# TOPIC 21 Electromagnetism

## Magnetic Fields due to currents

**1** On the axis of a long, uniform, current-carrying solenoid the ratio

$$\frac{\text{flux density at an end}}{\text{flux density at the centre}}$$

is

**A** 4 : 1 **D** 1 : 2
**B** 2 : 1 **E** 1 : 4
**C** 1 : 1

N77/II/20

**2** Two identical long solenoids carry the same constant current. When they are very far apart, the flux density at the centre of each end of each solenoid is $B$. The solenoids are now arranged coaxially end-to-end with the current in each flowing in the same sense. The flux density on the axis in the region of contact is

**A** 0 **B** $\frac{1}{2}B$ **C** $B$ **D** $B\sqrt{2}$ **E** $2B$

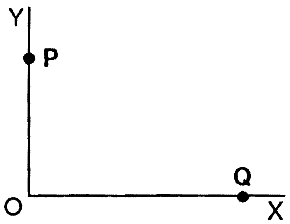
J80/II/21

**3** Two circular coils P and Q lie in the same plane and are concentric. Coil P has 10 turns of radius 4 cm and carries a current of 1.0 A. Coil Q has 20 turns of radius 12 cm and the current in it is adjusted in magnitude and direction so that the resultant field at the common centre is zero. What is the current in coil Q?

**A** 0.75 A **D** 4.5 A
**B** 1.5 A **E** 6.0 A
**C** 2.25 A

N82/II/20

**4** The diagram shows a flat surface with lines OX and OY at right angles to each other.




Which current in a straight conductor will produce a magnetic field at O in the direction OX?

**A** at **P** into the plane of the diagram
**B** at **P** out of the plane of the diagram
**C** at **Q** into the plane of the diagram
**D** at **Q** out of the plane of the diagram

J89/I/19; J2000/I/19

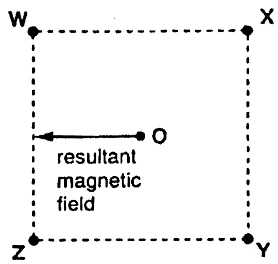
**5** A long, air-cored solenoid has $N$ turns, is of length $l$, has cross-sectional area $A$, and carries current $I$. The uniform magnetic flux density near the middle of the solenoid is parallel to the axis and has the value $\frac{\mu_0 NI}{l}$.

What is the magnetic flux through the cross-section in this region?

**A** $\mu_0 NI$ **B** $\frac{\mu_0 NI}{A}$ **C** $\mu_0 NIA$ **D** $\frac{\mu_0 NIA}{l}$ **E** $\frac{\mu_0 NI}{lA}$

N89/I/18; J92/I/19

**6** Four parallel conductors, carrying equal currents, pass vertically through the four corners of a square **WXYZ**. In two conductors, the current is directed into the page and, in the other two, it is directed out of the page.




It is required to produce a resultant magnetic field at O in the direction shown.

What must be the directions of the currents?

| | *into the page* | *out of the page* |
|---|---|---|
| **A** | W and X | Y and Z |
| **B** | W and Z | X and Y |
| **C** | X and Z | W and Y |
| **D** | Y and Z | W and X |

J91/I/17; J96/I/18

**7** The magnetic flux density $B$ of the field due to a long straight wire is given by

$$B = \frac{\mu_0 I}{2\pi d}.$$

An overhead power cable carries an alternating current of 2000 A r.m.s.

At what distance would the peak magnetic flux density due to the current in the cable be 100 μT?

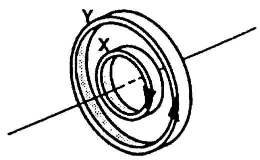
**A** 2.8 m **B** 4.0 m **C** 5.7 m **D** 8.0 m **E** 11 m

N92/I/19

**8** The magnetic flux density at the centre of a flat circular coil is given by the equation

$$B = \frac{\mu_0 NI}{2r}$$

Two such coils, **X** and **Y**, each with 100 turns, are arranged as shown in the diagram.



**X** has radius 0.050m and carries a current of 3.0 A, **Y** has radius 0.10m and carries a current of 6.0 A in the opposite direction to **X**.

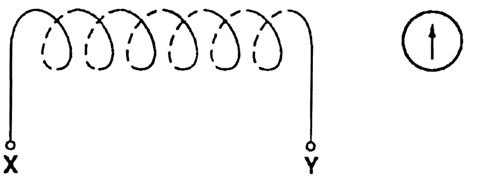
What is the magnitude of the total magnetic flux density at the centre of the coils?

| | | | |
|---|---|---|---|
| **A** | zero | **D** | 4500 $\mu_0$ |
| **B** | 1500 $\mu_0$ | **E** | 6000 $\mu_0$ |
| **C** | 3000 $\mu_0$ | | |

J93/I/18

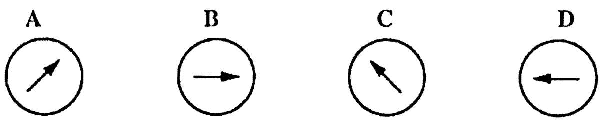
**9** A plotting compass is placed near a solenoid.

When there is no current in the solenoid, the compass needle points due north as shown.



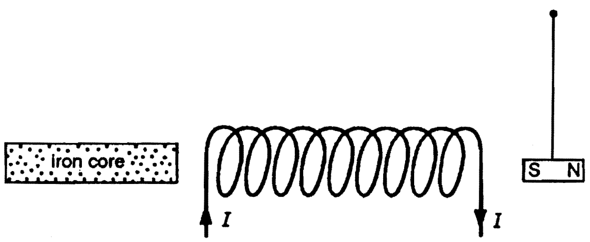

When there is a current from **X** to **Y**, the magnetic field of the solenoid at the compass is equal in magnitude to the Earth's magnetic field at that point.

In which direction does the plotting compass set?




J94/I/17

**10** The diagram shows a small magnet hanging on a thread near the end of a solenoid carrying a steady current $I$.




What happens to the magnet as the iron core is inserted into the solenoid?

**A** It moves towards the solenoid.
**B** It moves towards the solenoid and rotates through 180°.
**C** It moves away from the solenoid.
**D** It moves away from the solenoid and rotates through 180°. N94/I/19; N97/I/18

**11** The magnetic flux density at the end of a long solenoid is $B$. What is the flux density at the centre of the solenoid? Explain your reasoning. N78/I/7

**12** List the factors which determine the magnitude of the magnetic flux density at the centre of a long, current-carrying solenoid. State the dependence of the magnetic flux density on each factor. [5]
N88/III/5

**13** Fig. 1 shows a flat coil which is carrying a current.

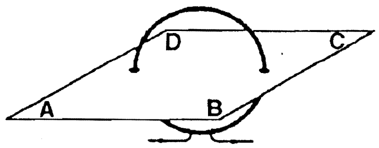



**Fig. 1**

*(a)* Draw a diagram to show the pattern of the magnetic field in the plane **ABCD.** Mark on your diagram the direction of the current in the coil and the direction of the magnetic field.

