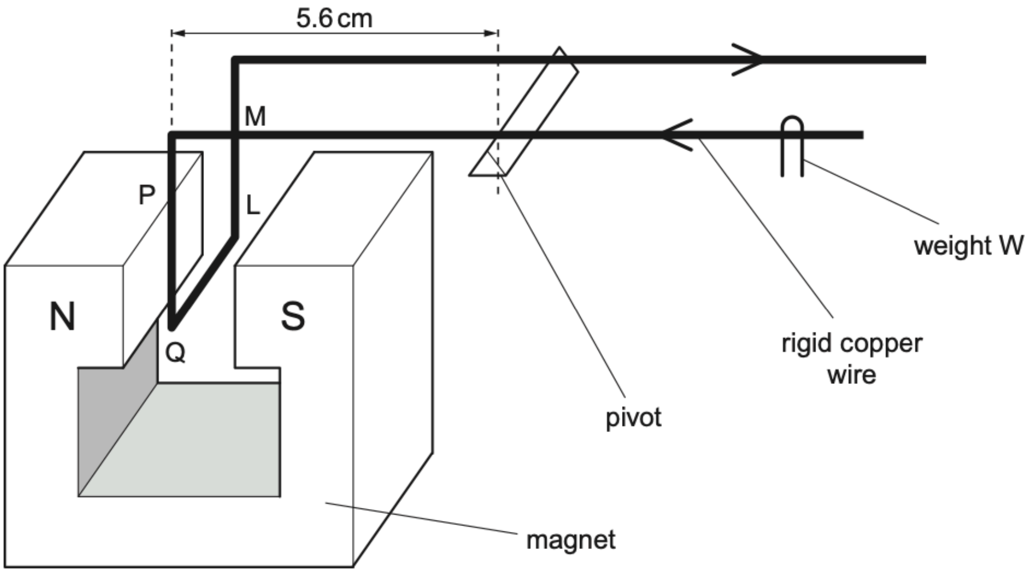

Fig. 8.1 (not to scale)

The wire is balanced horizontally by means of a small weight W.

The section of the wire between the poles of the magnet is shown in Fig. 8.2.

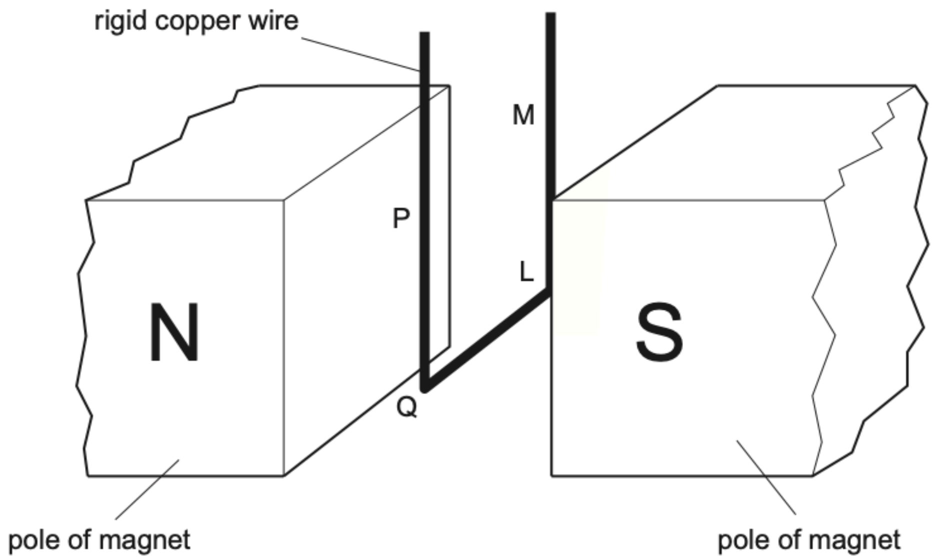

Fig. 8.2 (not to scale)

Explain why:

(i) section QL of the wire gives rise to a moment about the pivot

....

....

....

.... [3]

(ii) sections PQ and LM of the wire do not affect the equilibrium of the wire.

....

....

....

.... [2]

(c) Section QL of the wire has length 0.85 cm.

The perpendicular distance of QL from the pivot is 5.6 cm.

When the current in the wire is changed by 1.2 A, W is moved a distance of 2.6 cm along the wire in order to restore equilibrium. The mass of W is 1.3×10^{-4} kg.

(i) Show that the change in moment of W about the pivot is 3.3×10^{-5} N m.

[2]

(ii) Use the information in **(i)** to determine the magnetic flux density *B* between the poles of the magnet.

B = ... T [3]

[Total: 13]

21 **(a)** A coil of wire is situated in a uniform magnetic field of flux density *B*.
The coil has diameter 3.6 cm and consists of 350 turns of wire, as illustrated in Fig. 9.1.

