

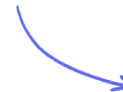
## Structured Questions

# 5.4 Magnetic Effects of Electric Currents

5.4.1 Magnetic Fields / 5.4.2 Magnetic Force on a Charge / 5.4.3 Magnetic Force on a Current-Carrying Conductor / 5.4.4 Solving Problems Involving Magnetic Forces

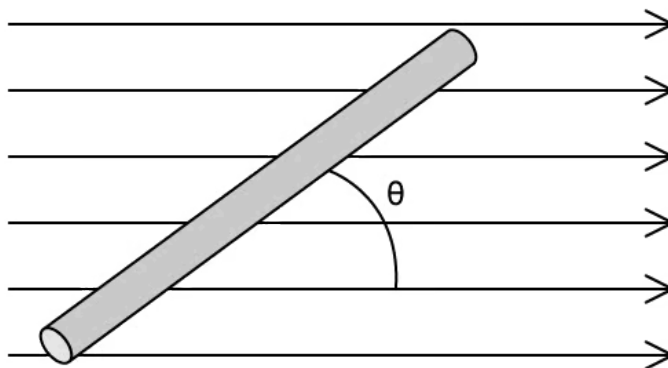
|                      |             |
|----------------------|-------------|
| Easy (5 questions)   | /50         |
| Medium (5 questions) | /51         |
| Hard (5 questions)   | /41         |
| <b>Total Marks</b>   | <b>/142</b> |

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# Easy Questions

1 (a) The diagram shows a current-carrying conductor at an angle  $\theta$  to an external B field.



The force acting on the current-carrying conductor when it lies at different angles to the field can be calculated using the equation

$$F = BIL \sin \theta$$

State what the symbols  $B$ ,  $I$  and  $L$  represent.

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(3 marks)

(b) State the angle,  $\theta$ , between the conductor and the B field which would result in the largest force being exerted on the conductor.

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(1 mark)

- (c) State the angle,  $\theta$ , between the conductor and the B field which would result in there being no force exerted on the conductor from the B field.

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(1 mark)

- (d) The conductor in the diagram in part (a) has a length of 1.2 m and a current of 0.85 A flowing through it. The conductor is placed at  $30^\circ$  to the B field, which has a magnetic flux density of 70 mT.

Calculate the force acting on the conductor.

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(3 marks)

2 (a) The diagram shows a magnetic B field.

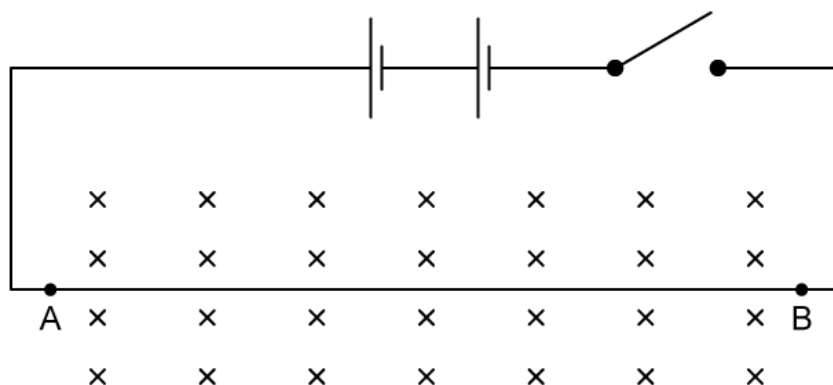


State whether the magnetic field is acting into or out of the page.

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**(1 mark)**

(b) A circuit is built with a section of wire, between the points A and B, running perpendicular to a magnetic field.



When the switch is closed, state the direction of:

(i) The current through wire AB.

[1]

(ii) The force acting on wire AB.

[1]

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**(2 marks)**

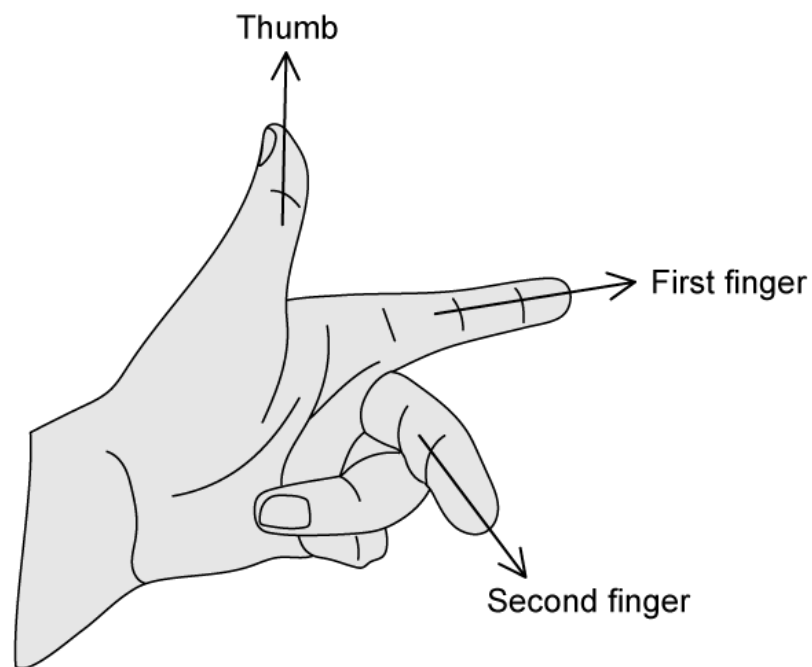
(c) State two ways of increasing the size of the force acting on the current carrying conductor.