*(b)* Explain why no magnetic force is experienced by a straight current-carrying conductor placed along the axis of the coil. [6]
J89/III/5

**14** *(a)* Figure 2 shows a cross-section through a solenoid.

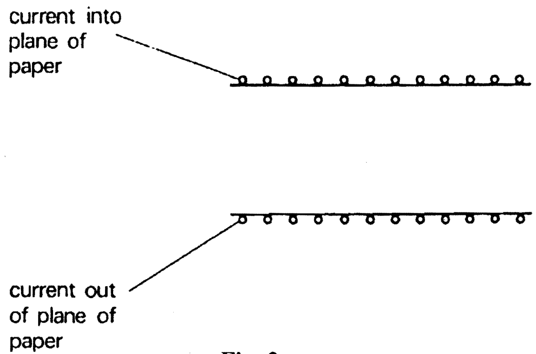



**Fig. 2**

Sketch on Fig. 2 the pattern of the magnetic flux which would be obtained when a direct current passes around the solenoid. Mark on your sketch the direction of the magnetic flux due to the current in the solenoid. [3]
J93/II/4 (part)

**15** *(a)* Figure 3 shows a section of a current-carrying wire.

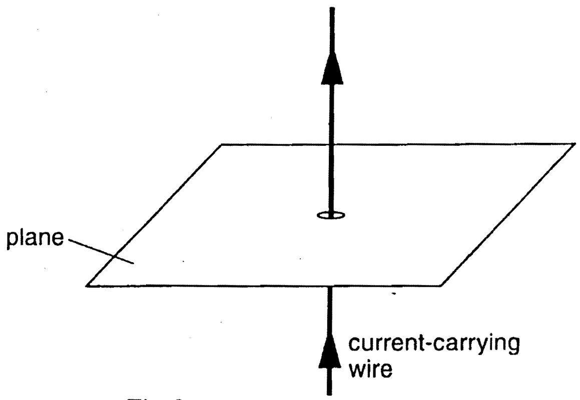



**Fig. 3**

On Fig. 3, sketch the pattern of the magnetic field around the wire in the plane normal to the axis of the wire. [2]
N96/II/3 (part)

16 Fig. 4 illustrates the pattern of the magnetic flux due to a current in a solenoid.

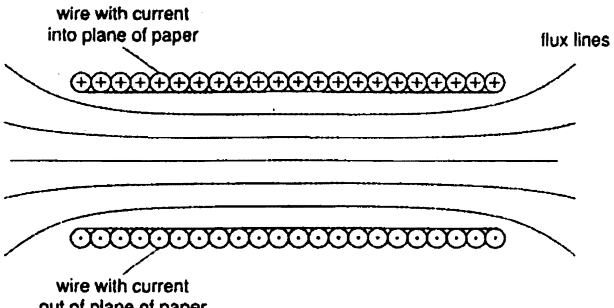



Fig. 4

*(a)* On Fig. 4,

(i) draw arrows to show the direction of the magnetic field in the solenoid,

*(ii) draw a line to represent a current-carrying conductor in the magnetic field which does not experience a force due to the magnetic field. Label the conductor C. [2]

*(b)* The coils of wire on an electromagnet are usually wound on a ferrous core. State two properties of the core which are important in its use in an electromagnet. [2]

J97/II/3

## *Long Questions*

17 Draw diagrams to illustrate the magnetic fields near (i) a short bar magnet, (ii) the end of a solenoid, and (iii) a long, straight wire carrying a current.

Describe an experiment to determine the ratio of the magnetic flux density at the end of a long solenoid to that at its centre.

Alternating current passes down a long, straight wire. A nearby search coil is connected to the $y$-plates of a cathode ray oscilloscope. The coil is turned to the position that gives the maximum $y$-deflection on the c.r.o. The distance $x$ between coil and wire is then varied and at each distance the maximum amplitude $a$ of the trace is noted.

*(a)* Show how the coil is arranged relative to the wire.

*(b)* State how $a$ varies with $x$.

*(c)* Explain how this relationship between $a$ and $x$ arises.

N76/III/4

18 Draw diagrams to illustrate the magnetic field of *(a)* a bar magnet, *(b)* a long, straight current-carrying wire, *(c)* a solenoid.

Show the conventional direction of the currents and field lines, and explain how you decide the polarity of the solenoid.

N79/III/3 (part)

19 Define *magnetic flux density*, and *magnetic flux*. Draw a diagram to illustrate the flux pattern near a long straight current-carrying wire. Indicate the direction of conventional current and of the flux. Show also how the flux pattern is modified if a uniform magnetic field is applied at right angles to the wire. N84/III/5 (part)

20 *(b)* The load on the spring is replaced by a bar magnet, as shown in Fig. 5. A pole of the magnet is situated near to one end of a solenoid.

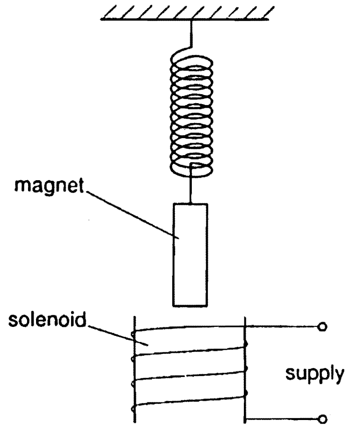



Fig. 5

Explain why

(i) when a direct current in the solenoid is switched on, the magnet moves vertically,

*(ii) when alternating current passes through the solenoid, the magnet oscillates,

(iii) when the frequency of the alternating current in (ii) is varied, the amplitude of vibration of the magnet is dependent on the applied frequency. [8]

N97/III/3 (part)

## Force on a Current-carrying Conductor

21 Fig. 6 represents a straight wire carrying a steady current from X to Y. The wire lies between the poles of two similar horseshoe-type permanent magnets, each of which produces a uniform field in the direction NS at right angles to the wire.

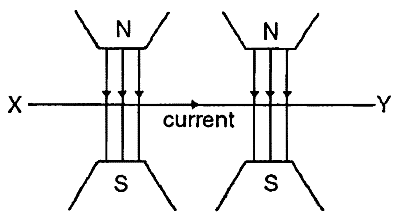



Fig. 6

The wire experiences

**A** a force in the direction XY.
**B** a force in a direction at right angles to XY and NS.
**C** no resultant force.
**D** a force in the direction NS.
**E** a couple tending to rotate the wire about an axis parallel to NS. J77/II/17

**22**

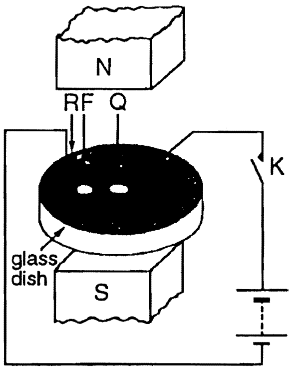
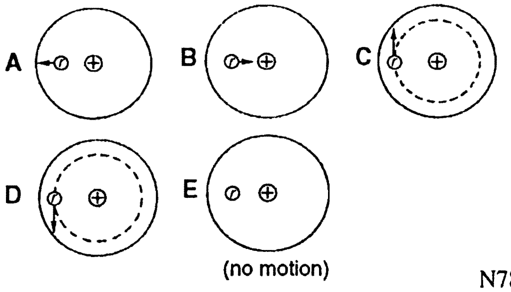



Fig. 7

The inner wall of a glass dish was lined with a copper ring R and a copper rod Q was placed exactly in the middle of the dish. Rod Q was connected, via a switch, to the positive plate, and ring R was connected to the negative plate, of a battery. The arrangement was placed between the poles of a strong magnet. The dish was then filled with copper(II) sulphate solution and a small float F added to indicate any motion of the liquid – see Fig. 7. The following sketches indicate possible motions of the float as seen from above when switch K was closed. Which one is *correct*?