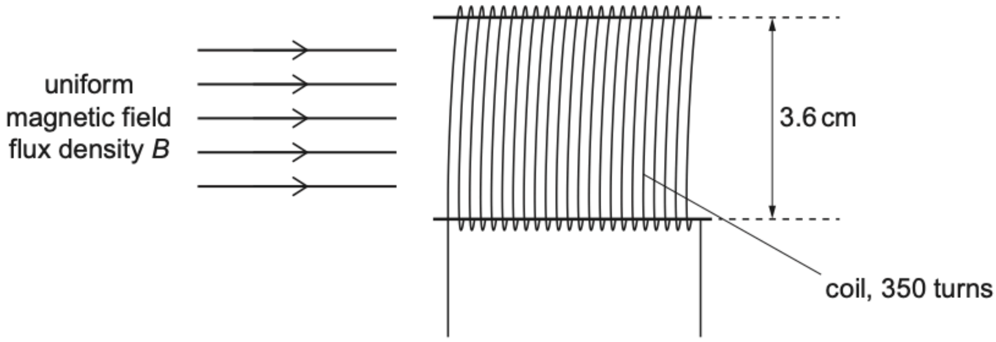

Fig. 9.1

The variation with time *t* of *B* is shown in Fig. 9.2.

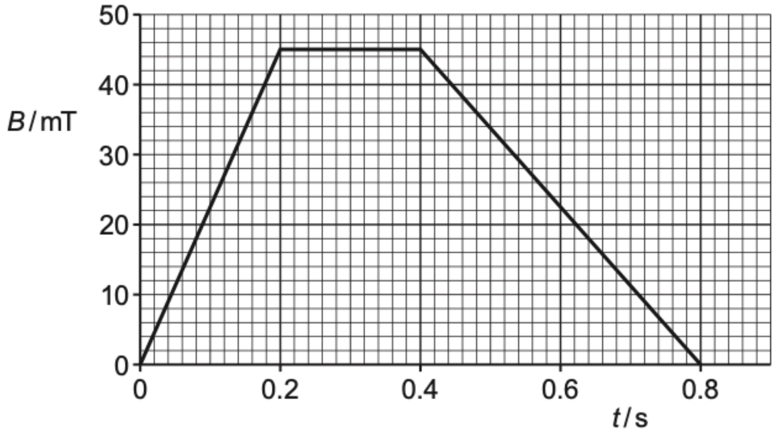

Fig. 9.2

(i) Show that, for the time $t = 0$ to time $t = 0.20$ s, the electromotive force (e.m.f.) induced in the coil is 0.080 V.

[2]

(ii) On the axes of Fig. 9.3, show the variation with time t of the induced e.m.f. E for time $t = 0$ to time $t = 0.80$ s.

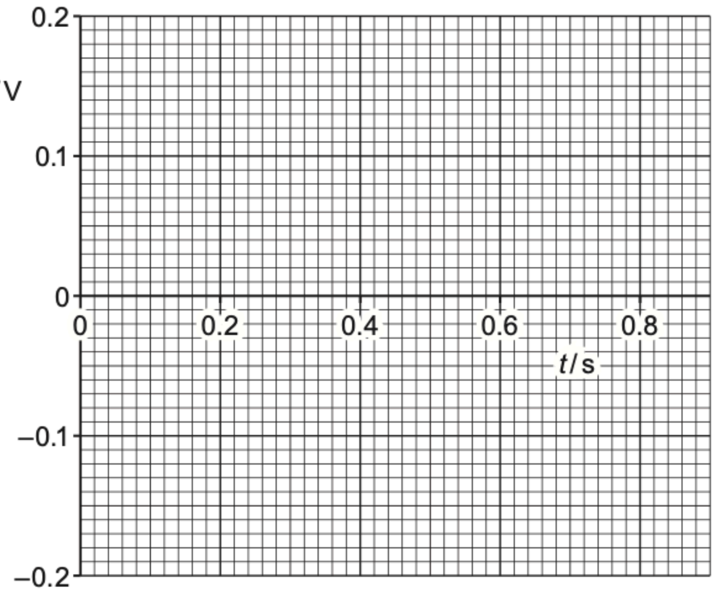

Fig. 9.3

[4]

(b) A bar magnet is held a small distance above the surface of an aluminium disc by means of a rod, as illustrated in Fig. 9.4.

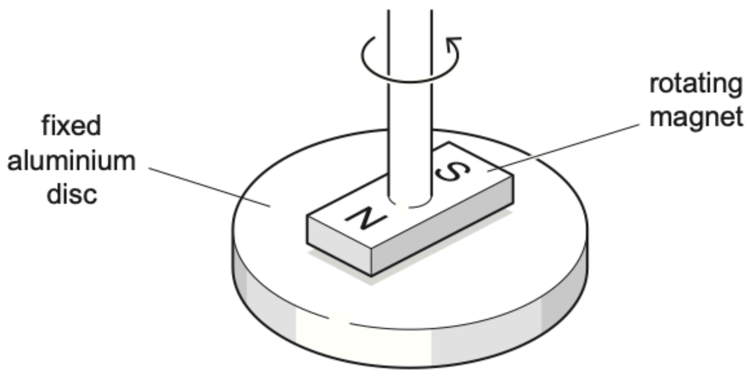

Fig. 9.4

The aluminium disc is supported horizontally and held stationary.

