MAGNETIC FIELDS WORKSHEET
A-Level Physics 9702

MJ25/41/Q7

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

....

....

.... [2]

(b) A particle of mass *m* and charge +*Q* moves at speed *v* into a region where there is a uniform magnetic field, as shown in Fig. 7.1.

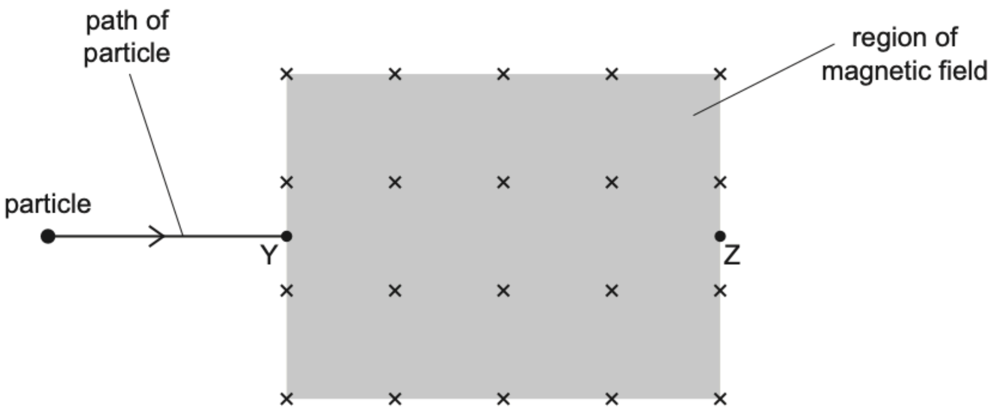

Fig. 7.1

The uniform magnetic field is into the page and has flux density *B*. The particle enters the region of the field at point Y.

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(i) State an expression, in terms of some or all of *m*, *Q*, *B* and *v*, for the magnetic force *F* that acts on the particle when it is at point Y.

F = ... [1]

(ii) On Fig. 7.1, draw an arrow at point Y to indicate the direction of the force in **(b)(i)**. [1]

(iii) On Fig. 7.1, draw a line to show a possible path for the particle through the region of the magnetic field. [1]

(c) (i) Explain how an electric field can be used with the magnetic field to ensure that the particle in **(b)** now passes through point Z.

....

....

....

....

.... [3]

(ii) Derive an expression for *v* in terms of *B* and the electric field strength *E*.

v = ... [2]

[Total: 10]

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2 (a) (i) State what is represented by a gravitational field line. MJ25/42/Q2

....

....

.... [2]

(ii) The Earth may be considered as a uniform sphere, as shown in Fig. 2.1.

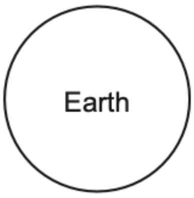

Fig. 2.1

On Fig. 2.1, draw field lines to represent the Earth's gravitational field outside the Earth. [2]

(b) The Earth's magnetic field may be considered as being due to the Earth acting as a long solenoid, as shown in Fig. 2.2.

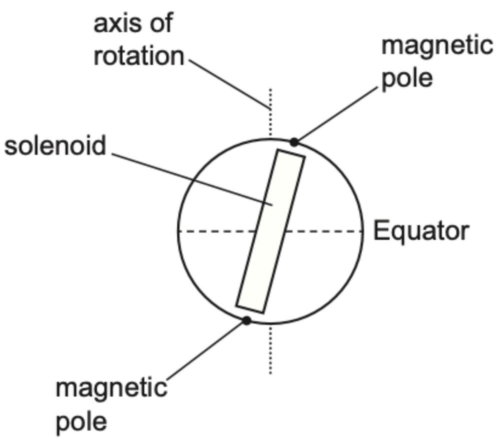

Fig. 2.2

The magnetic poles do not align with the geographic poles, which are on the axis of rotation.

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Fig. 2.3 is a copy of Fig. 2.2 without the labels but with two magnetic field lines shown.

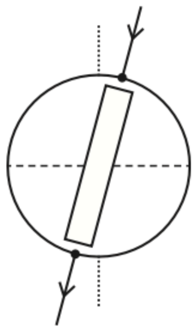

Fig. 2.3

(i) On Fig. 2.3, label the magnetic poles with the letters N and S to indicate which one is the magnetic N pole and which one is the magnetic S pole. [1]

(ii) On Fig. 2.3, draw field lines to represent the Earth's magnetic field outside the Earth. [2]

(c) An observer moves around the surface of the Earth.

(i) Use your answer in **(a)(ii)** to explain why the observed gravitational field of the Earth does not vary around the surface.

....

....

.... [2]

(ii) With reference to your answer in **(b)(ii)**, describe how the observed magnetic field of the Earth varies around the surface.

....

....

....

....

.... [3]

[Total: 12]

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3 A rectangular coil PQRS of wire is free to rotate about its axis XY, as shown in Fig. 6.1.

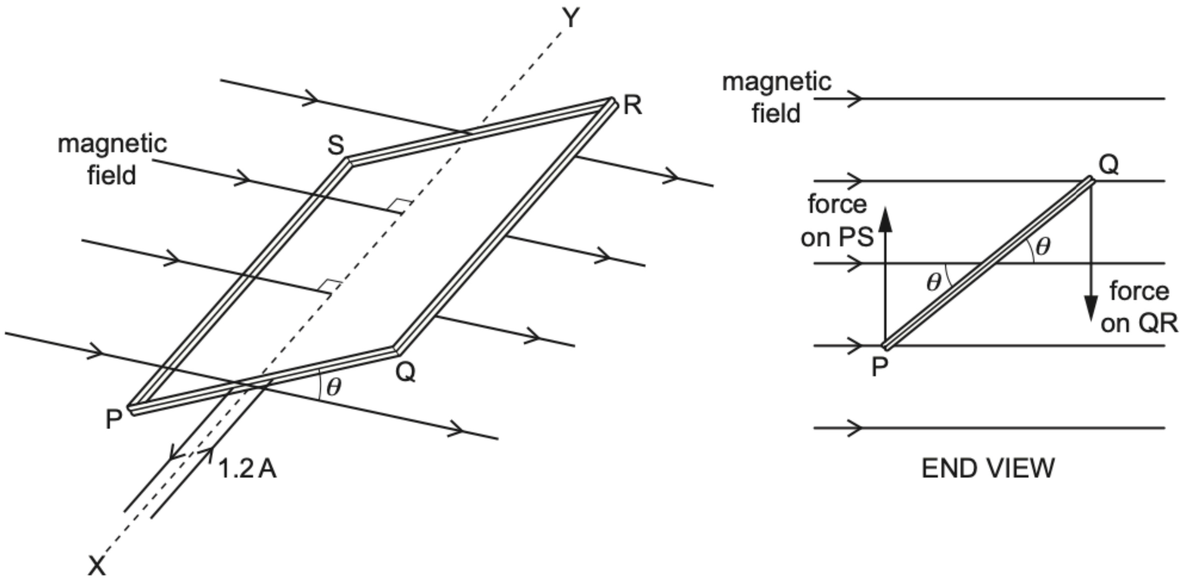

Fig. 6.1 (not to scale)

The coil has length QR of 5.4 cm, width PQ of 2.5 cm and has 190 turns of wire.
The plane of the coil is at an angle θ to a uniform magnetic field of flux density 5.2×10^{-3} T.
The axis XY of the coil is normal to the field.
The current in the coil is 1.2 A.