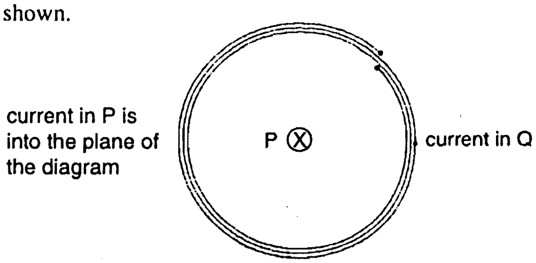

N78/II/20

**23** Two moving-coil galvanometers, '1' and '2', are constructed with exactly similar permanent magnets springs but with coils of different numbers of turns ($n_1$, $n_2$), effective areas ($A_1$, $A_2$) and resistances ($R_1$, $R_2$). When they are connected in series in the same circuit, their deflections are respectively $\theta_1$ and $\theta_2$. The ratio $\theta_1/\theta_2$ equals

- **A** $A_1n_2/A_2n_1$
- **B** $A_1R_2/A_2R_1$
- **C** $n_1R_2/n_2R_1$
- **D** $A_1n_1/A_2n_2$
- **E** $A_2R_1/A_1R_2$

J79/II/22

**24** A long straight wire P is placed along the axis of a flat circular coil Q. The wire and the coil each carry a current as shown.

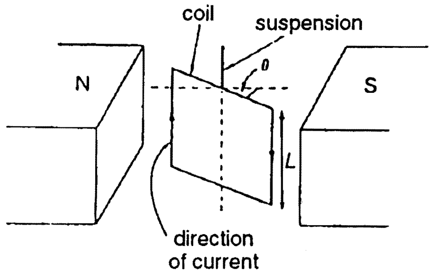



What can be deduced about the force acting on each part of Q due to the current in P?

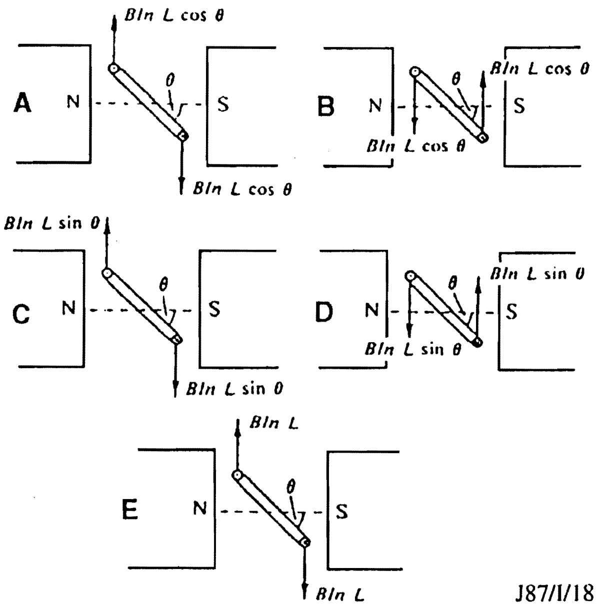
- **A** The force is away from P.
- **B** The force is towards P.
- **C** The force is perpendicular to the plane of the diagram.
- **D** There is no force in any direction.

N86/I/19; J99/I/19

**25** A current $I$ is carried by a square coil of $n$ turns and side $L$ suspended vertically as shown in a uniform horizontal magnetic field of flux density $B$.

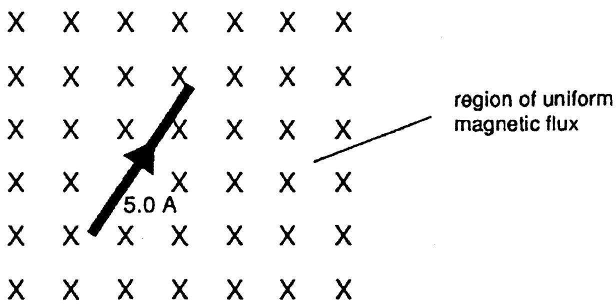



Which one of the following plan diagrams correctly shows the magnitude and direction of the forces acting on the vertical sides of the coil?




J87/I/18

**26** A wire of length 3.0 cm is placed at right angles to a magnetic field of flux density 0.040 T.



The wire carries a current of 5.0 A.

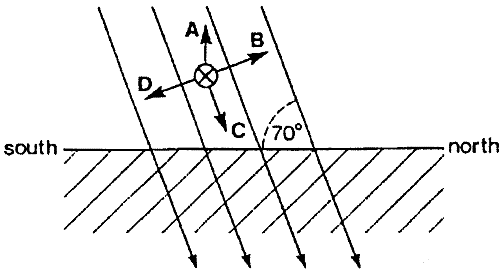
What is the magnitude of the force which the field exerts on the wire?

- **A** less than 0.006 N
- **B** 0.0060 N
- **C** greater than 0.006 N but less than 0.6 N
- **D** 0.60N
- **E** greater than 0.6 N

J93/I/19

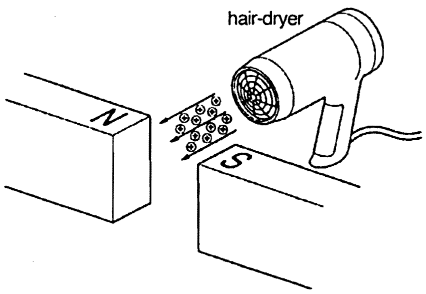
**27** A horizontal power cable carries a steady current in an east-to-west direction, i.e. into the plane of the diagram.

Which arrow shows the direction of the force on the cable caused by the Earth's magnetic field, in a region where this field is at 70° to the horizontal?




J95/I/18

**28** Hot air from a hair-dryer contains many positively charged ions. The motion of these ions constitutes an electric current.




The hot air is directed between the poles of a strong magnet, as shown.

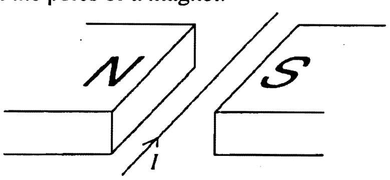
What happens to the ions?

They are deflected

- **A** towards the north pole N.
- **B** towards the south pole S.
- **C** downwards.
- **D** upwards.

J97/I/19

**29** The diagram shows a wire, carrying a current $I$, placed between the poles of a magnet.

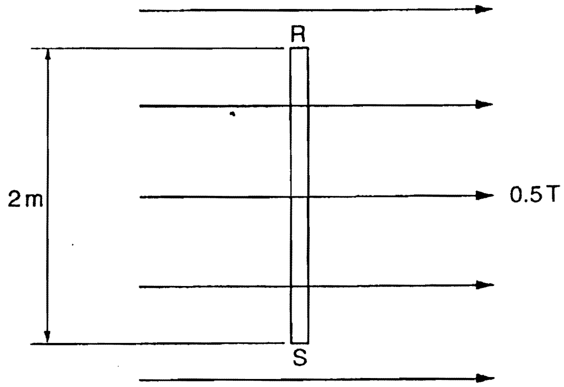



In which direction does the force on the wire act?

- **A** downwards
- **B** upwards
- **C** towards the N pole of the magnet
- **D** towards the S pole of the magnet

J98/I/18

**30** The diagram shows a current-carrying conductor RS of length 2m placed perpendicularly to a magnetic field of flux density 0.5 T. The resulting force on the conductor is 1 N acting into the plane of the paper.




What is the magnitude and direction of the current?