The magnet is rotated about a vertical axis at constant speed.

Use laws of electromagnetic induction to explain why there is a torque acting on the aluminium disc.

....

....

....

....

....

.... [4]

[Total: 10]

22 **(a)** A long straight vertical wire carries a current I. The wire passes through a horizontal card EFGH, as shown in Fig. 8.1 and Fig. 8.2.

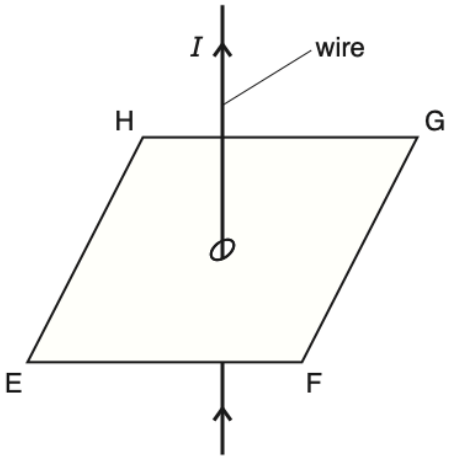

Fig. 8.1

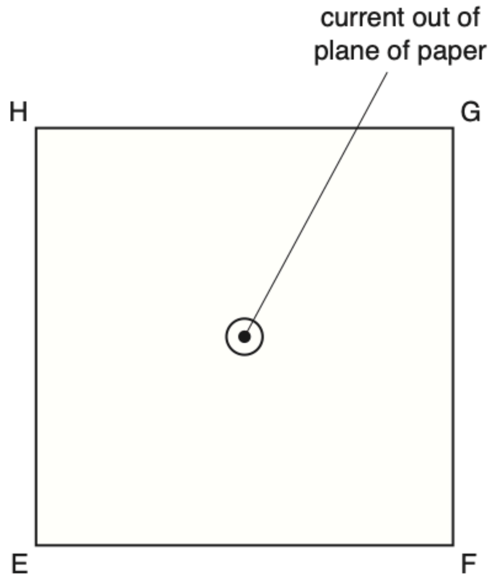

Fig. 8.2 (view from above)

On Fig. 8.2, draw the pattern of the magnetic field produced by the current-carrying wire on the plane EFGH. [3]

(b) Two long straight parallel wires P and Q are situated a distance 3.1 cm apart, as illustrated in Fig. 8.3.

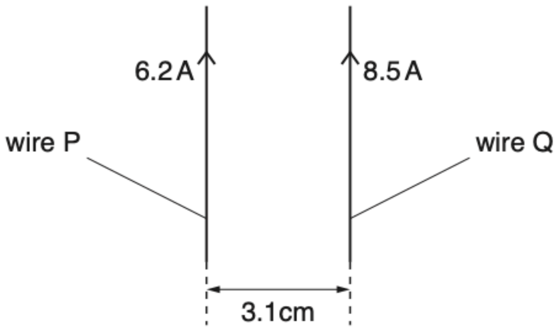

Fig. 8.3

The current in wire P is 6.2 A. The current in wire Q is 8.5 A.

The magnetic flux density B at a distance x from a long straight wire carrying current I is given by the expression

$$B = \frac{\mu_0 I}{2\pi x}$$

where μ_0 is the permeability of free space.

Calculate:

(i) the magnetic flux density at wire Q due to the current in wire P

flux density = ... T [2]

(ii) the force per unit length, in $N m^{-1}$, acting on wire Q due to the current in wire P.

force per unit length = ... $N m^{-1}$ [2]

(c) The currents in wires P and Q are different in magnitude.

State and explain whether the forces per unit length on the two wires will be different.

....

....

.... [2]

[Total: 9]