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(2 marks)

(d) When the force, the magnetic field and the current are all mutually perpendicular to each other, the directions of each can be interpreted using a technique known as Fleming's Left Hand Rule.



State what is represented by the direction of:

- (i) The thumb [1]
- (ii) The first finger [1]
- (iii) The second finger [1]

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(3 marks)

3 (a) Define magnetic flux density.

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(2 marks)

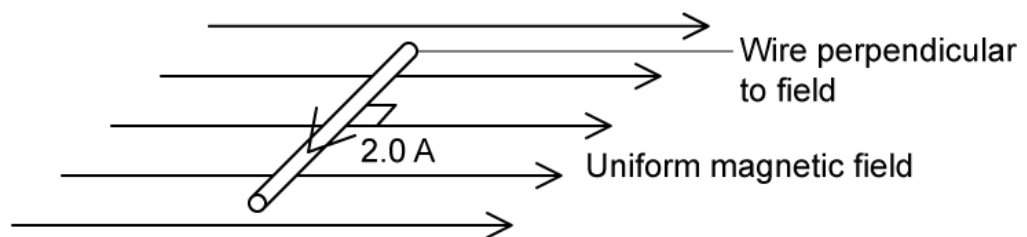
(b) State the unit for magnetic flux density.

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(1 mark)

(c) A wire of length 15 cm has a mass of 30 g and current of 2.0 A flowing through it. When the wire is placed inside a uniform magnetic field it 'floats' in equilibrium in the magnetic field.



(i) Calculate the weight of the wire

[3]

(ii) Hence determine the size of the force produced by the magnetic field acting on the wire when it is carrying current

[2]

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**(5 marks)**

**(d)** Calculate the magnetic flux density required to keep the wire 'floating' in equilibrium.

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**(3 marks)**



4 (a) The equation used to calculate the force acting on a moving charged particle is

$$F = qvB\sin\theta$$

State what each symbol in the above equation represents.

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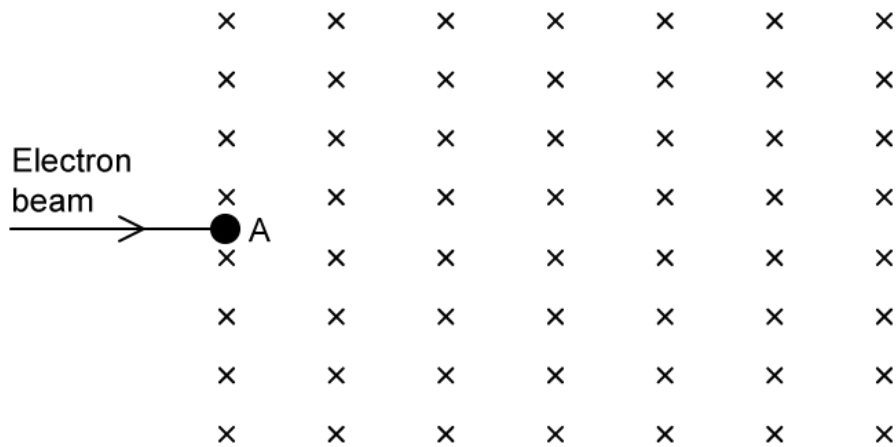
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(5 marks)

(b) A beam of electrons is fired into a uniform magnetic field of flux density 0.5 T, as shown. An electron enters the magnetic field at point A.



Draw an arrow, labelled F, from point A to show the direction of the force acting on the electron.

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**(2 marks)**

- (c)** The electron is travelling at a speed of  $4.8 \times 10^7 \text{ m s}^{-1}$  in the magnetic field where magnetic flux density  $B = 0.5 \text{ T}$

Calculate the force on the electron when it enters the magnetic field and is travelling perpendicular to it.

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**(2 marks)**

- (d)** On your sketch, continue the path of the electron beam

- (i) Through the magnetic field [2]
- (ii) After it has emerged from the magnetic field [2]

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**(4 marks)**

- 5 (a) When a moving charge enters a magnetic field the magnetic field produces a force on the charge, which can be calculated using

$$F = qvB\sin\theta$$

where  $q$  = charge,  $v$  = velocity,  $B$  = magnetic flux density, and  $\theta$  = the angle between the velocity of the charge and the direction of the magnetic field.