- **A** 1 A from R to S
- **B** 1 A from S to R
- **C** 2 A from R to S
- **D** 2 A from S to R

N98/I/19

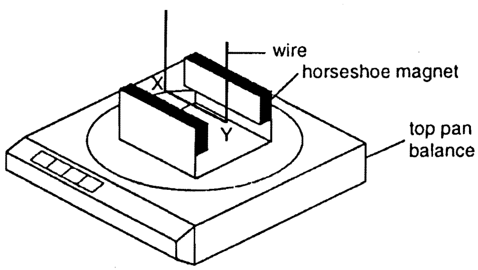
**31** An electron is moving along the axis of a solenoid carrying a current.

Which of the following is a correct statement about the electromagnetic force acting on the electron?

- **A** The force acts radially inwards.
- **B** The force acts radially outwards.
- **C** The force acts in the direction of motion.
- **D** No force acts.

N98/I/27

**32** A horseshoe magnet rests on a top-pan balance with a wire situated between the poles of the magnet.




With no current in the wire, the reading on the balance is 142.0 g.

With a current of 2.0 A in the wire in the direction XY, the reading on the balance changes to 144.6 g.

What is the reading on the balance, when there is a current of 3.0 A in the wire in the direction YX?

A 138.1 g
B 140.7 g
C 145.9 g
D 148.5 g

N2000/I/19

**33**

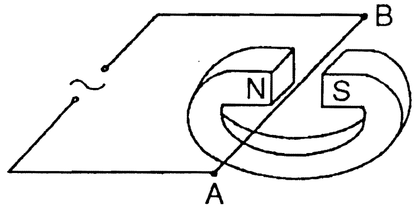



**Fig. 8**

A copper wire is stretched between two fixed points A and B and carries an alternating current of frequency *f*. Describe and explain what will happen if a magnet is arranged to apply a strong magnetic field perpendicular to the central portion of the wire, as shown in Fig. 8.

N79/I/7

**34** Taking the flux density due to the Earth's magnetic field as 100 μT, obtain a rough estimate of the magnitude of the magnetic force acting on the filament of a car headlamp bulb.

J85/III/4

**35** A particle of mass $M$ and charge $+Q$ moves with speed $v$ at right angles to a magnetic field of flux density $B$.

*(a)* Write down an equation for the magnitude of the force $F$ acting on the particle. [1]

*(b)* Fig. 9 shows the position and the direction of motion of the positively-charged particle at one instant of time.

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

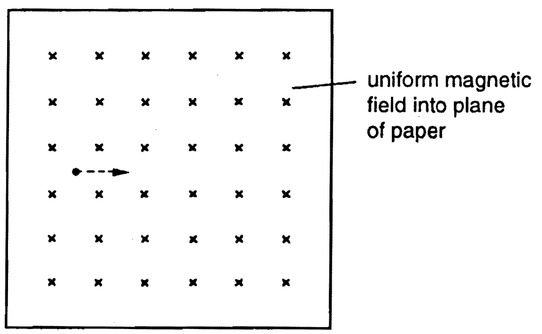



**Fig. 9**

Draw an arrow and label it $F$ to indicate the direction of the force on the particle. [1]

*(c)* On Fig. 9 draw a solid line to represent the resultant path of the particle. [2]

N92/II/3 (part)

**36** A wire frame ABCD is supported on two knife-edges P and Q so that the section PBCQ of the frame lies within a solenoid, as shown in Fig. 10.

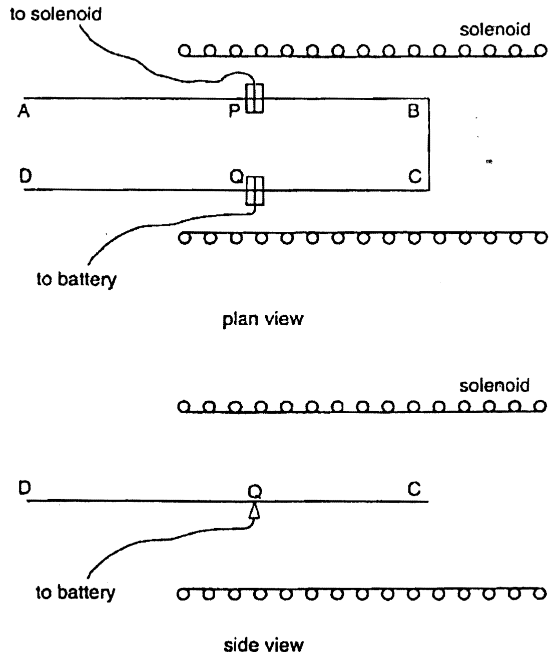



**Fig. 10**

Electrical connections are made to the frame through the knife-edges so that the part PBCQ of the frame and the solenoid can be connected in series with a battery. When there is no current in the circuit, the frame is horizontal.

*(a)* When the frame is horizontal and a current passes through the frame and solenoid, what can you say about the direction of the force, if any, due to the magnetic field of the solenoid acting on

(i) side BC,

(ii) side PB? [3]

*(b)* State two ways in which you could reverse the direction of the force on side BC. [1]

*(c)* (i) The solenoid has 700 turns $m^{-1}$ and carries a current of 3.5 A. Given that the magnetic flux density $B$ on the axis of a long solenoid is

$$B = \mu_0 ni,$$

calculate the magnetic flux density in the region of side BC of the frame.

(ii) Side BC has length 5.0 cm. Calculate the force acting on BC due to the magnetic field in the solenoid.

(iii) A small piece of paper of mass 0.10 g is placed on the side DQ and positioned so as to keep the frame horizontal. Given that QC is of length 15.0 cm, how far from the knife-edge must the paper be positioned? [5]

N94/II/4

37 A metal wire of length 0.57 m and cross-sectional area $1.0 \times 10^{-6}$ m$^2$ is situated at right angles to a uniform magnetic field of flux density $1.8 \times 10^{-3}$ T, as illustrated in Fig. 11.

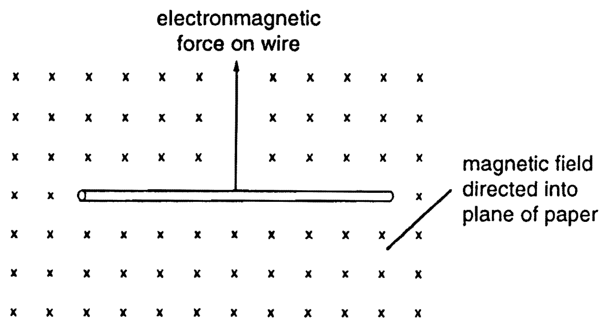



**Fig. 11**

The metal of the wire has density $7.9 \times 10^3$ kg m$^{-3}$ and resistivity $8.8 \times 10^{-8}$ Ω m.

A potential difference is applied between the ends of the wire so that there is an electromagnetic force acting on the wire.

*(a)* On Fig. 11, mark the direction of the current in the wire. [1]

*(b)* For the wire, calculate

(i) its weight,

weight = ........................

(ii) its resistance.

resistance = ............Ω[5]

*(c)* Calculate the potential difference required between the ends of the wire for the electromagnetic force on the wire to equal its weight.

potential difference = ............... V [3]

*(d)* The horizontal component of the Earth's magnetic field is $1.8 \times 10^{-5}$ T. State and explain why, in practice, current-carrying wires are not seen to lift off the ground. [2]

N99/II/4

## *Long Questions*

38 Give an equation that defines *magnetic flux density*, in terms of the force on a current-carrying conductor, explaining clearly the terms you employ. Draw a diagram showing the directions of the vector quantities involved.