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

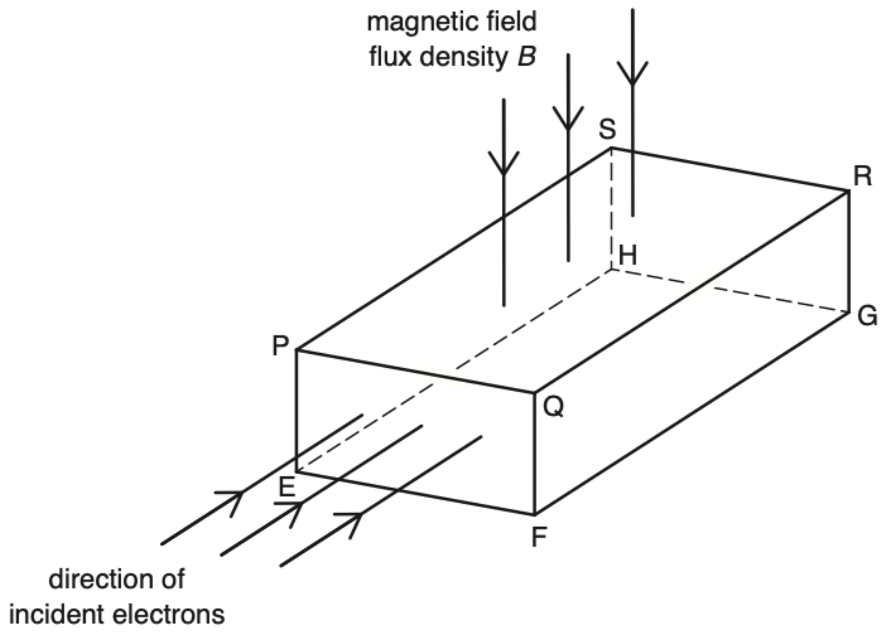

Fig. 8.1

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 $6.0 \times 10^{28}\,m^{-3}$.

[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]

[Total: 8]

24 A solenoid is connected in series with a battery and a switch, as illustrated in Fig. 8.1.

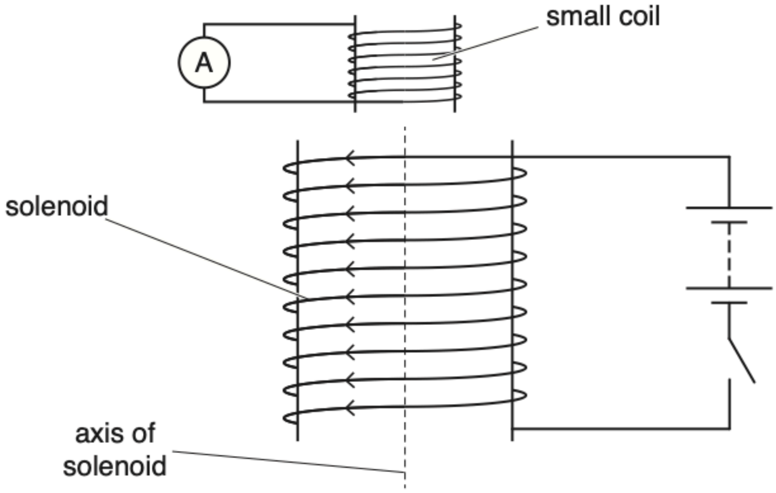

Fig. 8.1

A small coil, connected to a sensitive ammeter, is situated near one end of the solenoid.

As the current in the solenoid is switched on, there is a changing magnetic field inside the solenoid.

(a) **(i)** State what is meant by a *magnetic field*.

....

.... [1]

(ii) On Fig. 8.1, draw an arrow on the axis of the solenoid to show the direction of the magnetic field inside the solenoid. Label this arrow P. [1]

(b) As the current in the solenoid is switched on, there is a current induced in the small coil. This induced current gives rise to a magnetic field in the small coil.

(i) State Lenz's law.

....

....

.... [2]

(ii) Use Lenz's law to state and explain the direction of the magnetic field due to the induced current in the small coil. On Fig. 8.1, mark this direction with an arrow inside the small coil.

....

....

....

.... [3]

(c) The small coil has an area of cross-section $7.0 \times 10^{-4}\,m^2$ and contains 75 turns of wire.

A constant current in the solenoid produces a uniform magnetic flux of flux density 1.4 mT throughout the small coil.

The direction of the current in the solenoid is reversed in a time of 0.12 s.

Calculate the average e.m.f. induced in the small coil.

e.m.f. = ... V [3]

[Total: 10]

MJ19/42/Q8

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

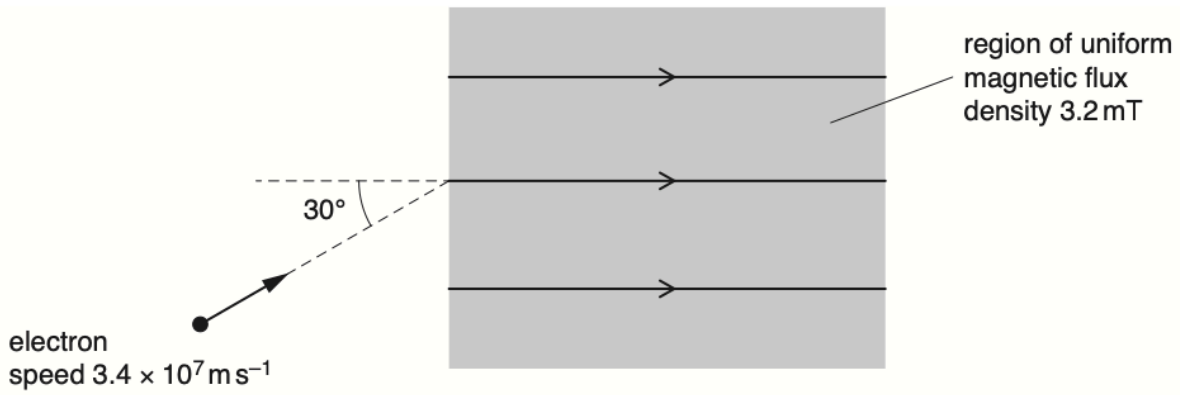

Fig. 8.1

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]