(a) **(i)** Calculate the magnitude of the force on side QR of the coil.

force = ... N [3]

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(ii) Use your answer in **(a)(i)** to show that the torque τ on the coil is given by

$$\tau = 1.6 \times 10^{-3} \cos\theta \, \text{N m}.$$

[2]

(iii) Using the expression in **(a)(ii)** sketch, on the axes of Fig. 6.2, a graph to show the variation of the torque τ with angle θ for values of θ between 0 and 360°. Label the τ axis with an appropriate scale.

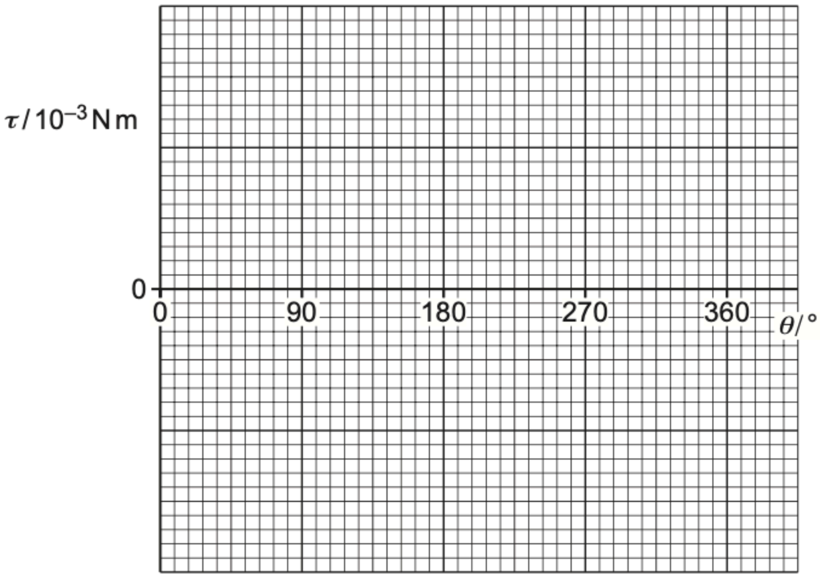

Fig. 6.2

[3]

(b) The coil is now replaced by an identical coil wound on a ferrous core.

Suggest, with a reason, how the torque on this coil compares with the torque on the original coil.

....

....

.... [2]

[Total: 10]

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4 A bar magnet is suspended from a spring. One pole of the magnet oscillates freely in a coil of wire, as shown in Fig. 7.1.

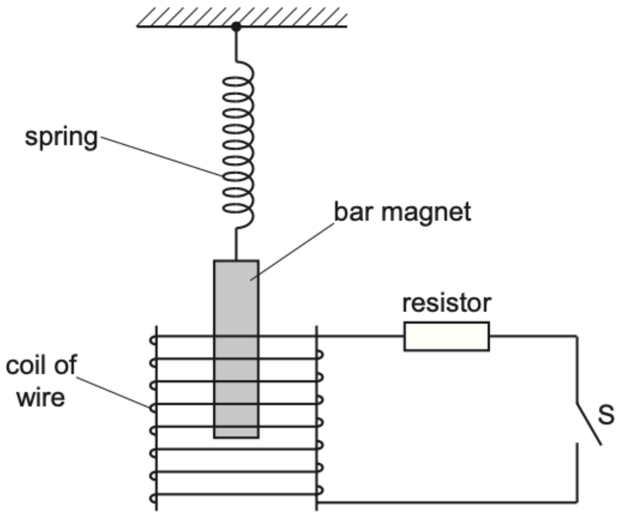

Fig. 7.1

The switch S is initially open.

(a) The switch S is now closed. As a result, the oscillations of the magnet are lightly damped.

(i) State what is meant by damping.

....

....

.... [2]

(ii) Describe what is observed to indicate that the damping is light.

....

.... [1]

(iii) By reference to electromagnetic induction and to conservation of energy, explain why the oscillations are damped.

....

....

....

.... [3]

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(b) The procedure in **(a)** is repeated after replacing the resistor with one of greater resistance.

Suggest, with a reason, the effect of this change on the oscillations.

....

....

.... [2]

[Total: 8]

March25/42/Q6

5 An electric field and a magnetic field are used to form a velocity selector. Charged particles, called ions, pass into a region of uniform electric and magnetic fields that is between parallel plates, as shown in Fig. 6.1.

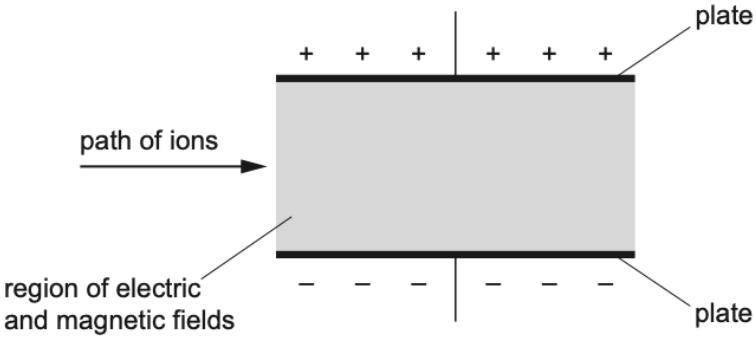

Fig. 6.1

(a) The potential difference (p.d.) between the plates of the velocity selector is V. The separation of the plates is d and the magnetic flux density is B.

Show that the speed u of ions that pass undeviated through the velocity selector is given by

$$u = \frac{V}{Bd}.$$

[2]

(b) Positive ions with kinetic energy 4.1×10^{-17} J and mass 3.2×10^{-27} kg pass undeviated through the velocity selector when V is equal to 980 V and d is equal to 3.6×10^{-2} m.

Determine B.

B = ... T [3]

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(c) A proton passes undeviated through the velocity selector.

An alpha particle enters the velocity selector at the same speed as the proton.

State how the expression in **(a)** predicts that the alpha particle also passes undeviated through the velocity selector.

....

.... [1]

(d) By reference to Fig. 6.1 and to the forces acting on a positive ion, determine the direction of the magnetic field. Explain your reasoning.

....

....

....

....

....

.... [3]

(e) The positive ions in **(b)** enter the velocity selector with greater kinetic energy.

On Fig. 6.1, sketch the path of these ions. [2]

[Total: 11]

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6 **(a)** State Faraday's law of electromagnetic induction.

....

....

.... [2]

(b) A metal rod is accelerated uniformly from rest in a uniform magnetic field as shown in Fig. 7.1.

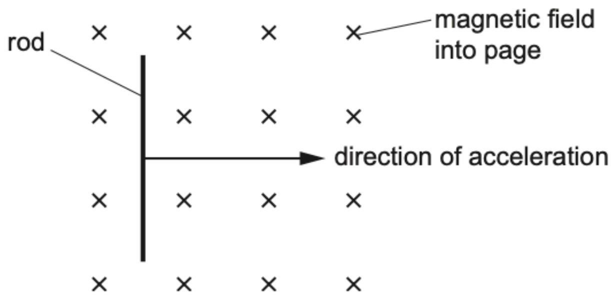

Fig. 7.1

The rod has length l and the flux density of the magnetic field is B.

An electromotive force (e.m.f.) is induced in the rod. The variation with time t of the induced e.m.f. E is shown in Fig. 7.2.

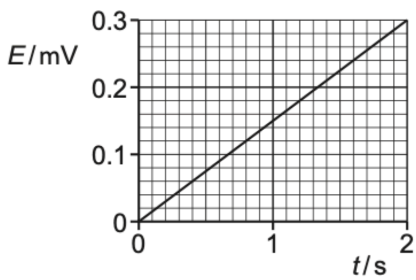

Fig. 7.2

(i) Explain how Fig. 7.2 shows that E is proportional to the velocity v of the rod.

....

....