The magnetic force provides the centripetal force which causes the charge to move in a circular orbit. The equation to calculate centripetal force acting on an object is

$$F = \frac{mv^2}{r}$$

where  $m$  = mass of the object,  $v$  = speed of the object and  $r$  = radius of the circular orbit.

Using the equations given above, show that the radius of the circular orbit of the charged object inside the magnetic field can be given as

$$r = \frac{mv}{qB}$$

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(3 marks)

- (b) State three ways of increasing the radius of the circular orbit.

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(3 marks)

- (c) An electron is travelling at right angles to a uniform magnetic field which has a magnetic flux density of 5.6 mT. The speed of the electron is  $3.0 \times 10^6 \text{ m s}^{-1}$ .

Use the following information to calculate the radius of the circular orbit of the electron:

Mass of an electron,  $m = 9.11 \times 10^{-31} \text{ kg}$

Charge of an electron,  $q = 1.60 \times 10^{-19} \text{ C}$

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**(3 marks)**

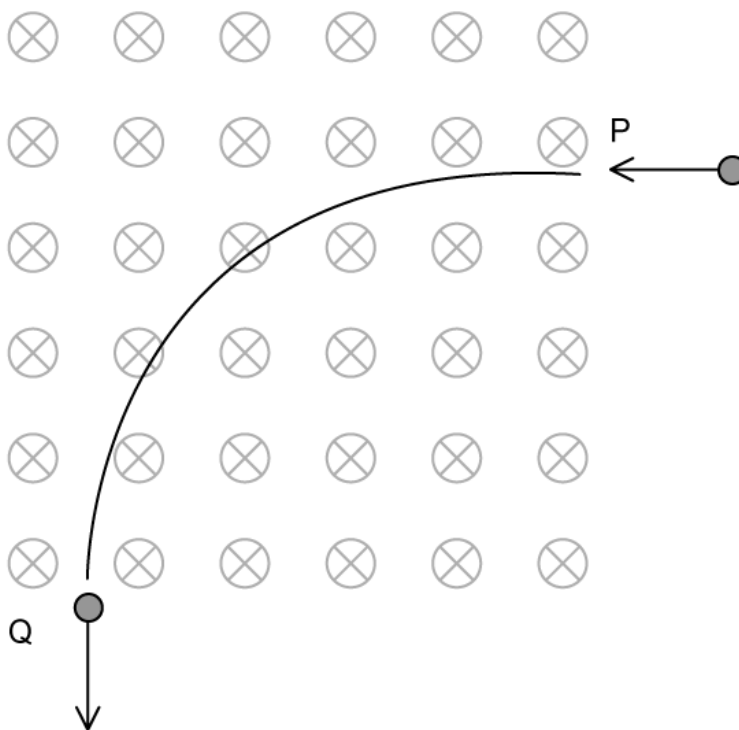
- (d) Name the particle accelerator which accelerates charged particles along a spiral path.

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**(1 mark)**

# Medium Questions

- 1 (a) A proton of mass  $m$  and electric charge  $q$  enters a region of magnetic field at point P and exits at point Q. The speed of the proton at P is  $v$ . The path followed by the proton is a quarter of a circle.



State and explain whether the speed of the proton at P is the same as the speed at Q.

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(3 marks)

- (b) Outline why the path of the proton is circular.

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(2 marks)

- (c) Show that the radius of the circular path is given by  $R = \frac{mv}{qB}$ , where  $B$  is the magnetic flux density.

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(2 marks)

- (d) The speed of the proton is  $3.2 \times 10^6 \text{ ms}^{-1}$  at P and the magnetic flux density is 0.21 T.

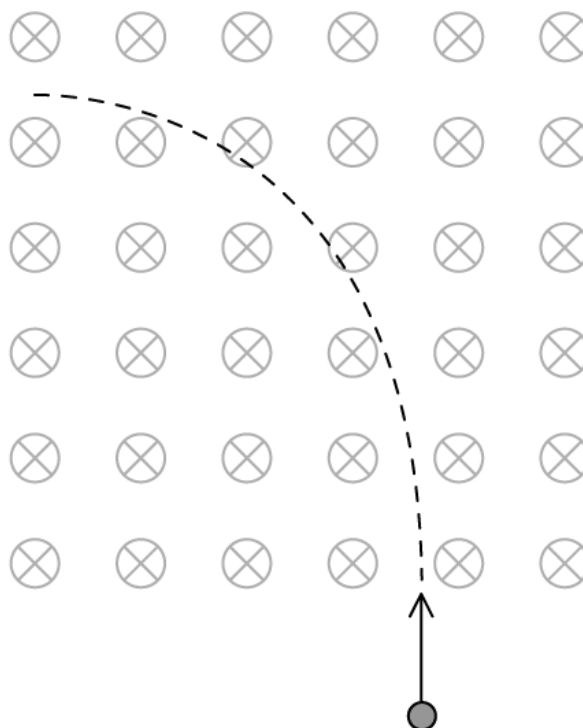
Show that the radius of the path is 16 cm.