J78/III/3 (part)

39 Write down equations which define

*(a)* magnetic flux density $B$ in terms of the force on a wire,

*(b)* magnetic flux $\phi$ in terms of flux density.

Draw diagrams to illustrate your definitions, making clear the vector nature of the quantities concerned.

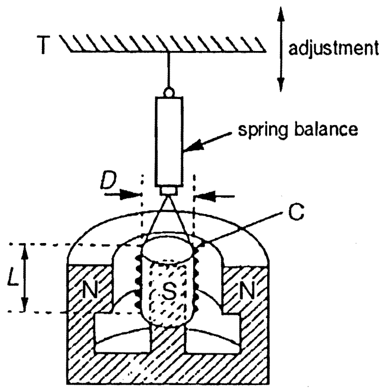



**Fig. 12**

A loudspeaker magnet NSN has its moving coil C attached to a spring balance, see Fig. 12. (The paper cone, normally attached to the cardboard cylinder forming the coil, is not shown.) Current was passed through the coil C, and the spring balance support T was then adjusted so that the coil C was restored to its original position. The readings $F$ on the balance for various currents $I$ were

| | | | | |
|---|---|---|---|---|
| $I$/A | 0.20 | 0.405 | 0.60 | 0.81 |
| $F$/N | 1.50 | 2.02 | 2.48 | 3.05 |

Determine the force per unit current required to restore the cone, and find the zero error of the balance.

If the mean diameter, $D$, of the coil is 0.025 m and the number of turns is 50, calculate the flux density at the coil, assuming that the field is radial.

*If the length, $L$, of the coil is 0.030 m, estimate the charge which will flow through an external resistor connected to the coil, when the coil is completely removed from the magnet. The total resistance of the whole circuit is 25 Ω. (You may assume that, as the coil is removed, the uppermost turn of the coil C cuts none of the magnetic flux and that the lower most turn cuts all the flux.)

J79/III/3

40 A magnet AB is pivoted at its centre of gravity on a freely moving non-conducting rod CD, supported midway between two long straight conducting wires EF and GH, see Fig. 13.

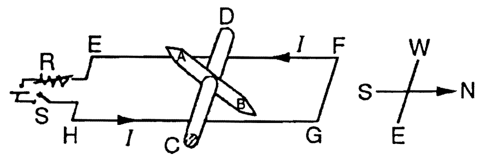



**Fig. 13**

The wires are parallel, in the same horizontal plane, and lie in the North-South direction. With the switch S open, the magnetic field of the Earth causes the magnet to dip as shown. When the switch is closed, the resistor R can be adjusted so that the field due to the current $I$ causes the magnet to set horizontally in the same plane as EFGH. This happens when the field due to the wires neutralises the vertical component of the Earth's magnetic field. Calculate the vertical component of the flux density of the Earth's magnetic field if $I$ = 3.0 A and EH = FG = 0.50 m.

Discuss what would happen to the pivoted magnet if the current $I$ were increased to a very large value

*(a)* in the same direction as shown on the diagram,

*(b)* in a direction opposite to that shown.

[$\mu_0 = 4\pi \times 10^{-7}$ H m$^{-1}$.] N79/III/3 (part)

**41** Write down the equation relating the flux density of a uniform magnetic field with the force it produces on a long, straight conductor carrying a current $I$ and making an angle $\theta$ with the field. Draw a clear three-dimensional diagram to illustrate the direction of this force relative to the current and field vectors. What happens as $\theta$ tends to zero?

A small rectangular coil of $N$ turns has sides of length $a$ and $b$. Derive an expression for the torque exerted when it carries a current $I$ in a uniform field of flux density $B$ when the *plane* of the coil makes an angle $\phi$ with the field. Such a coil is pivoted about a vertical axis in a uniform horizontal field. The torque required to prevent it turning is $T_1$. After rotation through 90°, the torque required is $T_2$. Derive an expression for the flux density $B$ in terms of $a, b, N, I, T_1$ and $T_2$.

N81/III/4

**42** Define *magnetic flux density* and hence deduce an expression for the force on a charge moving perpendicularly to a magnetic field. Draw clear diagrams to show the direction of the force in relation to the direction of motion of the charge and the field direction in the case of *(a)* positive charge, *(b)* negative charge. N82/III/4 (part)

**43**

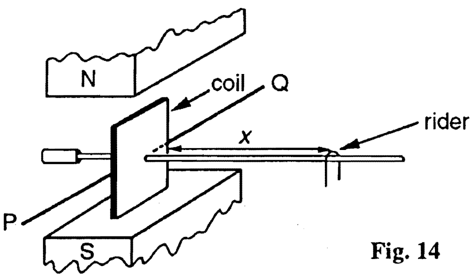



Fig. 14

Write down the equation defining *magnetic flux density* in terms of $F$ the force it produces on a long, straight conductor of length $L$ carrying a current $I$ at an angle $\theta$ to the field. Draw a clear diagram to illustrate the direction of the force relative to the current and magnetic field.

A small square coil of $N$ turns has sides of length $L$ and is mounted so that it can pivot freely about a horizontal axis PQ, parallel to one pair of sides of the coil, through its centre (see Fig. 14). The coil is situated between the poles of a magnet which produces a uniform magnetic field of flux density $B$. The coil is maintained in a vertical plane by moving a rider of mass $M$ along a horizontal beam attached to the coil. When a current $I$ flows through the coil, equilibrium is restored by placing the rider a distance $x$ along the beam from the coil. Starting from the definition of magnetic flux density, show that $B$ is given by the expression

$$B = \frac{Mgx}{IL^2N}.$$

If the current is supplied by a battery of constant e.m.f. and negligible internal resistance, discuss the effect on $x$ if the coil is replaced by one wound with similar wire but having

*(a)* sides of length $L$ with $2N$ turns,

*(b)* $N$ turns with sides of length $L/2$. J87/III/12

**44** *(a)* Draw a clear fully labelled diagram to illustrate the direction of the force $F$ acting on a straight conductor carrying a current $I$ at an angle $\theta$ to a uniform magnetic field of flux density $B$. Write down an expression for the force per unit length of the wire in terms of $B$, $I$ and $\theta$. [4]

*(b)* A U-tube of uniform square cross-section has electrodes sealed inside the upper and lower walls of the horizontal section, the two arms of the tube being vertical (see Fig. 15). The tube is partially filled with liquid sodium and a direct current is passed between the electrodes. A uniform horizontal magnetic flux is to be applied to the horizontal section of the tube in a direction normal to the vertical plane containing the tube.

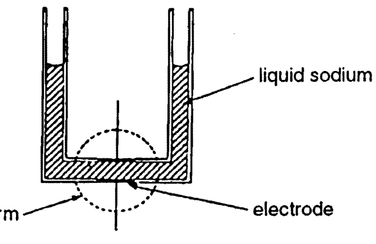



Fig. 15

(i) With the aid of a diagram, explain why the level of the liquid in the two vertical arms of the tube will change on application of the field. [6]

(ii) Calculate the difference between the heights of the liquid levels given that
the area of cross-section of the tube = $1.2 \times 10^{-4}$ m$^2$
the current between the electrodes = 5.0 A,
the magnetic flux density = 0.20 T,
the density of liquid sodium = 900 kg m$^{-3}$. [6]

(iii) Discuss the effect of increasing the area of the electrodes within the region of the magnetic flux on the difference in the vertical heights of the liquid levels. Assume that the current is supplied from a d.c. source of constant e.m.f. and negligible internal resistance. [6]

N88/III/10

**45** *(a)* (i) Write down the expression for $F$, the force on a long, straight conductor of length $l$ carrying a current $I$ at an angle $\theta$ to a uniform magnetic field of flux density $B$.