[Total: 6]

1 7(a)	(induced) e.m.f. is (directly) proportional to rate	M1
1	of change of (magnetic) flux (linkage)	A1
(b)(i)	Φ = BA	C1
1	= 7.2 × 10^{-3} × 3.2 × 10^{-4} = 2.3 × 10^{-6} Wb	A1
(b)(ii)	tangent drawn at steepest point on Fig. 7.2	C1
1	evidence of multiplication by 340	C1
	maximum rate of change of flux = 0.82 Wb s^{-1}	A1
1 b)(iii)	V_0 = 0.82 V **or** V_0 given as identical numerical answer to the answer in **(b)(ii)**	A1
b)(iv) 1	sinusoidal curve of period 2.0 ms from t = 0 to t = 6.0 ms	B1
	all peaks at +V_0 and all troughs at –V_0	B1
	line showing V = 0 at (and only at) t = 0, 1.0, 2.0, 3.0, 4.0, 5.0 and 6.0 ms	B1
1 b)(v)	A = 0.82 V **or** A has same numerical value as answer in **(b)(iii)**, with unit V	A1
	B = 2π / (2.0 × 10^{-3})	C1
	= 3100 rad s^{-1}	A1

2 5(a)	*any 2 points from*: • (angular) displacement • velocity • momentum • (centripetal) acceleration • (resultant) force	B2
(b)(i) 2	$Bqv = mv^2 / r$	M1
	$v = 2\pi r / T$	M1
	completion of algebra leading to $B = 2\pi m / qT$	A1
b)(ii)	B = (2π × 4 × 1.66 × 10^{-27}) / (2 × 1.60 × 10^{-19} × 2.5 × 10^{-6})	C1
2	= 0.052 T	A1
b)(iii) 2	**either** the same because T is independent of r **or** the same because B, q and m are unchanged **or** the same because both radius and speed have doubled	B1
b)(iv)	$qE = Bqv$	C1
2	$E = Bv$ = 0.052 × 1.1 × 10^6 = 5.7 × 10^4 N C^{-1}	A1

3 6(a)	• force per unit length • force per unit current • length / current perpendicular to field *1 mark for any two points, 2 marks for all three points*	**B2**
3 (b)(i)	into the page	**B1**
3 (b)(ii)	$F = Bqv$	**C1**
	$= 4.8 \times 10^{-3} \times 1.6 \times 10^{-19} \times 1.7 \times 10^{7} = 1.3 \times 10^{-14}$ N	**A1**
3 (b)(iii)	arrow at point X pointing down the page	**B1**
3 (b)(iv)	$F = mv^2 / r$	**C1**
	$1.3 \times 10^{-14} = (9.11 \times 10^{-31}) \times (1.7 \times 10^{7})^2 / r$	**C1**
	(r = 0.020 m) $d = 2r$ d = 0.040 m	**A1**
3 6(c)	path shows upwards deflection such that the curvature is always anticlockwise within the field	**B1**
	circular path with larger radius	**B1**
	line enters field at X and leaves field at distance 2d vertically from X	**B1**

4 7(a)(i)	$V_H = BI / ntq$ $= (4.0 \times 10^{-6} \times 5.4) / (1.5 \times 10^{16} \times 1.8 \times 10^{-3} \times 1.60 \times 10^{-19}) = 5.0$ V	**A1**
4 7(a)(ii)	sketch: straight diagonal line from (0, 0) to t = 0.020 s **and** straight diagonal line between two non-zero V_H values of same sign from t = 0.040 to 0.050 s	**B1**
	horizontal straight line at V_H = 5.0 V from t = 0.020 to 0.040 s	**B1**
	horizontal straight line at V_H = 2.5 V from t = 0.050 to 0.080 s	**B1**
4 7(b)(i)	e.m.f. = rate of change of (magnetic) flux (linkage)	**C1**
	$E = NA\,\Delta B / \Delta t$ **or** $E = NA \times$ gradient (at t = 0.010 s)	**C1**
	$E = 3000 \times 3.4 \times 10^{-4} \times (4.0 \times 10^{-6}) / (0.020) = 2.0 \times 10^{-4}$ V	**A1**
4 7(b)(ii)	sketch: line showing non-zero E from t = 0 to t = 0.020 s and from t = 0.040 s to t = 0.050 s, and E = 0 at all other times	**B1**
	'top hats' showing constant non-zero E from t = 0 to t = 0.020 s and from t = 0.040 s to t = 0.050 s	**B1**
	magnitude of E shown as 2.0×10^{-4} V in both non-zero sections	**B1**
	sign of E in the t = 0 to t = 0.020 s region opposite to the sign of E in the t = 0.040 s to t = 0.050 s region	**B1**