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(2 marks)

- 2 (a) The diagram shows a charged particle entering a region of magnetic field that is directed into the page.



The path of the particle is a quarter circle.

Justify why the particle is positive.

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(2 marks)

- (b) The proton enters the region with a speed of  $5.4 \times 10^6 \text{ ms}^{-1}$ . The magnetic flux density of the field is 0.35 T.

Calculate the radius of the protons circular path.

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(3 marks)

(c) Calculate the time the proton spends in the region of the magnetic field.

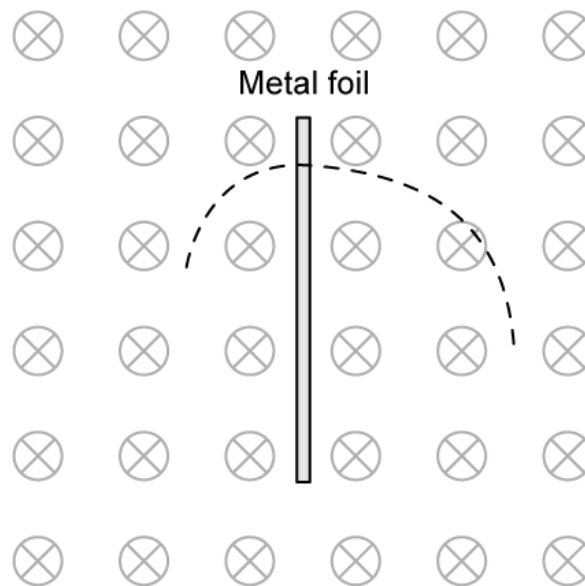
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**(3 marks)**

(d) The diagram shows the path of a charged particle passing through a thin metallic foil.



State and explain the direction of motion of the particle and the sign of its charge.

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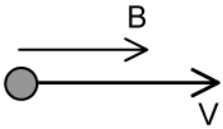

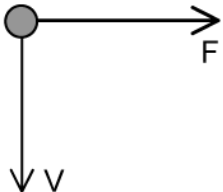
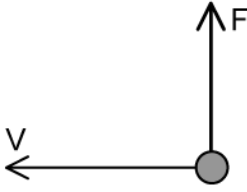
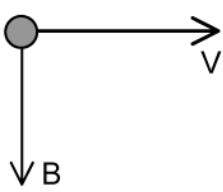
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**(3 marks)**



3 (a) Positive charges are seen passing through different magnetic fields.

Determine the direction of the missing quantity between  $B$ ,  $v$  and  $F$  for each:

|       |   | Direction |
|-------|---|-----------|
| (i)   |    |           |
| (ii)  |    |           |
| (iii) |   |           |
| (iv)  |  |           |
| (v)   |  |           |

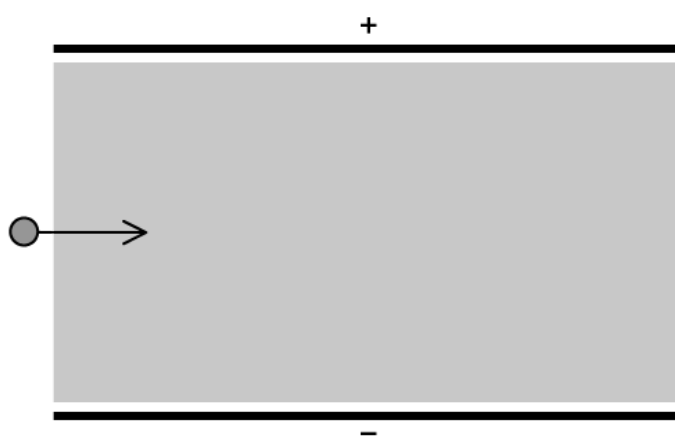
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(5 marks)

- (b) The diagram shows two parallel plates. The electric field between them is directed from top to bottom and has a magnitude  $2.6 \times 10^3 \text{ N C}^{-1}$ . The shaded region is a region of magnetic field normal to the page.



Deduce the magnetic field magnitude and direction so that an electron experiences zero net force when travelling through the plates with a speed of  $3.0 \times 10^5 \text{ ms}^{-1}$ .

(3 marks)

- (c) Suggest and give a reason whether a proton shot with the same speed through the plates experiences zero net force.

(2 marks)

(d) The electron's speed is halved.