(ii) Draw a clear diagram to illustrate the direction of the force relative to the direction of the current and of the magnetic field.

(iii) Hence define the *tesla*. [6] N91/III/5 (part)

46 *(b)* A glass U–tube is constructed from hollow tubing having a square cross–section of side 2.0 cm, as shown in Fig. 16.

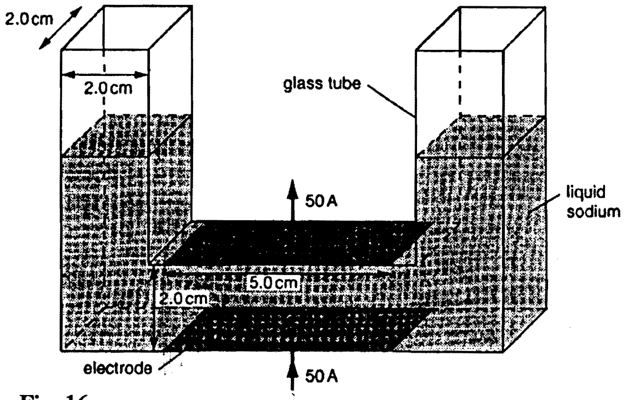



**Fig. 16**

The U-tube has vertical arms and a horizontal section between the arms. Electrodes are set into the upper and lower faces of the horizontal section. Each electrode is of length 5.0 cm and width 2.0 cm. The U-tube contains liquid sodium of density $9.6 \times 10^2$ kg m$^{-3}$ and of resistivity $4.8 \times 10^{-8}\ \Omega$ m.

(i) In these calculations, you may assume that the liquid sodium outside the electrodes has no effect on the resistance between the electrodes. Calculate

1. the resistance of the liquid sodium between the electrodes,
2. the potential difference $V$ between the electrodes required to maintain a current of 50 A in the liquid sodium. [4]

(ii) A uniform horizontal magnetic field of flux density 0.12 T is now applied at right-angles to the axis of the horizontal section of the tube in the region between the electrodes as shown in Fig. 17.

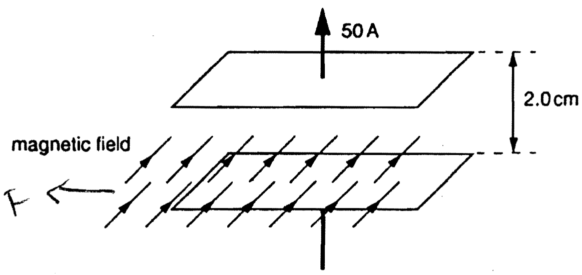



Fig. 17

A force is exerted on the liquid due to the magnetic field. For this force,

1. state and explain its direction,
2. calculate its magnitude. [4]

(iii) By considering the pressure difference which the force in (ii) causes, determine the difference in height of the surfaces of the liquid sodium in the vertical arms of the U-tube. [4]

*(c)* The technique outlined in *(b)* has been used as a means of pumping liquids. Suggest

(i) **one** advantage and **one** disadvantage of the technique when compared with conventional mechanical pumps,

(ii) why the potential difference required to maintain the current is larger when the liquid is in motion than when stationary. [5]

N97/III/4 (part)

## Force between Parallel Conductors

47 An experimenter investigates the variation of $F$, the force per unit length, between two long, parallel conductors a distance $d$ apart carrying direct currents. A straight-line graph should be obtained on plotting

**A** $F$ against $d$.
**B** $F$ against $1/d$.
**C** $F$ against $1/d^2$.
**D** lg $F$ against $d$.
**E** $F$ against lg $d$.

J76/II/19; N80/II/22; N82/II/21

48 Two long, parallel wires X and Y carry currents of 3 A and 5 A respectively. The force per unit length experienced by X is $5 \times 10^{-5}$ N to the right as shown in the diagram (Fig. 18).

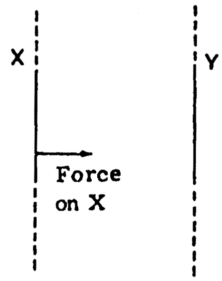


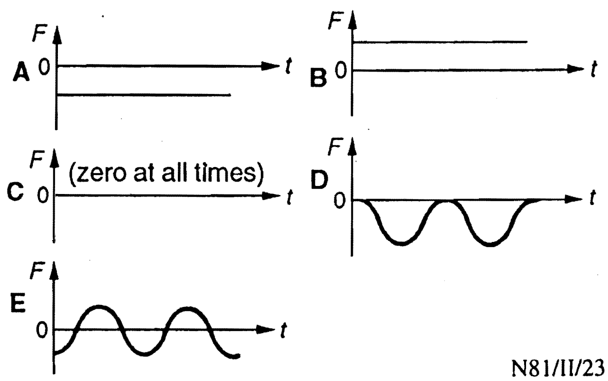

**Fig. 18**

The force per unit length experienced by wire Y is

**A** $2 \times 10^{-5}$ N to the left.
**B** $3 \times 10^{-5}$ N to the right.
**C** $3 \times 10^{-5}$ N to the left.
**D** $5 \times 10^{-5}$ N to the right.
**E** $5 \times 10^{-5}$ N to the left.

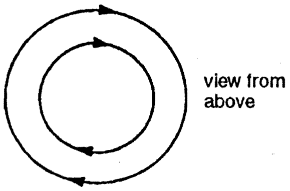
J79/II/20

*49 Two parallel conductors carry equal sinusoidal alternating currents differing in phase by π rad. Which one of the following graphs shows how $F$, the mutual force of attraction, varies with time $t$?




N81/II/23

**50** A small flat circular coil lies inside a similar larger coil. Each coil carries a current as shown.




What is experienced by the small coil due to these currents?

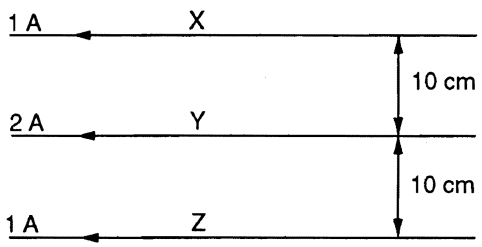
**A** a torque about a horizontal axis
**B** a torque about a vertical axis
**C** a vertical force along the axis
**D** no resultant force J85/I/20; N2000/I/18

**51** The ampere is defined as the current which, flowing in two straight, thin, parallel wires of length $l$ separated by a distance $d$ in a vacuum, generates a force $F$ per unit length on each wire. What are the correct values of $l$, $d$ and $F$?

| | $l$/m | $d$/m | $F$/N m$^{-1}$ |
|---|---|---|---|
| **A** | $\infty$ | 1 | $2 \times 10^{-7}$ |
| **B** | $\infty$ | 1 | $4\pi \times 10^{-7}$ |
| **C** | $\infty$ | $2\pi$ | $4\pi \times 10^{-7}$ |
| **D** | 1 | 1 | $2 \times 10^{-7}$ |
| **E** | 1 | $2\pi$ | $4\pi \times 10^{-7}$ |

N85/I/13

**52** Three long, parallel, straight wires X, Y and Z are placed in the same plane in a vacuum as shown. in the diagram below.