5 6(a)	a region where a force acts on	**M1**
	a current-carrying conductor **or** a <u>moving</u> charge **or** a magnetic material / magnetic pole	**A1**
5 6(b)	concentric circles around the wire	**B1**
	spacing between circles increases with distance from wire	**B1**
	arrows showing direction of field is clockwise	**B1**
5 (c)(i)	$F = BIL$	**C1**
	force per unit length $= BI$ $= 2.6 \times 10^{-3} \times 5.0$ $= 0.013$ N m^{-1}	**A1**
5 (c)(ii)	to the right	**B1**
5 (c)(iii)	force (per unit length) has the same magnitude due to Newton's 3rd law	**B1**
	$0.013 = 1.5 \times 10^{-3} \times I$ current = 8.7 A	**A1**

6(a)(i)	product of (magnetic) flux density and area	M1
	area perpendicular to the (magnetic) field	A1
6(a)(ii)	flux $= B \times \pi r^2$ $= 0.17 \times \pi \times 0.36^2$	C1
	$= 6.9 \times 10^{-2}$ Wb	A1
6(b)	time for one revolution = 1 / 25 s	C1
	e.m.f. = rate of cutting flux **or** $\Delta\Phi / \Delta t$	C1
	$= 0.069 \times 25$ $= 1.7$ V	A1
6(c)	current (in disc) is perpendicular to magnetic field **or** current causes force to act on disc	B1
	force opposes rotation of disc	B1
	left-hand rule indicates current is from rim to axle	B1

7(a)	it is zero when (plane of) probe is parallel to the (magnetic) field (lines)	B1
	it is maximum when (plane of) probe is perpendicular to (magnetic) field (lines)	B1
7(b)(i)	number density of charge carriers	B1
7(b)(ii)	smaller value of n so greater Hall voltage / V_H	B1
7(c)	(36 mV corresponds to) 48 mT	C1
	use of 1.4 s or (8.6 – 7.2) s	C1
	$E = \Delta BAN / \Delta t$	C1
	$= \dfrac{48 \times 10^{-3} \times 0.018^2 \times \pi \times 780}{1.4}$ $= 0.027$ V	A1

8(a)(i)	PQRS and WXYZ	B1
8(a)(ii)	force on charge carriers is perpendicular to both (magnetic) field and current	B1
	as charge carriers are deflected to one side, an electric field is set up	B1
	(steady V_H when) electric and magnetic forces on charge carriers are equal (and opposite)	B1
8(b)(i)	n: number density of charge carriers	B1
	t: distance PW (or SZ or QX or RY)	B1
	q: charge on each charge carrier	B1
8(b)(ii)	V_H inversely proportional to t	B1
	(so t needs to be small for) V_H to be large enough to measure	B1

9(a)	force per unit current	M1
	force per unit length	M1
	current / wire is perpendicular to (magnetic) field (lines)	A1
9(b)(i)	current (in coil) is perpendicular to magnetic field (so force on wire)	B1
	force (on wire) is perpendicular to current and field (so is vertical) **or** current and field are both horizontal (so force is vertical)	B1
9(b)(ii)	$NBIL = mg$	C1
	$B = (2.16 \times 10^{-3} \times 9.81) / (40 \times 3.94 \times 0.0300)$	C1
	$= 4.48 \times 10^{-3}$ T	A1
9(b)(iii)	(magnetic) forces (on balance and newton meter) are (equal and) opposite	B1
	reading $= 0.563 - (2.16 \times 10^{-3} \times 9.81)$ $= 0.542$ N	A1

10 (a)	product of (magnetic) flux density and area	M1
	where area is perpendicular to the (magnetic) field	A1
10 (b)(i)	$N\Phi$ = BAN	C1
	= 400 × 10^{-3} × 0.12^2 × 8	C1
	= 0.046 Wb	A1
10 (b)(ii)	(line is a) straight line	B1
10 (b)(iii)	(induced) e.m.f. = rate of change of flux linkage	C1
	e.m.f. = $N\Phi / t$ = 0.046 / 0.60 = 0.077 V	A1
10 (c)	(induced e.m.f. causes) current flow (in the coil)	B1
	either	
	current (in magnetic field) causes forces to act on the coil	B1
	(opposite sides of) coil forced inwards	B1
	or	
	current causes dissipation of energy in the resistance of the coil	(B1)
	temperature of the coil rises	(B1)