Suggest whether the electron would still be undeflected for the same magnetic field found in (b).

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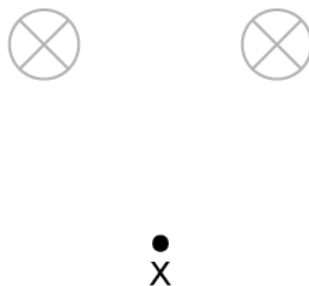
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**(3 marks)**

4 (a) In the national grid electricity is generated by current carrying wires within a magnetic field.

There are two wires carrying equal currents into the page.



Determine the direction of the magnetic field at point X.

Use a diagram to help you with your answer.

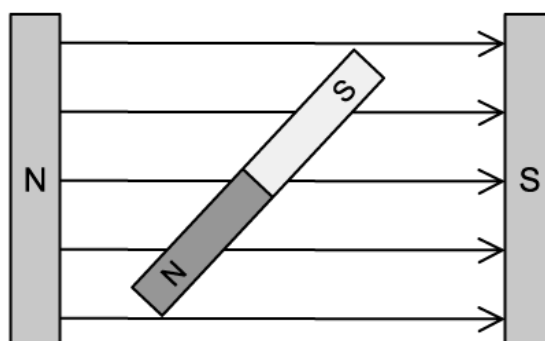
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**(3 marks)**

(b) A bar magnet is placed in a uniform magnetic field as shown in the diagram.



Suggest whether there is a net force on the bar magnet, causing it to move to a different position. Explain your answer.

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**(2 marks)**

**(c)** The bar magnet does move in a specific type of motion. Determine how it will move.

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**(2 marks)**

**(d)** A taut electrical wire carries electricity between a generator and the step-up transformer. The current is 2000 A and the magnetic field of the Earth at the position of the wire is  $4.50 \times 10^{-5}$  T and makes an angle of  $45^\circ$  below the horizontal.

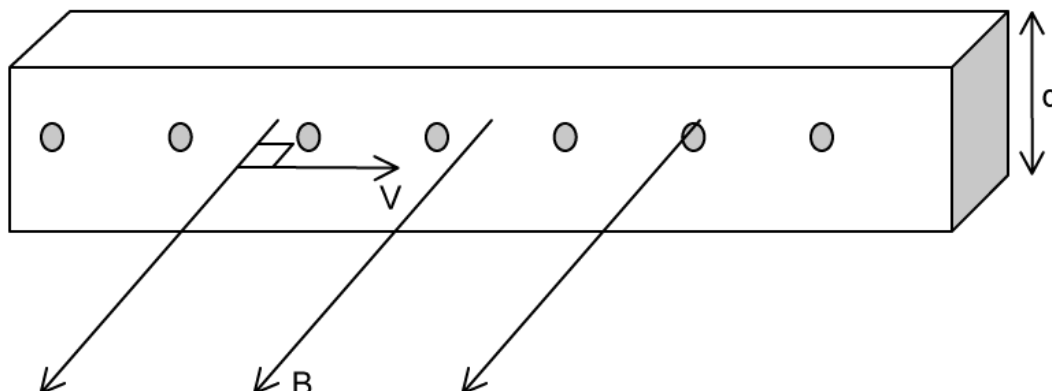
Calculate the force experienced by a 25.0 m length of this wire.

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**(2 marks)**

- 5 (a) A current  $I$  passes through a conductor. The electrons move with a drift speed  $v$ . A magnetic field  $B$  at right angles to the direction of motion of the electrons is also present in the conductor.



Draw the arrows to indicate the directions of the:

- (i) Conventional current in the conductor
- (ii) Magnetic force on the electron

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(2 marks)

- (b)  $A$  is the cross-sectional area of the conductor,  $q$  is the charge of one electron,  $n$  is the number of electrons per unit volume and  $v$  is the drift speed of the electrons.

Show that the current on the conductor is given by  $I = qnAv$ .

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(3 marks)

- (c) The number density of the electrons is  $3.5 \times 10^{28} \text{ m}^{-3}$ . The current in the wire is 0.30 A and its cross-sectional area is  $4.4 \times 10^{-6} \text{ m}^2$ .

Hence, calculate the drift velocity of the electrons moving in the conductor.

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**(2 marks)**

- (d) The magnitude of the magnetic field within this current carrying conductor is 0.30 T.

Calculate the magnitude of the force on the electrons in the conductor.

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**(2 marks)**

# Hard Questions

- 1 (a) Alpha particles travel in a vacuum at speed  $v$  and enter an area where there is a uniform magnetic field of flux density  $B$ . In this area, it begins to move in a circular trajectory.

Show that the momentum of a single alpha particle is given by:

$$p = 2eBr$$

where  $e$  is the elementary charge and  $r$  is the orbital radius.