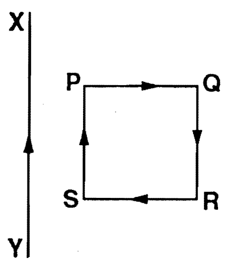



Given that the force per unit length between two long, parallel, straight wires placed 10 cm apart, each carrying a current of 1 A, is $2 \times 10^{-6}$ N m$^{-1}$, what is the net force per unit length acting on Z?

**A** $3.0 \times 10^{-6}$ N m$^{-1}$
**B** $3.5 \times 10^{-6}$ N m$^{-1}$
**C** $4.0 \times 10^{-6}$ N m$^{-1}$
**D** $4.5 \times 10^{-6}$ N m$^{-1}$
**E** $5.0 \times 10^{-6}$ N m$^{-1}$ J88/I/14

**53** A long straight wire **XY** lies in the same plane as a square loop of wire **PQRS** which is free to move. The sides **PS** and **QR** are initially parallel to **XY.**

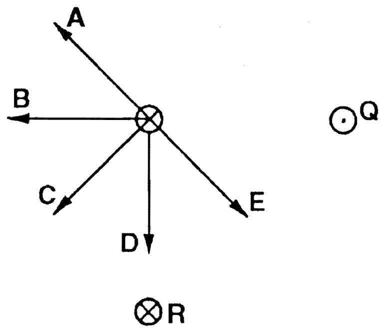
The wire and loop carry steady currents as shown in the diagram.




What will be the effect on the loop?

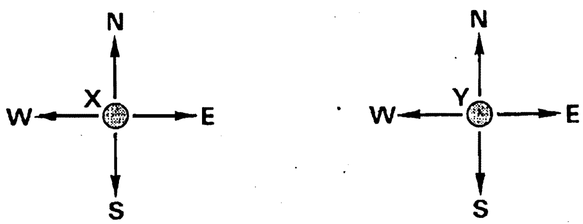
**A** It will move towards the long wire.
**B** It will move away from the long wire.
**C** It will rotate about an axis parallel to **XY**.
**D** It will be unaffected.
**E** It will contract. N89/I/19

**54** The diagram shows three long straight wires **P, Q** and **R** normal to the plane of the paper. Wires **P** and **R** carry currents directed into the plane of the paper, and wire **Q** carries a current directed out of the paper. All three currents have the same magnitude.




Which arrow best shows the direction of the resultant force on wire **P**? J90/I/20

**55** The diagram shows two long straight parallel wires, **X** and **Y**, carrying currents in the same direction into the paper.

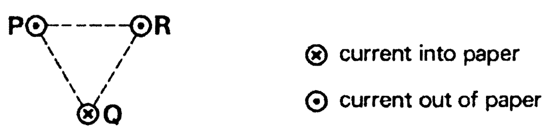



What are the directions of the forces on **X** and **Y**?

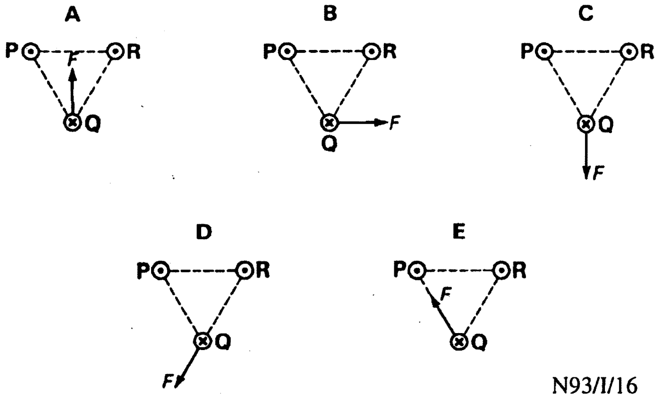
| | *direction of force on* **X** | *direction of force on* **Y** |
|---|---|---|
| **A** | N | S |
| **B** | E | E |
| **C** | E | W |
| **D** | S | N |
| **E** | W | E |

N92/I/18

**56** Three long vertical wires pass through the corners of an equilateral triangle **PQR**. They carry equal currents into or out of the paper in the directions shown in the diagram.

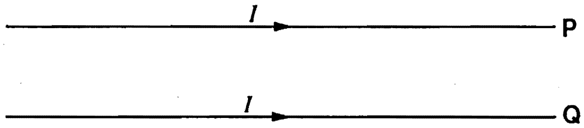


Which diagram shows the direction of the resultant force $F$ on the wire at Q?




N93/I/16

**57** The diagram shows two parallel wires **P** and **Q** in the plane of the paper. **P** is fixed; **Q** is free to move.

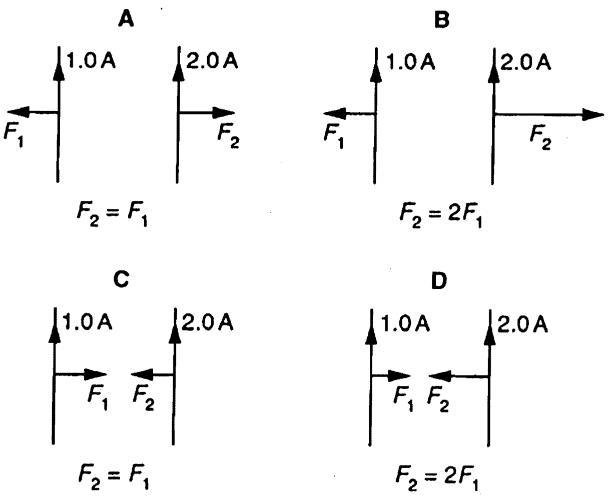



When the same current $I$ passes through each wire in the same direction, **Q** moves

**A** away from **P** in the plane of the paper.
**B** downwards into the paper.
**C** towards **P** in the plane of the paper.
**D** upwards out of the paper. J96/I/19

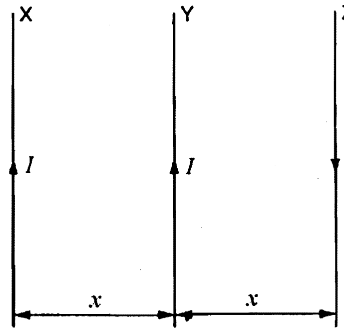
**58** Two long, straight, parallel wires carry currents of 1.0 A and 2.0 A.

Which diagram shows the directions and relative magnitudes $F_1$ and $F_2$ of the forces per unit length on each of the wires?




N96/I/18

**59** The diagram shows three parallel wires X, Y and Z that carry currents of equal magnitude in the directions shown.




The resultant force experienced by Y due to the currents in X and Z is

**A** perpendicular to the plane of the paper.
**B** to the left.
**C** to the right.
**D** zero. N99/I/18

**60** Given that the force between two long parallel conductors of length $l$, a distance $a$ apart, carrying currents $I_1$ and $I_2$, is $F = \mu_0 I_1 I_2 l / 2\pi a$, use the definition of the ampere to show that $\mu_0$ the permeability of free space, is $4\pi \times 10^{-7}$ J s$^2$ C$^{-2}$ m$^{-1}$. J80/I/5

**61** *(a)* A long strip ABC of aluminium foil is hung over a wooden peg as shown in Fig. 19. A car battery is connected for a short time between A and C.