.... [2]

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(ii) Use Faraday's law to show that the variation of E with time t is given by

$$E = Blat$$

where a is the acceleration of the rod.

[3]

(iii) The length of the rod is 0.45 m. The acceleration a of the rod is $7.8\,m\,s^{-2}$.

Determine the value of B.

B = ... T [2]

[Total: 9]

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

....

....

.... [2]

(b) A long, straight wire carries a current into the page, as shown in Fig. 7.1.

Fig. 7.1

On Fig. 7.1, draw four field lines to represent the magnetic field around the wire due to the current in it. [3]

(c) Two identical wires X and Y are placed parallel to each other. The wires both carry current into the page, as shown in Fig. 7.2.

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(i) Explain why the two wires exert a magnetic force on each other.

....

....

....

.... [2]

(ii) On Fig. 7.2, draw an arrow to show the direction of the magnetic force exerted on wire X. Label your arrow F. [1]

(iii) The current in X is double the current in Y.

State how the magnetic force exerted on wire Y compares with the magnetic force exerted on wire X.

....

....

.... [2]

(iv) The direction of the current in both wires is now reversed.

State, with a reason, the effect of this change on the direction of the force on wire X.

....

.... [1]

[Total: 11]

8 A metal wheel consists of an axle A, eight spokes and a rim, as shown in Fig. 1.1. **ON24/42/Q1**

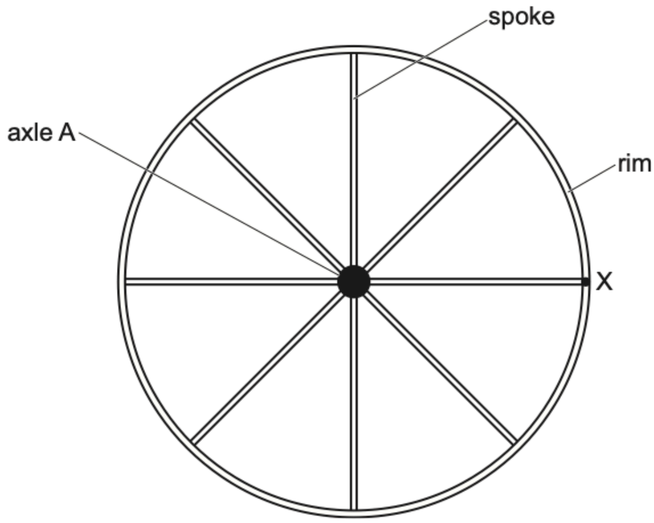

Fig. 1.1

Point X is on the rim at the end of one of the spokes.

The rim has a radius of 0.85 m.
The wheel is rotating clockwise with an angular speed of 140 rad s^{-1}.

(a) For point X, determine:

(i) the speed

speed = ... m s^{-1} [2]

(ii) the centripetal acceleration.

acceleration = ... m s^{-2} [2]

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(b) There is a uniform magnetic field of flux density 0.18 T into the plane of the page.

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

....

....

.... [2]

(ii) Show that the time taken for point X to complete one revolution is 45 ms.

[1]

(iii) Calculate the magnetic flux cut by spoke AX during one revolution of the wheel.
Give a unit with your answer.

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

(iv) Determine the magnitude of the electromotive force (e.m.f.) induced across spoke AX.

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

(v) Use Lenz's law to explain whether the potential is higher at end A or end X of the spoke.

....

....

.... [1]

[Total: 13]

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9 **(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.

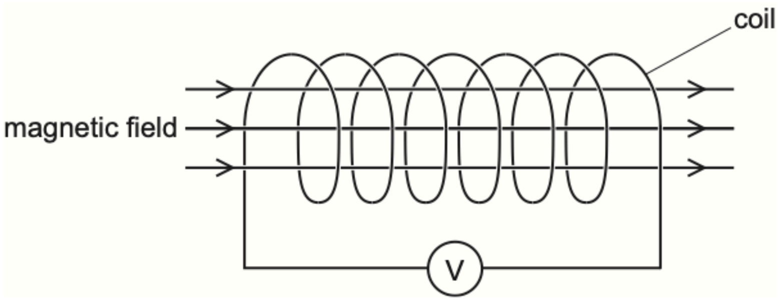

Fig. 7.1

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.

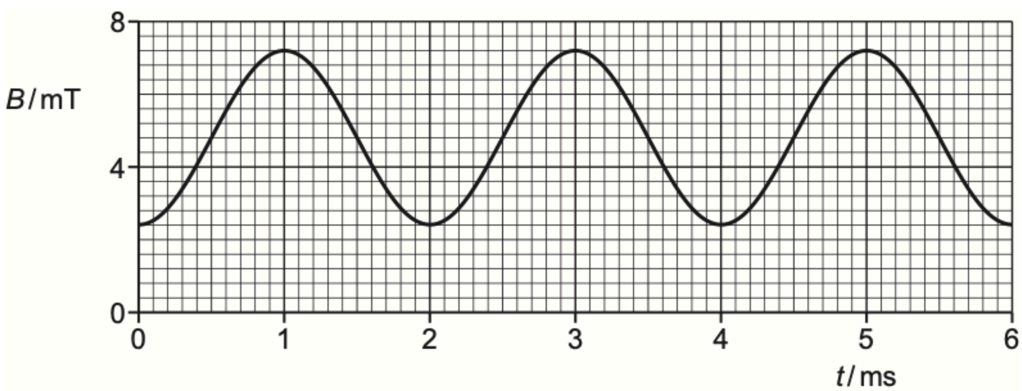

Fig. 7.2

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]

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(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 $t = 6.0\,ms$.

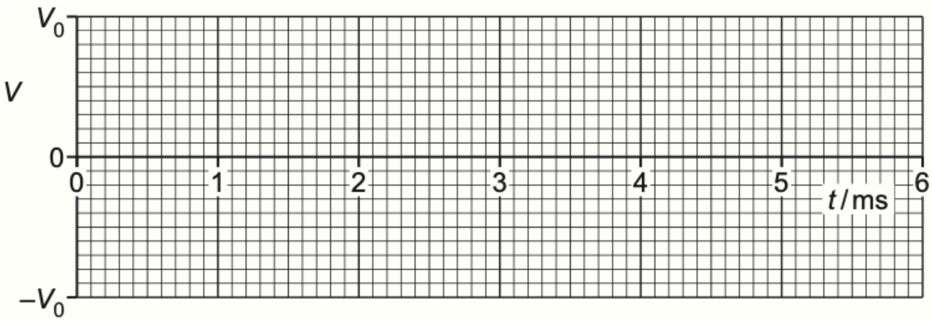

Fig. 7.3

[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]

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10 **(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]

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(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]

11 (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.