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(3 marks)

- (b) An alpha particle moves across the Earth's equator towards the east. At this point, the Earth's magnetic field has a direction due north and is parallel to the surface.

Deduce the direction of the force acting on the alpha particle at this instant.

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(3 marks)

- (c) Charged particles from the sun, carried by the 'solar wind', may become trapped in the Earth's magnetic field near its poles, causing the sky to glow. Some of these charged particles travel in a circle of radius 45 km in a region where the flux density is  $6.0 \times 10^{-5}$  T.

Show that these charged particles cannot be electrons.

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(3 marks)

- 2 (a)** An electron is incident normally into a region of uniform magnetic flux density 0.50 T at a speed of  $1.3 \times 10^7 \text{ m s}^{-1}$ .

Show that the percentage reduction in the magnetic force exerted on the electron is 50% when the electron is incident at an angle of  $30^\circ$ .

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**(3 marks)**

- (b)** Two electrons, X and Y, travel in a uniform magnetic field. X has kinetic energy  $E_X$  and Y has kinetic energy  $E_Y$ .

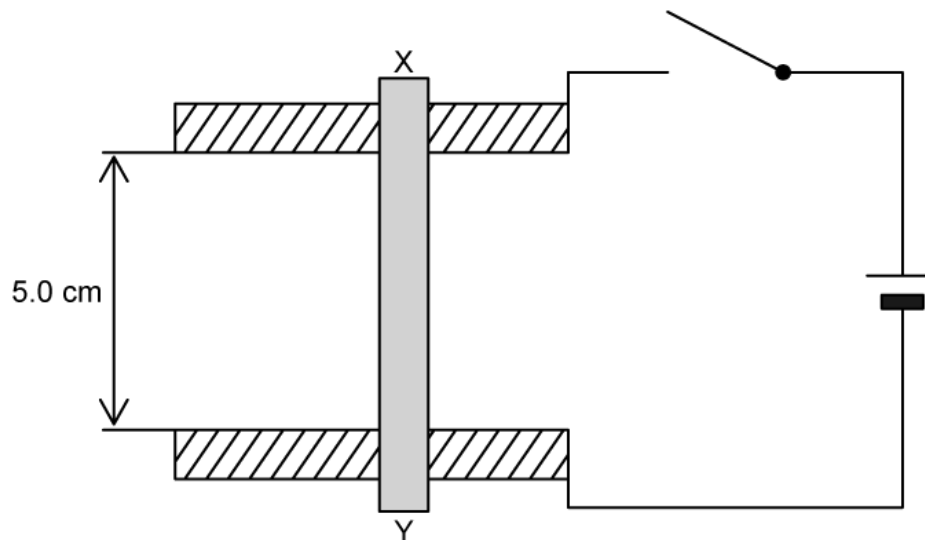
Calculate the ratio  $\frac{E_X}{E_Y}$  if X is incident at  $30^\circ$  to the field but Y is incident normally to it.

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**(2 marks)**

- (c)** A cylindrical aluminium bar XY of mass 6.0 g rests on two horizontal aluminium rails, separated by 5.0 cm.



The rails are connected via a switch to a cell that can drive a current of 4.5 A through XY. A magnetic field of flux density 0.20 T acts into the screen.

Calculate the angle to the horizontal to which the rails must be tilted in order to keep XY stationary.

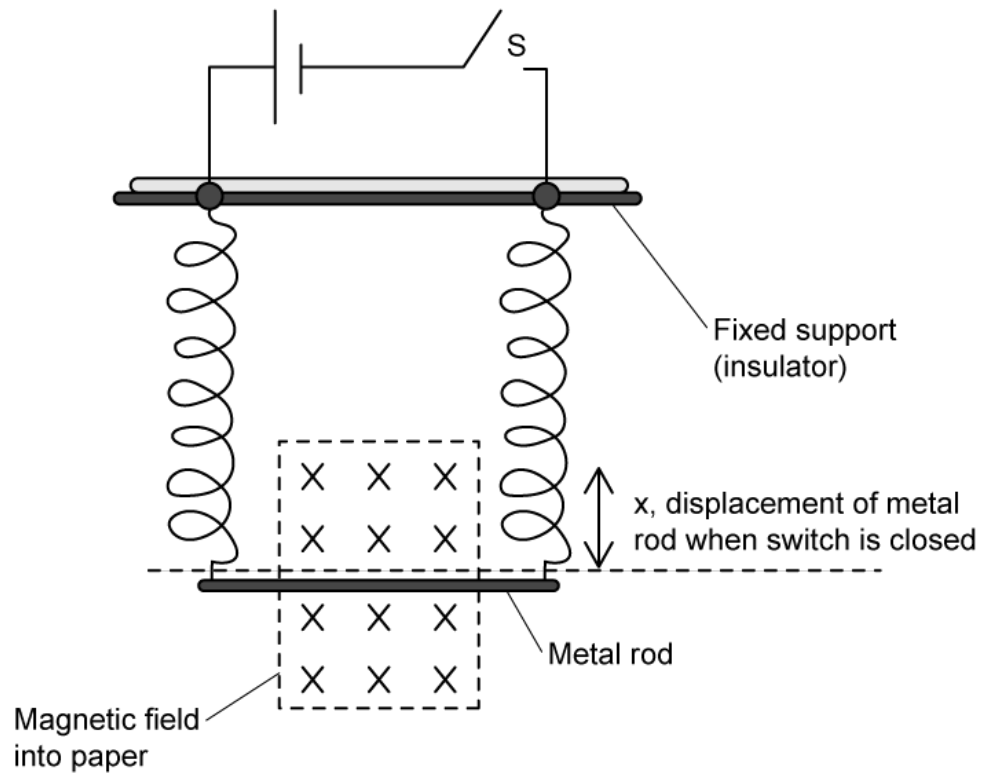
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**(3 marks)**