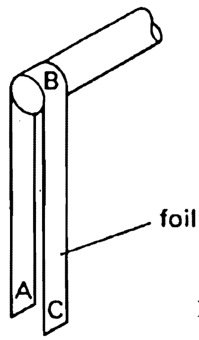



**Fig. 19**

Describe and explain what will be seen to happen to the foil whilst there is a current. [5]

J91/II/5 (part)

**62** *(c)* Two wires **X** and **Y**, which are at right angles to the plane of the paper, carry currents $I_1$, and $I_2$ out of the plane of the paper and are separated by a distance $r$ as shown in Fig. 20. Current $I_1$, causes a magnetic field of flux density $\dfrac{\mu_0 I_1}{2\pi r}$ at **Y**.

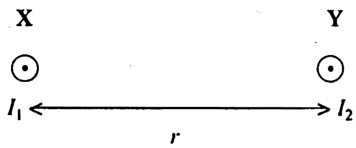



**Fig. 20**

(i) Show on Fig. 20 the direction of the magnetic field which $I_1$ causes at **Y**.

(ii) Find the value of the force per unit length of wire which $I_1$ causes on wire **Y**.

(iii) Show on Fig. 20 the direction of the force on wire **Y**. [3]

J92/II/1 (part)

**63** *(a)* A long length of aluminium foil *ABC* is hung over a wooden rod as shown in Fig. 21.

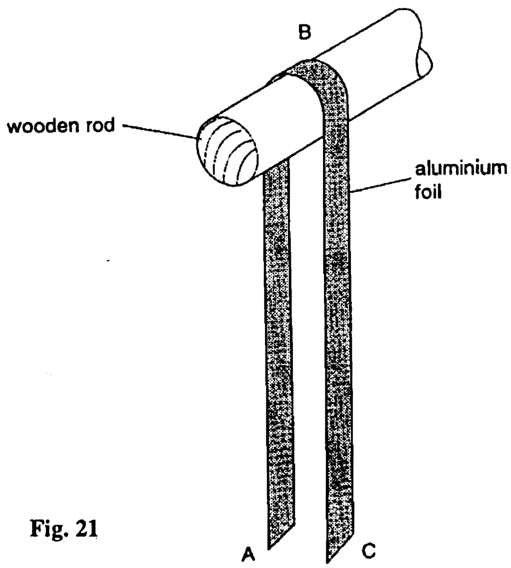



**Fig. 21**

A large current is momentarily passed through the aluminium foil in the direction *ABC*, and the foil moves. The foil is not damaged.

(i) On Fig. 21, draw arrows to indicate the directions in which *AB* and *BC* move.

(ii) Explain, in terms of physical principles, why the foil moves in this way. [5]

J95/II/4 (part)

## *Long Questions*

**64** Sketch the form of the magnetic field due to a long, straight, current-carrying wire and give the formula for the flux density at a nearby point. Hence, deduce a formula for the force per unit length on another long, straight wire carrying a current of the same magnitude in the same direction.

Sketch the fields and show the forces on such parallel conductors *(a)* for currents flowing in the same direction, *(b)* for currents flowing in opposite directions.

Two long, parallel, vertical wires 0.3 m apart are placed east-west of one another. The current in the westerly wire is 20 A and the other is 30 A. Both currents flow upwards. If the horizontal component of the Earth's magnetic flux density is $2.0 \times 10^{-5}$ T, calculate the resultant force on one metre of each wire.

[$\mu_0 = 4\pi \times 10^{-7}$ H m$^{-1}$.] J78/III/3 (part)

**65** Define the *ampere*. Write down a formula for the magnetic field strength near a long, straight, current-carrying wire. Hence show that this requires the value of $\mu_0$ to be $4\pi \times 10^{-7}$ H m$^{-1}$.

Estimate the maximum mechanical force between two neighbouring turns in the same winding of an air-cored transformer. The turns are 2 mm apart, the core diameter is 0.08 m, and the r.m.s. value of the sinusoidal current is 0.5 A. You may use the formula for the force between a pair of long straight parallel wires. How may this be justified?

J79/III/2 (part)

**66** Write down an expression for the force between two long parallel current-carrying conductors. Define the *ampere*. Show how this definition is equivalent to fixing the value of $\mu_0$. J84/III/5 (part)

**67** *(b)* Two long straight parallel wires are separated by a distance *d*. Each carries current *I* in the same direction.

(i) Explain, with the aid of sketches, the forces which exist between the two wires. Predict the directions of the forces.

(ii) *B*, the magnetic flux density due to a long straight wire, is given by the expression

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

Derive an expression for the force per unit length between the two wires. [8]

*(c)* One particular overhead powerline consists of two parallel cables with a separation of 6.0 m.

The current in each cable is 200 A.

(i) Calculate the force per unit length on each cable.

(ii) Hence explain why it is not possible, by looking at the cables, to detect the instant at which the current is switched on. [6]

N91/III/5 (part)

## Hall Effect

**68** A certain device uses the Hall effect in a semiconductor to measure magnetic fields. A particular increase in temperature results in an increase of 2% in the number of charge carriers in the semiconductor. The sensitivity of the device

**A** increases by 4%.
**B** increases by 2%.
**C** is unchanged.
**D** decreases by 2%.
**E** decreases by 4%.

J83/II/20

**69** An experiment to demonstrate the Hall effect is set up, first with a metal specimen, and then with a semiconductor sample of the same dimensions. For the same values of applied magnetic flux density and current in each sample, the Hall voltage across the metal is found to be very much less than that across the semiconductor. Account for this difference. N86/II/4

70 A positive charge $q$ moves with constant velocity $v$ in a strip of semiconductor material of width $d$. A uniform magnetic field of flux density $B$ acts downward and normal to the strip as shown in Fig. 22.

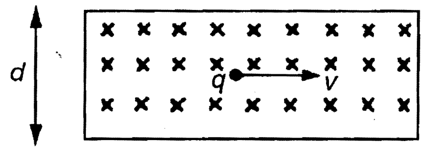



Fig. 22

*(a)* Show on a diagram the magnitude and direction of the force which the magnetic field exerts on the charge.

*(b)* For equilibrium there must be an equal and opposite force on the charge caused by a potential difference set up across the width of the strip. Derive an expression for this potential difference. [5]

N88/II/5

## *Long Questions*

71 Explain what is meant by the *Hall effect* and outline an experiment to demonstrate it.

Using a simple free electron model, show that the Hall coefficient $R_H$, i.e. transverse electric field/(flux density × current density), is given by $R_H = 1/ne$ where $n$ is the number of electrons per unit volume and $e$ the charge on the electron.

What information may be provided by the magnitude and the sign of the Hall coefficient? J76/III/5 (part)

72 You have available apparatus of a typical school laboratory. With the aid of circuit diagrams and equations, and indicating the magnitude of relevant quantities, describe how you would

*(b)* use a thin slice of semiconductor to find the ratio of the magnetic flux density at the middle of a long solenoid to that at its end. N79/III/4 (part)

73 Explain the origin of the Hall effect. Include a diagram showing clearly the directions of the Hall voltage and other relevant vector quantities for a specimen in which electron conduction predominates.

A slice of indium antimonide is 2.5 mm thick and carries a current of 150 mA. A magnetic field of flux density 0.5 T, correctly applied, produces a maximum Hall Voltage of 8.75 mV between the edges of the slice. Calculate the number of free charge carriers per unit volume, assuming that they each have a charge of $-1.6 \times 10^{-19}$ C. Explain your calculation clearly.

What can you conclude from the observation that the Hall voltage in different conductors can be positive, negative or zero? J80/III/5