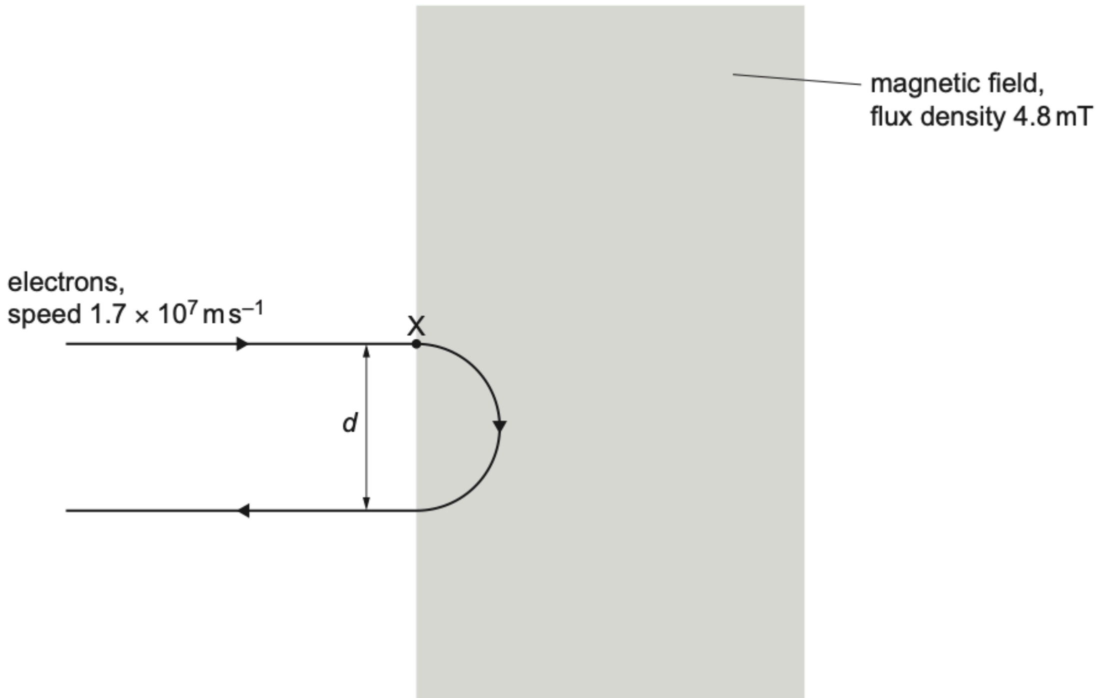

Fig. 6.1

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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 $3.4 \times 10^{7}\,\text{m s}^{-1}$ 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]

[Total: 12]

12 **(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.

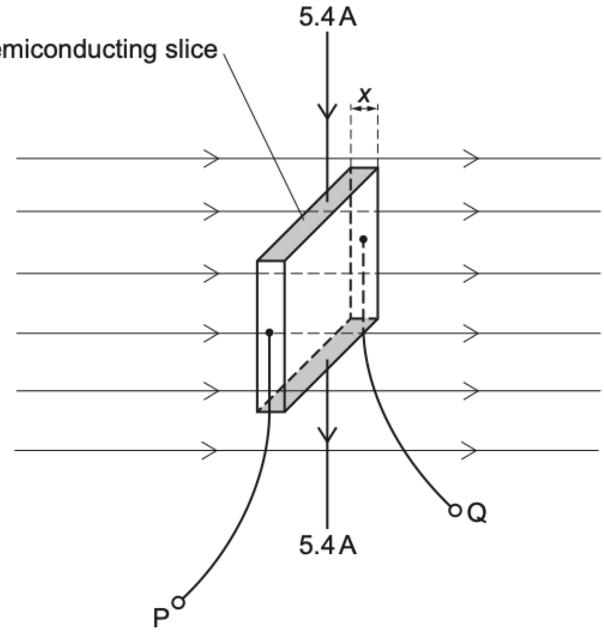

Fig. 7.1

The thickness x of the slice is 1.8 mm. The number density of charge carriers in the semiconducting material is $1.5 \times 10^{16}\,\text{m}^{-3}$.
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.

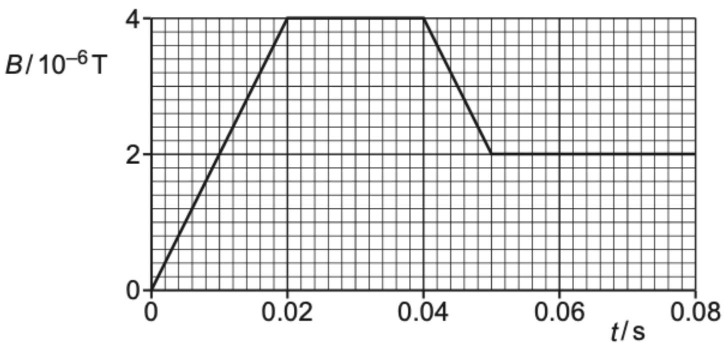

Fig. 7.2

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

[1]

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

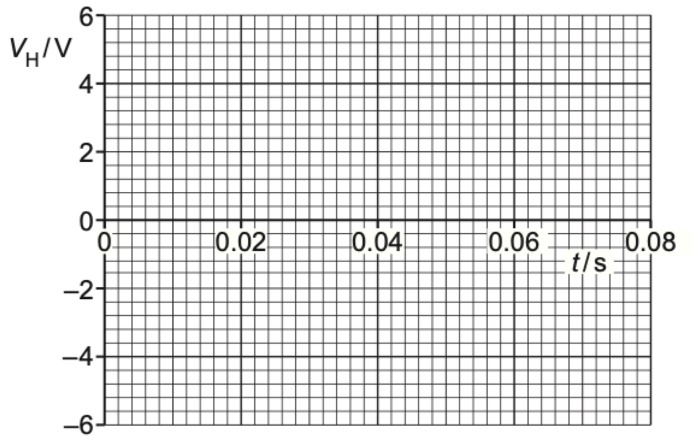

Fig. 7.3

[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 3.4×10^{-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 2.0×10^{-4} V.

[3]

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

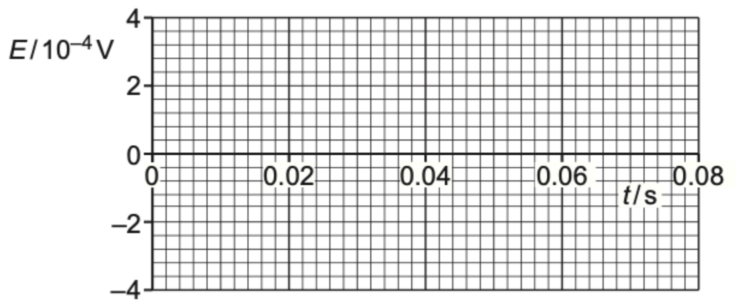

Fig. 7.4

[4]

[Total: 11]

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13 **(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.

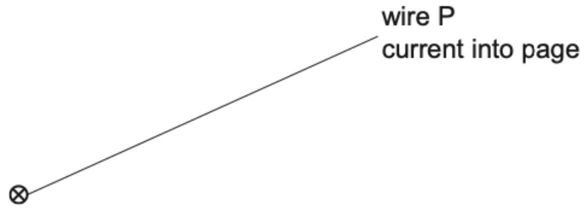

Fig. 6.1

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 5.0A out of the page, is placed parallel to wire P, as shown in Fig. 6.2.

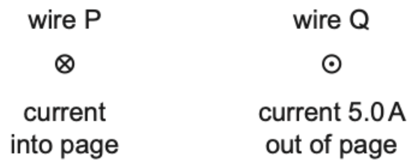

Fig. 6.2

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]

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(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

14 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.