- (d)** A similar metal rod is suspended in a magnetic field by two identical, vertical springs. The cell and the rod have negligible internal resistance.



When the switch  $S$  is closed, the metal rod is displaced a distance  $x$  from its starting point.

Show that, when both the spring constant and electrical resistance of each spring is doubled, closing  $S$  would cause the rod to be displaced by  $\frac{x}{4}$ .

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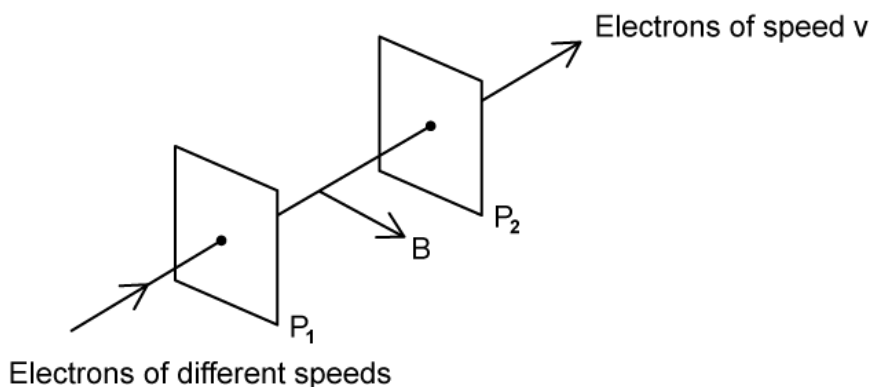
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**(3 marks)**

- 3 (a)** A beam of electrons, each travelling at various speeds, passes through a hole in plate  $P_1$ .  $P_2$  is parallel to  $P_1$ , also with a hole in it. The region between the plates contains a uniform electric field and a uniform magnetic field. Both the electric field strength  $E$  and the magnetic flux density  $B$  are adjustable.



Electrons that are undeviated travel with a particular speed  $v$  along the straight line joining the holes in  $P_1$  and  $P_2$ .

Deduce the direction of the electric field between the plates.

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**(2 marks)**

- (b)** Mark with an X a position on  $P_2$  that would indicate where electrons with a speed greater than  $v$  may strike  $P_2$ .

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**(2 marks)**

- (c)** The equipment is adjusted such that a single electron is shot with kinetic energy  $K$  through the hole in  $P_1$ . The distance between the plates  $d$  is fixed, and electric field is switched off, such that the electron is incident in a region of uniform magnetic flux density  $B$  only.

Show that the maximum magnetic flux density  $B_{\max}$  that ensures the electron reaches  $P_2$  is given by:

$$B_{max} = \frac{\sqrt{2m_e K}}{ed}$$

where  $m_e$  is the rest mass of the electron and  $e$  is its charge.

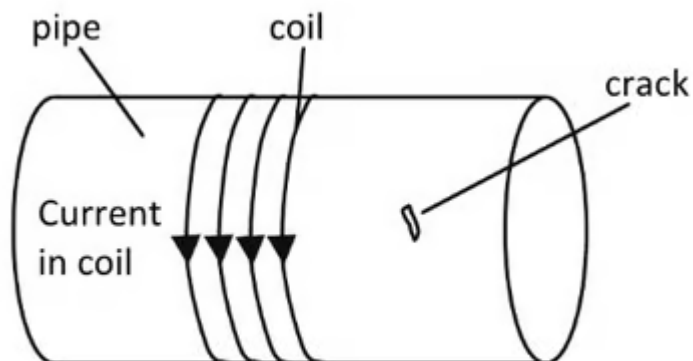
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**(3 marks)**

- 4 (a) Very small cracks in some metals can be detected by a method which includes the use of magnetism. In a particular method for steel pipes, a coil of wire is wrapped around it, and a current passed through the coil. This magnetises the pipe and cracks in the direction shown in the image can be found by sprinkling iron filings on the pipe.