11 (a)	there must be a current (in the wire)	B1
	(wire) must be at a non-zero angle to the magnetic field	B1
11 (b)(i)	arrow from X pointing horizontally to the left	B1
	arrow from Y pointing diagonally upwards and to the left at about 45°	B1
	arrow from Z pointing horizontally to the right	B1
11 (b)(ii)	(flux densities at W and X are approximately) equal	B1
	(flux density at) Y greater than (flux density at) Z	B1
11 (c)	current in wire creates magnetic field around wire	B1
	(each) wire sits in the magnetic field created by the other	B1
	(for each wire,) current / wire is perpendicular to magnetic field (due to other wire), (so) experiences a (magnetic) force	B1

12 (a)	less in smaller solenoid	B1
12 (b)	greater in smaller solenoid	B1
12 (c)(i)	direction of (induced) e.m.f.	M1
	such as to (produce effects that) oppose the change that caused it	A1
12 (c)(ii)	change of flux (linkage) in smaller solenoid induces e.m.f. in smaller solenoid	B1
	(induced) current in smaller solenoid causes field around it	B1
	the two fields (interact to) create an attractive force	B1

13 (a)	newton per ampere per metre	M1
	where current/wire is perpendicular to magnetic field	A1
13 (b)(i)	$F = BIL \sin\theta$	C1
	B = 1.0 / (5.0 × 0.060 × sin 50°) = 4.4 mT	A1
13 (b)(ii)	(from Fleming's left-hand rule) force on wire is upwards, so reading decreases	B1
13 (b)(iii)	frame will rotate (so that PQ becomes perpendicular to the field)	B1

14	(a)(i)	arrow from Q pointing downwards, labelled B	B1
14	(a)(ii)	arrow from Q pointing towards P, labelled F	B1
14	(b)(i)	force is proportional to product of both currents (I and $2I$) **or** Newton's third law	B1
		forces are equal	B1
14	(b)(ii)	opposite	B1

15	(a)	region where there is a force exerted on	M1
		a current-carrying conductor **or** a <u>moving</u> charge **or** a magnetic material/magnetic pole	A1
15	(b)(i)	face PSWV shaded	B1
15	(b)(ii)	accumulating electrons cause an electric field (between the faces)	B1
		force due to electric field opposes force due to magnetic field	B1
		accumulation stops when magnetic force equals electric force	B1
15	(c)(i)	number density of charge carriers	B1
15	(c)(ii)	PV **or** QT **or** SW	B1
15	(d)	(for semiconductor,) n is (much) smaller so V_H (much) larger	B1

16	(a)	• force per unit length • force per unit current • length/current perpendicular to field *1 mark for any two points, 2 marks for all three points*	B2
16	(b)	change in potential energy = change in kinetic energy **or** $qV = \frac{1}{2}mv^2$	B1
		$v = \sqrt{(2qV / m)}$	A1
16	(c)(i)	magnetic force = centripetal force **or** $Bqv = mv^2 / r$	M1
		clear substitution of expression for v and correct algebra leading to $q / m = 2V / B^2r^2$	A1
16	(c)(ii)	$q / m = (2 \times 230) / [(0.38 \times 10^{-3})^2 \times 0.14^2]$	C1
		$= 1.6 \times 10^{11}$ C kg^{-1}	A1
16	(c)(iii)	(for α-particle,) q / m is (much) smaller	B1
		r would be <u>much</u> larger	B1

17	(a)(i)	at least one anticlockwise arrow and no clockwise arrows	B1
17	(a)(ii)	(force is to the) left	B1
17	(a)(iii)	force is the same	B1
		Newton's third law (of motion) *or* force depends on the product of the two currents	B1

18	(a)(i)	(induced) e.m.f. (directly) proportional to rate	M1
		of change of magnetic flux (linkage)	A1
18	(a)(ii)	e.m.f. = 0 apart from thin pulses at t_1 and t_2	B1
		rectangular pulses centred on t_1 and t_2, of widths 2 small squares and 1 small square respectively	B1
		e.m.fs. at t_1 and t_2 have opposite polarities	B1
		magnitude of e.m.f. at t_2 double the magnitude of e.m.f. at t_1	B1
18	(b)	V_H shown as zero before (t_1 – 2 squares) and after (t_2 + 2 squares) and rises to a constant non-zero value between t_1 and t_2	M1
		change at t_1 shown as 2 small squares wide and change at t_2 shown as 1 small square wide	A1

19	(a)	concentric circles centred on the wire	B1
		separation of lines increasing with distance from wire	B1
		arrows show anti-clockwise direction	B1
19	(b)(i)	current in (each) wire creates a magnetic field (at the other wire)	B1
		current (in wire) at 90° to field causes force	B1
19	(b)(ii)	force on each wire towards other wire/attractive	B1
19	(c)	Newton's third law pair of forces so yes (forces are equal) **or** force proportional to product of both currents so yes (forces are equal)	B1