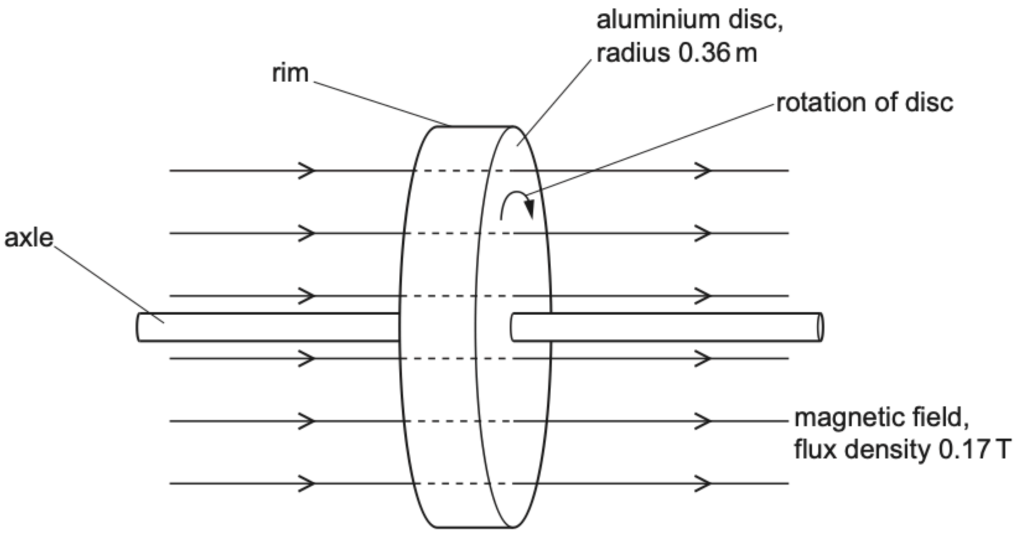

Fig. 6.1

(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]

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15 **(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.

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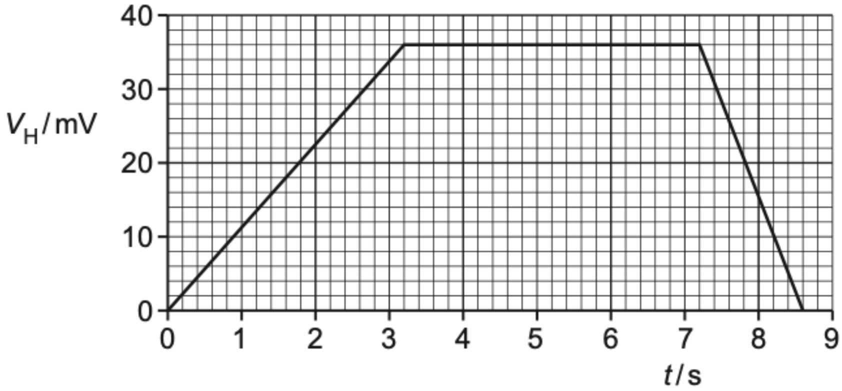

Fig. 6.1

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]

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

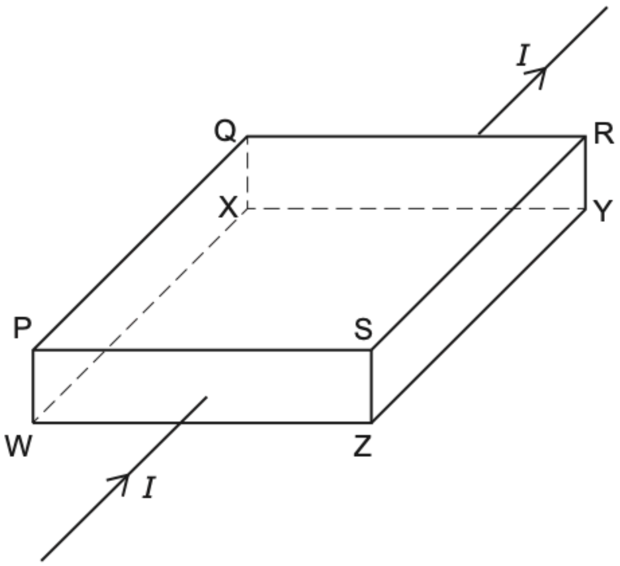

Fig. 6.1 (not to scale)

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

17 (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.

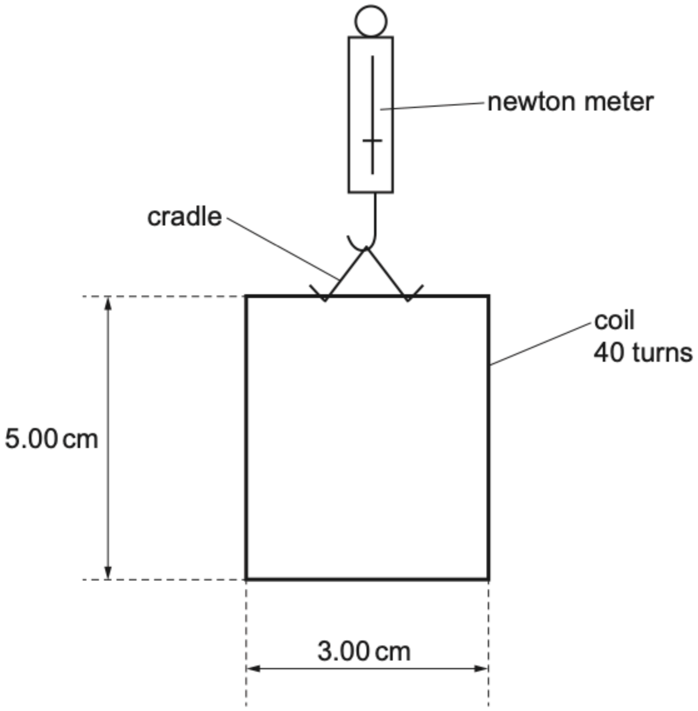

Fig. 7.1

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.

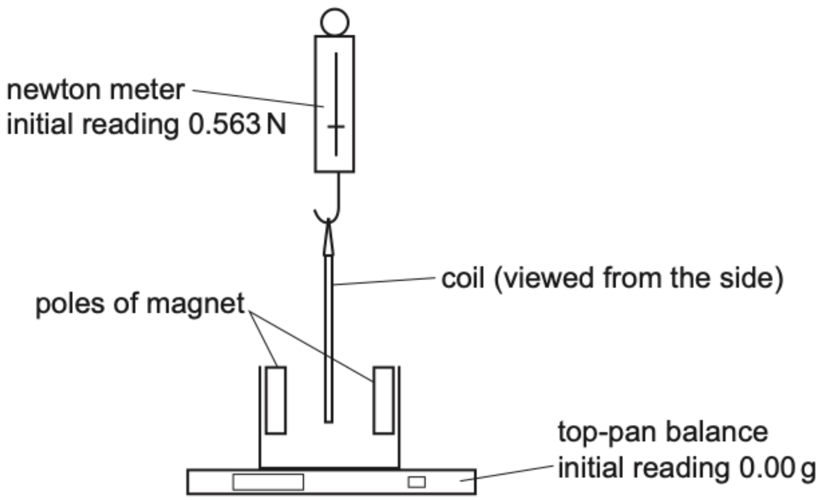

Fig. 7.2

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.

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(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

18 **(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.

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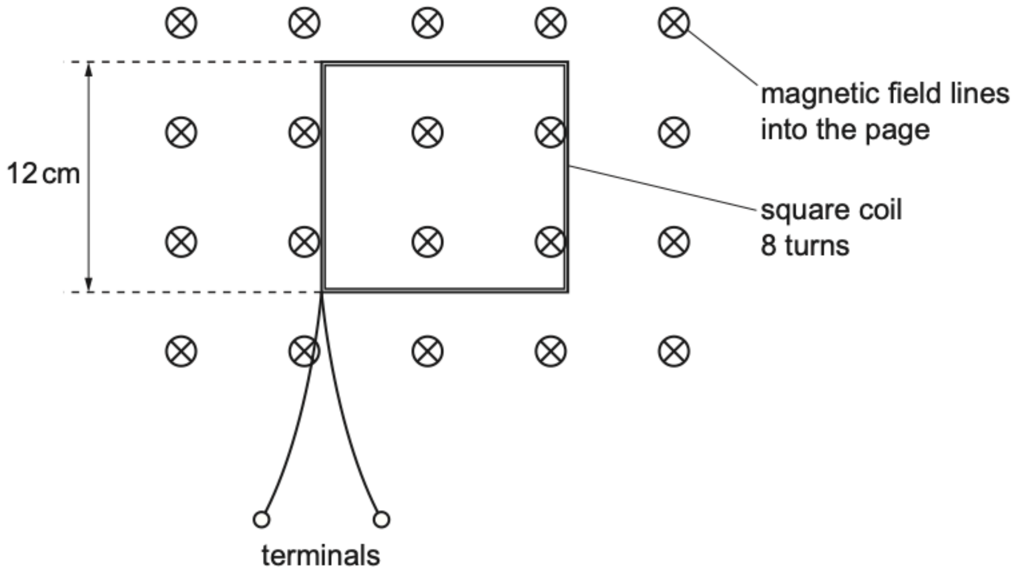