Cracks along or parallel to the length of the pipe do not show up.

Deduce why this method cannot be used for copper pipes.

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(2 marks)

- (b) Explain why iron filings cluster around the crack shown in the image in part (a).

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(2 marks)

- (c) The crack only shows up if it is across the direction of the field.

Describe and explain how the coil in the image in part (a) should be arranged so that the magnetic field it produces will show cracks cracks that are along the pipe.

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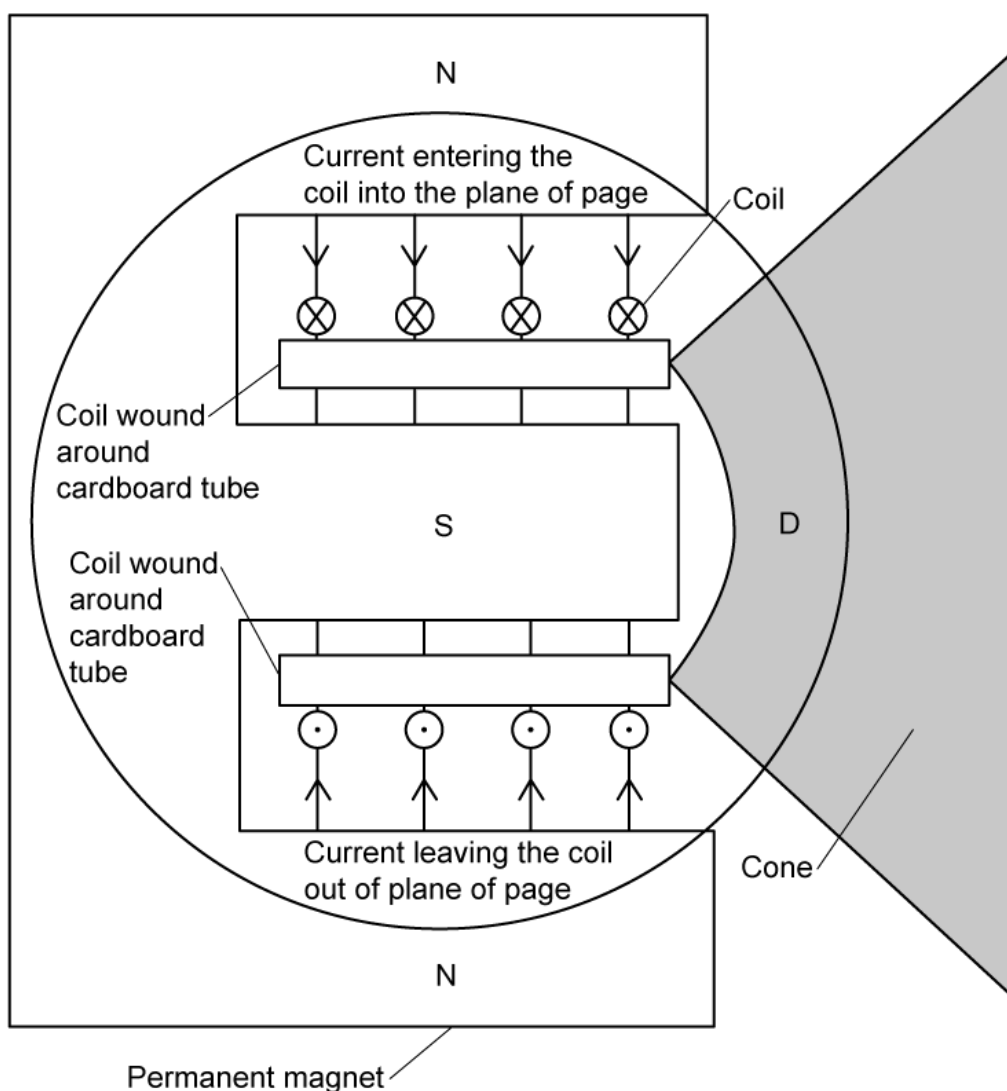
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(3 marks)



- 5 (a) The image shows the main features of a loudspeaker L. A current-carrying coil is positioned within the magnetic field provided by a permanent magnet, and the current directions in the coil at a particular instant is shown.



The dust cap D prevents dust from blocking the gap between the cardboard tube and the south pole of the magnet.

Identify, on the diagram, the direction of the force on the coil at this particular instant with the current directions shown.

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(2 marks)

(b) Describe how the magnitude and direction of the force on the coil varies over a complete cycle.

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**(2 marks)**

(c) The coil consists of 200 turns, each of average diameter 2.0 cm. The magnetic flux density created by the permanent magnet is 0.40 mT. The peak current in the coil is 0.48 mA.

Calculate the maximum magnetic force on the coil.

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**(3 marks)**