20	(a)	magnetic field normal to current	B1
		newton per ampere	B1
		newton per metre	B1
20	(b)(i)	current in wire QL gives rise to a force **or** wire QL is perpendicular to the magnetic field	B1
		force on wire QL is vertical	B1
		force does not act through the pivot	B1
20	(b)(ii)	forces act through the same line **or** forces are horizontal	B1
		forces are equal (in magnitude) and opposite (in direction)	B1
20	(c)(i)	change $= mg \times (\Delta)L$	C1
		$= 1.3 \times 10^{-4} \times 9.81 \times 2.6 \times 10^{-2} = 3.3 \times 10^{-5}$ N m^{-1}	A1
20	(c)(ii)	change $= B \times (\Delta)I \times L \times x$	C1
		$3.3 \times 10^{-5} = B \times 1.2 \times 0.85 \times 10^{-2} \times 5.6 \times 10^{-2}$	C1
		$B = 0.058$ T	A1

21	(a)(i)	e.m.f. $= (\Delta)B \times AN / t$	C1
		$= 45 \times 10^{-3} \times \pi \times (1.8 \times 10^{-2})^2 \times 350 / 0.20 = 0.080$ V	A1
21	(a)(ii)	0 to 0.2 s: straight horizontal line at 0.080 V or –0.080 V	B1
		0.2 s to 0.4 s: zero	B1
		0.4 s to 0.8 s: straight horizontal line at 0.040 V or –0.040 V	B1
		opposite polarity to 0 to 0.2 s line	B1
21	(b)	either disc cuts flux lines (of the magnet) **or** there is a changing flux in the disc	B1
		(by Faraday's law) e.m.f. is induced in the disc	B1
		e.m.f. causes (eddy) currents in the disc	B1
		current in the magnetic field (of the magnet) causes force on disc	B1

22	(a)	concentric circles (around the wire)	M1
		at least 3 circles shown, all with increasing separation	A1
		direction anticlockwise	B1
22	(b)(i)	$B = (4\pi \times 10^{-7} \times 6.2) / (2\pi \times 3.1 \times 10^{-2})$	C1
		$= 4.0 \times 10^{-5}$ T	A1
22	(b)(ii)	$F = BIL$ **or** $F / L = BI$	C1
		$F / L = 4.0 \times 10^{-5} \times 8.5$ $= 3.4 \times 10^{-4}$ N m^{-1}	A1
22	(c)	correct application of Newton's 3rd law to the forces **or** F / L is proportional to the product of the two currents	M1
		so same magnitude	A1

23	(a)	magnitude: (force =) *Bqv*	B1
		direction: P→Q **or** E→F **or** S→R **or** H→G	B1
23	(b)(i)	EHSP and FGRQ	B1
23	(b)(ii)	PE **or** QF **or** RG **or** SH	B1
23	(c)(i)	*any one correct starting point from:* • (mass of 1 atom =) $27 \times 1.66 \times 10^{-27}$ • (amount of substance per unit volume =) 2.7 / 27 • 27 g (of substance) contains 6.02×10^{23} atoms • (2.7 g mass contains) 0.1 mol • (1 cm^3 volume contains) 0.1 mol • (1 m^3 volume contains) 10^5 mol	C1
		$n = (2.7 \times 10^3) / (27 \times 1.66 \times 10^{-27}) = 6.0 \times 10^{28}$ **or** $n = (2.7 / 27) \times 10^6 \times 6.02 \times 10^{23} = 6.0 \times 10^{28}$	A1
23	(c)(ii)	$V_H = (0.15 \times 4.6) / (6.0 \times 10^{28} \times 0.090 \times 10^{-3} \times 1.60 \times 10^{-19})$	C1
		$= 8.0 \times 10^{-7}$ V	A1

24	(a)(i)	region where a force is exerted on: a magnetic pole **or** a moving charge **or** a current-carrying wire	B1
24	(a)(ii)	arrow on axis of solenoid pointing downwards labelled P	B1
24	(b)(i)	direction of induced e.m.f./current	M1
		(tends to) oppose the change causing it	A1
24	(b)(ii)	magnetic field in solenoid is increasing	B1
		field in coil in opposite direction to oppose increase	B1
		arrow inside or just above small coil pointing in opposite direction to P	B1
24	(c)	e.m.f. $= N\Delta\phi / \Delta t$	C1
		$= (75 \times 1.4 \times 10^{-3} \times 2 \times 7.0 \times 10^{-4}) / 0.12$	C1
		$= 1.2 \times 10^{-3}$ V	A1

25	(a)(i)	$v_N = 3.4 \times 10^7 \times \sin 30°$ $= 1.7 \times 10^7$ m s^{-1}	A1
25	(a)(ii)	$mv^2 / r = Bqv$ **or** $r = mv / Bq$	C1
		$r = (9.11 \times 10^{-31} \times 1.7 \times 10^7) / (3.2 \times 10^{-3} \times 1.60 \times 10^{-19})$	C1
		$= 0.030$ m	A1
25	(b)	zero	B1
25	(c)	helix/coil	B1