Fig. 6.1

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

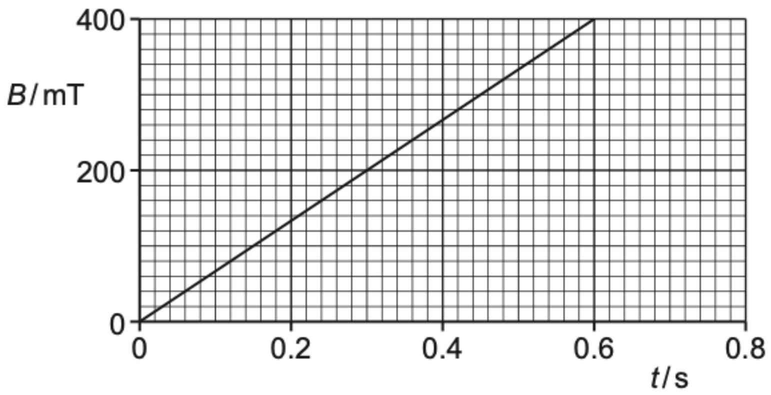

Fig. 6.2

(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]

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(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]

19 **(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.

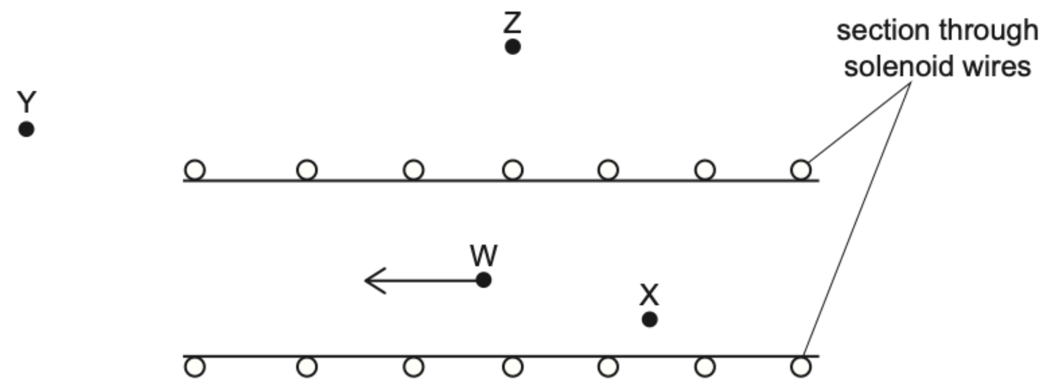

Fig. 6.1

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

20 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.

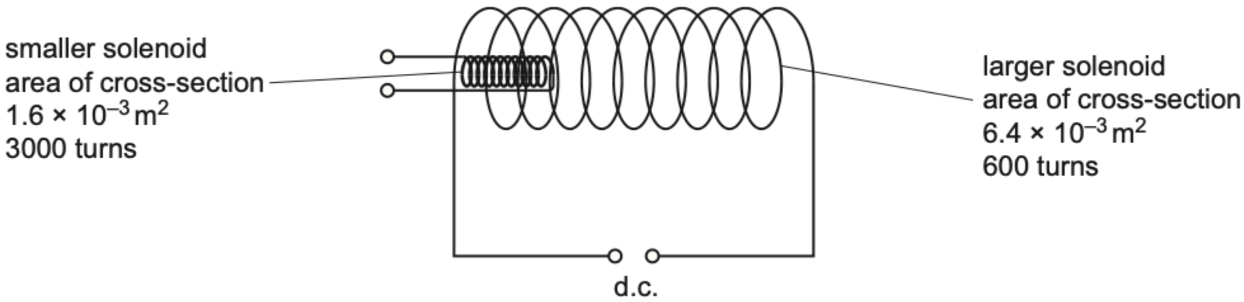

Fig. 6.1 (not to scale)

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.

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(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]

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21 **(a)** Define the *tesla*. **ON21/41/Q8**

....

....

.... [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.

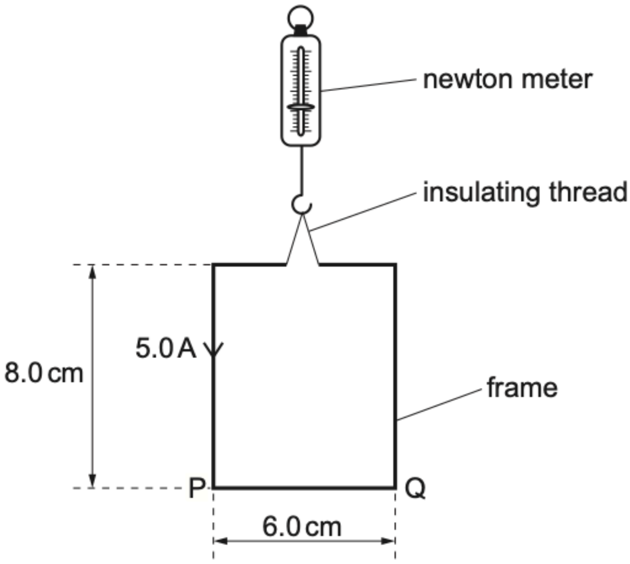

Fig. 8.1

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.

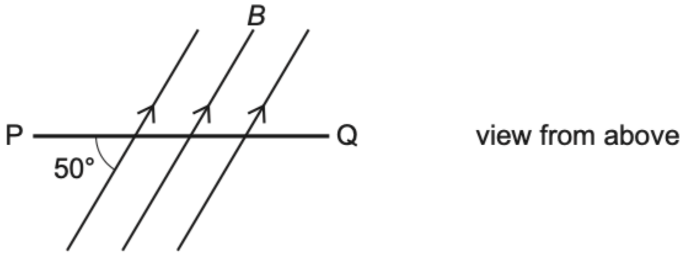

Fig. 8.2

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]

22 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]

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23 (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.

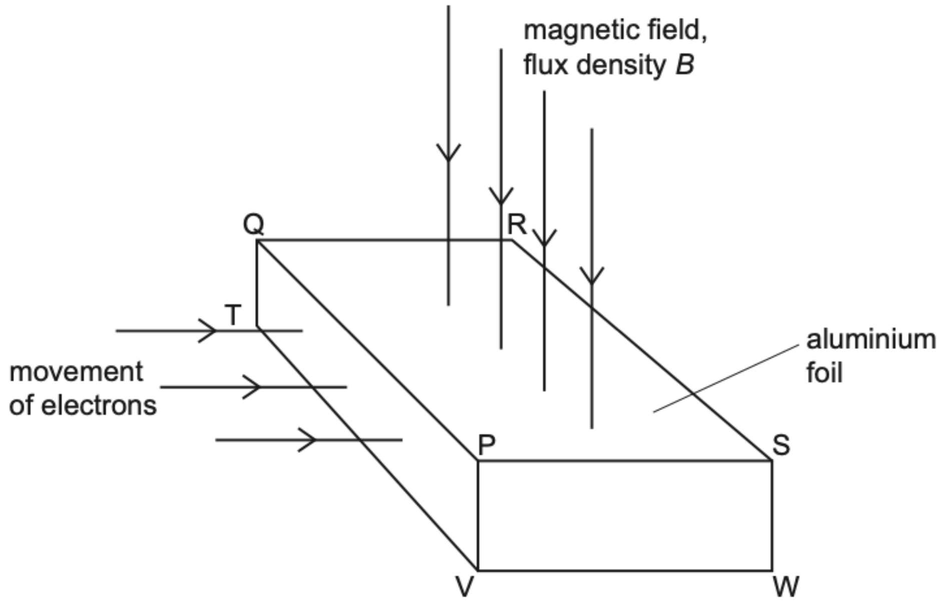

Fig. 9.1

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]

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(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]

24 **(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.

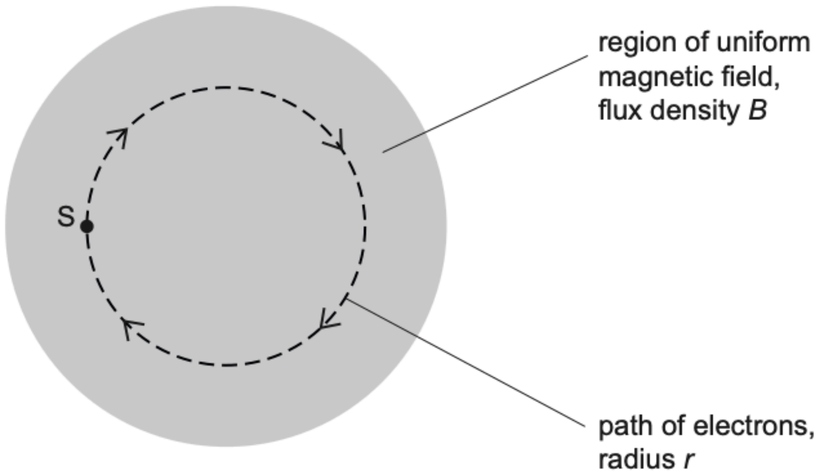

Fig. 8.1

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.

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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]

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1 (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	Ratio must be clear. **Ignore** symbols unless defined. **Ignore** references to units. 'Force per unit (current × length)' achieves both points. **Allow** 'wire perpendicular to field'. **Allow** 'flux (density)' for 'field'. **Do not allow** 'force' for 'field'.
7(b)(i)	$F = BQv$	B1	
7(b)(ii)	arrow at Y pointing vertically upwards	B1	
7(b)(iii)	upwards deflection showing circular path	B1	**Do not allow** if kinked at Y. **Allow** downwards deflection if consistent with arrow drawn in **(b)(ii)**.
7(c)(i)	electric field applied vertically downwards electric force on particle in opposite direction to magnetic force particle undeflected when magnitudes of electric and magnetic forces are equal	B1 B1 B1	May be shown in a diagram. May be shown in a diagram. **Allow** 'particle undeflected when $F_E = F_B$'. **Allow** 'reaches Z' for 'undeflected'.
7(c)(ii)	$EQ = BQv$ $v = E / B$	B1 A1	

2 (a)(i)	direction of force force acting on a (test) mass	B1 B1	
2(a)(ii)	radial lines arrows indicating direction towards centre of Earth	B1 B1	At least 4 radial lines needed. At least one arrow needed. All arrows shown must be in correct direction.
2(b)(i)	top pole labelled S and bottom pole labelled N	B1	
2(b)(ii)	correct pattern of field, as for a solenoid arrows indicating direction from N to S	B1 B1	
2(c)(i)	close to the surface, lines are approximately parallel all lines perpendicular to surface and pointing down towards surface	B1 B1	
2(c)(ii)	<u>any three points from:</u> <u>up to two points from:</u> • strongest at the poles • weakest near the Equator • strength increases from Equator to poles <u>up to two points from:</u> • perpendicular to surface at the poles • parallel to the surface near the Equator • angle to surface increases from Equator to poles	B3	 Or vice-versa. Or vice-versa. Or equivalent referenced to angle to the perpendicular.

3)(i)	$F = BIL$	C1	
	force on QR = 5.2 × 10^{-3} × 1.2 × 0.054 × 190	C1	Treat omission of 190 factor as a TE.
	= **0.064 N**	A1	Correct to at least 2 significant figures. AFC.
6(a)(ii)	torque = force × perpendicular distance between forces	C1	
	= 0.064 × 0.025 cos θ = (1.6 × 10^{-3}) cos θ N m	A1	Substitution and answer needed. No ECF from **(a)(i)**.
6(a)(iii)	one complete cycle of a sinusoidal curve between 0 and 360°	B1	**Do not allow** if amplitude varies.
	τ axis labelled to show maximum and minimum torques at ±1.6 × 10^{-3} N m	B1	At least one correct scale marking needed, both above and below τ = 0. Does not need to be at the peak/trough. All scale markings shown must be consistent.
	maximum at 0 and 360° and minimum at 180° (or vice versa), with torque shown as zero at 90° and 270°	B1	
6(b)	(ferrous core) increases magnetic flux density	B1	
	amplitude of torque increases	B1	**Allow** 'maximum' for 'amplitude of'.

4 'a)(i)	loss of energy (of oscillations)	B1	**Allow** 'reduction in amplitude (of oscillations)'.
	due to resistive forces	B1	
7(a)(ii)	*either*: amplitude (of oscillations) decreases gradually *or*: oscillations continue (for several periods)	B1	
7(a)(iii)	*either*: cutting of (magnetic) flux causes induced e.m.f. in coil *or*: induced e.m.f. causes current in resistor	B1	**Allow** 'cutting of magnetic flux causes (induced) current in resistor'.
	either: current causes dissipation of thermal energy in resistor *or*: current in resistor causes dissipation of thermal energy	B1	**Allow** 'heat' for 'thermal energy'.
	thermal energy comes from energy of oscillations	B1	**Allow** 'heat' for 'thermal energy'.
7(b)	thermal energy dissipated at a lower rate	B1	
	either: oscillations are less damped *or*: smaller decrease in amplitude of oscillations (in each period) *or*: oscillations continue for longer	B1	

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5 (a)	$F_B = F_E$	**B1**
	either: $Bqu = qE$ and $E = V / d$ leading to $u = V / Bd$ *or*: $Bqu = qV / d$ leading to $u = V / Bd$	**B1**

6(b)	$E_K = ½mu^2$	**C1**
	$u = \sqrt{[(2 \times 4.1 \times 10^{-17}) / (3.2 \times 10^{-27})]}$ $= 1.6 \times 10^5 ms^{-1}$	**C1**
	$B = 980 / (3.6 \times 10^{-2} \times 1.6 \times 10^5)$ $= 0.17 T$	**A1**
6(c)	expression is independent of mass and charge	**A1**
6(d)	*either*: electric force is downwards so magnetic force is upwards *or*: no resultant force so magnetic force is upwards	**B1**
	(positive ions so) current is from left to right	**B1**
	from (Fleming's) left-hand rule, magnetic field is into the page	**B1**
6(e)	curved path inside plates with consistent direction of curvature and with no discontinuity at entry or in curvature	**B1**
	direction of deflection is upwards	**B1**

6 7(a)	(induced) e.m.f. is (directly) proportional to rate	**M1**
	of change of (magnetic) flux (linkage)	**A1**
7(b)(i)	(uniform acceleration so) velocity is (directly) proportional to time	**M1**
	(Fig. 7.2 shows) e.m.f. is (directly) proportional to time so E is proportional to v.	**A1**

7(b)(ii)	($v = at$ so) distance moved in time $\Delta t = at\Delta t$	**C1**
	$\Phi = BA$	**C1**
	$E = (\Delta\Phi / \Delta t) = B \times L \times (at\Delta t) / \Delta t = BLat$	**A1**
7(b)(iii)	$B = (0.30 \times 10^{-3}) / (0.45 \times 7.8 \times 2.0)$	**C1**
	$= 4.3 \times 10^{-5} T$	**A1**

7 (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**
7(b)	concentric circles around the wire (at least two circles needed)	**B1**
	spacing between circles increases with distance from wire (at least four circles needed)	**B1**
	arrows showing direction of field is clockwise	**B1**
7(c)(i)	(each) wire sits in the (magnetic) field created by the other	**B1**
	current (in one wire) is perpendicular to (magnetic) field (due to other wire) so (magnetic) force acts (on wire)	**B1**
7(c)(ii)	arrow drawn, starting from X and pointing towards Y, labelled F	**B1**
7(c)(iii)	(forces have) equal magnitudes	**B1**
	(forces are in) opposite directions	**B1**
7(c)(iv)	no change (in the direction of the force) since both the current in X and the field due to Y have reversed	**B1**

8 (a)(i)	$v = r\omega$	**C1**
	$= 0.85 \times 140$ $= 120\ \text{m s}^{-1}$	**A1**
1(a)(ii)	$a = r\omega^2$ **or** $a = v^2 / r$	**C1**
	$a = 0.85 \times 140^2$ **or** $120^2 / 0.85$ $= 1.7 \times 10^4\ \text{m s}^{-2}$	**A1**
1(b)(i)	direction of (induced) e.m.f.	**M1**
	is such as to (produce effects that) oppose the <u>change</u> that caused it	**A1**
1(b)(ii)	$T = 2\pi / \omega$ $= 2\pi / 140 = 0.045\ \text{s} = 45\ \text{ms}$	**A1**
1(b)(iii)	$\Phi = BA$	**C1**
	$= 0.18 \times \pi \times 0.85^2$	**C1**
	$= 0.41\ \text{Wb}$	**A1**
1(b)(iv)	$E = \Phi / t$	**C1**
	$= 0.41 / 0.045$ $= 9.1\ \text{V}$	**A1**
1(b)(v)	force (on spoke) must be anticlockwise, so current is from A to X (by Fleming's left hand rule), so X is at the higher potential	**B1**

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9 a)	(induced) e.m.f. is (directly) proportional to rate	M1
	of change of (magnetic) flux (linkage)	A1
7(b)(i)	$\Phi = BA$	C1
	$= 7.2 \times 10^{-3} \times 3.2 \times 10^{-4}$ $= 2.3 \times 10^{-6}$ Wb	A1
7(b)(ii)	tangent drawn at steepest point on Fig. 7.2	C1
	evidence of multiplication by 340	C1
	maximum rate of change of flux = 0.82 Wb s^{-1}	A1
7(b)(iii)	V_0 = 0.82 V **or** V_0 given as identical numerical answer to the answer in **(b)(ii)**	A1
7(b)(iv)	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
7(b)(v)	A = 0.82 V **or** A has same numerical value as answer in **(b)(iii)**, with unit V	A1
	$B = 2\pi / (2.0 \times 10^{-3})$	C1
	= 3100 rad s^{-1}	A1

10 (a)	*any 2 points from*: • (angular) displacement • velocity • momentum • (centripetal) acceleration • (resultant) force	B2
5(b)(i)	$Bqv = mv^2 / r$	M1
	$v = 2\pi r / T$	M1
	completion of algebra leading to $B = 2\pi m / qT$	A1
5(b)(ii)	$B = (2\pi \times 4 \times 1.66 \times 10^{-27}) / (2 \times 1.60 \times 10^{-19} \times 2.5 \times 10^{-6})$	C1
	= 0.052 T	A1
5(b)(iii)	**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
5(b)(iv)	$qE = Bqv$	C1
	$E = Bv = 0.052 \times 1.1 \times 10^6$ $= 5.7 \times 10^4$ N C^{-1}	A1

11 (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
6(b)(i)	into the page	B1
6(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
6(b)(iii)	arrow at point X pointing down the page	B1

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6(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
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

12 (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
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
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
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

13 (a)	a region where a force acts on	M1
	a current-carrying conductor **or** a moving charge **or** a magnetic material / magnetic pole	A1
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
6(c)(i)	$F = BIL$	C1
	force per unit length $= BI$ $= 2.6 \times 10^{-3} \times 5.0$ $= 0.013$ N m^{-1}	A1
6(c)(ii)	to the right	B1
6(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

14 (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

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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 × 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

15)	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
6(b)(i)	number density of charge carriers	B1
6(b)(ii)	smaller value of n so greater Hall voltage / V_H	B1
6(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
	$= \frac{48 \times 10^{-3} \times 0.018^2 \times \pi \times 780}{1.4}$ = 0.027 V	A1

16 a)(i)	PQRS and WXYZ	B1
6(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
6(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
6(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

17 a)	force per unit current	M1
	force per unit length	M1
	current / wire is perpendicular to (magnetic) field (lines)	A1
7(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
7(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
7(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

18	6(a)	product of (magnetic) flux density and area	M1
		where area is perpendicular to the (magnetic) field	A1
	6(b)(i)	$N\Phi = BAN$	C1
		$= 400 \times 10^{-3} \times 0.12^2 \times 8$	C1
		$= 0.046$ Wb	A1
	6(b)(ii)	(line is a) straight line	B1
	6(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
	6(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)

19	6(a)	there must be a current (in the wire)	B1
		(wire) must be at a non-zero angle to the magnetic field	B1
	6(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
	6(b)(ii)	(flux densities at W and X are approximately) equal	B1
		(flux density at) Y greater than (flux density at) Z	B1
	6(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

20	6(a)	less in smaller solenoid	B1
	6(b)	greater in smaller solenoid	B1
	6(c)(i)	direction of (induced) e.m.f.	M1
		such as to (produce effects that) oppose the change that caused it	A1
	6(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

21 8(a)	newton per ampere per metre	M1
	where current/wire is perpendicular to magnetic field	A1
8(b)(i)	$F = BIL\sin\theta$	C1
	$B = 1.0 / (5.0 \times 0.060 \times \sin 50°)$ $= 4.4$ mT	A1
8(b)(ii)	(from Fleming's left-hand rule) force on wire is upwards, so reading decreases	B1
8(b)(iii)	frame will rotate (so that PQ becomes perpendicular to the field)	B1

22 8(a)(i)	arrow from Q pointing downwards, labelled B	B1
8(a)(ii)	arrow from Q pointing towards P, labelled F	B1
8(b)(i)	force is proportional to product of both currents (I and $2I$) **or** Newton's third law	B1
	forces are equal	B1
8(b)(ii)	opposite	B1

23 9(a)	region where there is a force exerted on	M1
	a current-carrying conductor **or** a moving charge **or** a magnetic material/magnetic pole	A1
9(b)(i)	face PSWV shaded	B1
9(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
9(c)(i)	number density of charge carriers	B1
9(c)(ii)	PV **or** QT **or** SW	B1
9(d)	(for semiconductor,) n is (much) smaller so V_H (much) larger	B1

24 (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
8(b)	change in potential energy = change in kinetic energy **or** $qV = ½mv^2$	B1
	$v = \sqrt{(2qV / m)}$	A1
8(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
8(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
8(c)(iii)	(for α-particle,) q / m is (much) smaller	B1
	r would be much larger	B1

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