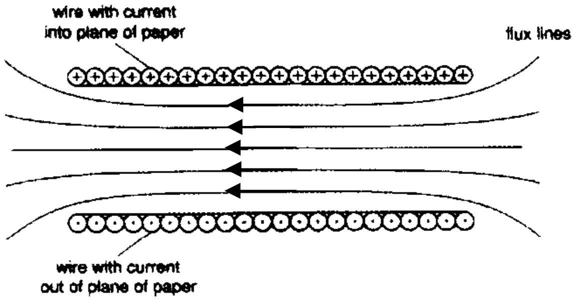
Electromagnetism Tutorial Solution

Discussion

Magnetic field lines

D1

(a) The figure illustrates the patterns of the magnetic flux due to a current in a solenoid.



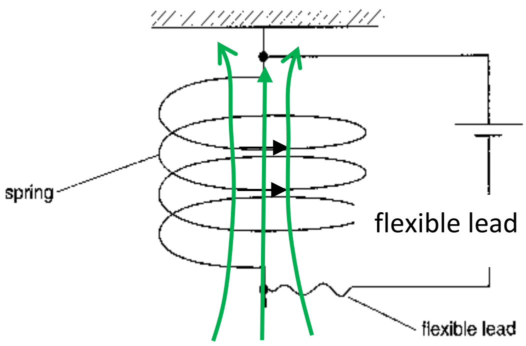
(i) On the figure, draw arrows to show the direction of the magnetic field in the solenoid. [1]

(ii) 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]

It can be easily magnetized / de-magentised, when the current is switched on/off. It concentrates the magnetic field lines and thereby increasing the magnetic flux density at the centre of the coil.

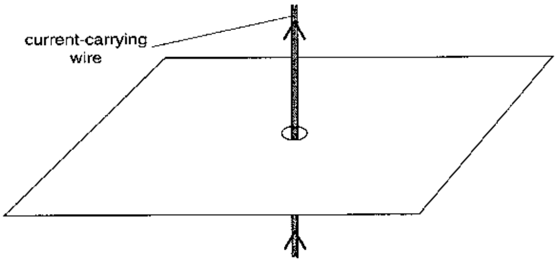
(b) A loosely-coiled spring is suspended from a fixed point as illustrated on the right.

Electrical connections are made to the ends of the spring. When a current is switched on in the spring, there is a small change in the length of the spring.

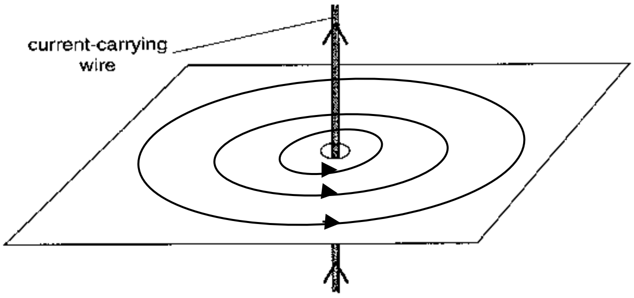


(i) Magnetic field lines

(i) On the figure, indicate the direction of the current in the individual turns of the spring and the direction of the magnetic field. [2]



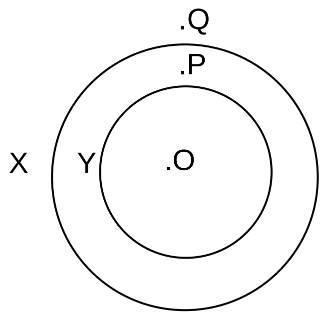
(ii) On the figure on the right, draw the pattern of the magnetic field due to a straight current-carrying wire. [1]



For this question, check to ensure that the circles they draw are further and further apart. The magnetic flux density should become weaker (field lines further apart) as the distance from the wire increases.

Also, it's a 3D plane, the shape of the field line is an ellipse.

D2. X and Y are two coaxial circular coils lying on a table. O, P and Q are three points on the table.



Initially, there is a constant current in coil X and no current in coil Y.

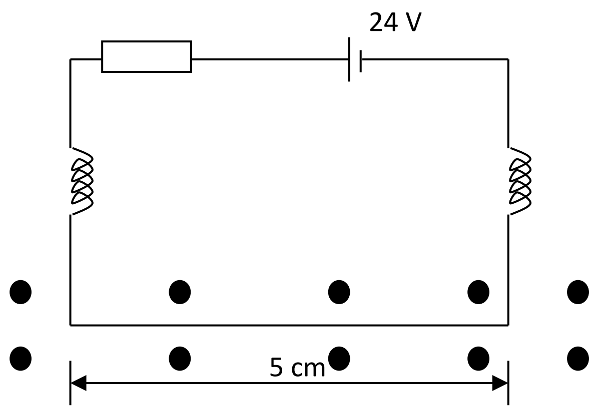
A small current is now passed through coil Y, which decreases the magnitude of the magnetic flux density at O. How does the magnitude of the flux density changes at P and Q?

	P	Q
A	Decreases	Decreases
B	Decreases	Increases
C	Increases	Decreases
D	increases	Increases

Solution:
Choose an arbitrary current direction in wire X.
Draw the magnetic field pattern due to the current in wire X at the positions O, P, Q.
Choose an arbitrary current direction in wire Y to get the resultant magnetic field effect in O.

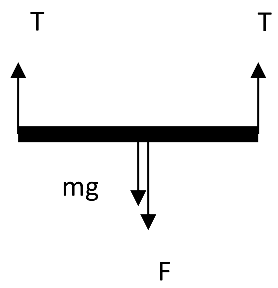
D3. Force on a current-carrying conductor in a magnetic field
A straight wire of mass 10 g and length 5 cm is suspended from two identical springs which, in turn, form a closed circuit as shown. The total resistance of the circuit is 12 Ω.

Each spring is stretched a distance of 0.5 m under the weight of the wire. When a magnetic field is turned on, directed out of the page (indicated by the dots), the springs are observed to stretched an additional 3 cm.



(a) Draw a free body diagram on the rod [2]
(b) Calculate the force constant of each spring [2]
(c) Calculate the magnetic flux density. [4]

(a)



T: tension acting rod due to spring

mg: weight of rod

F: magnetic force acting on rod

(b)
Using Hook's Law
$T = kx$
$2T = mg$
$kx = mg / 2$
$k = (mg/2)(1/x)$
$= [(0.01)(9.81)/2]\ (1/0.5)$
$= 0.0981\ Nm^{-1}$

(c)
$V = IR$
$24 = I\ (12)$
$I = 2.0\ A$

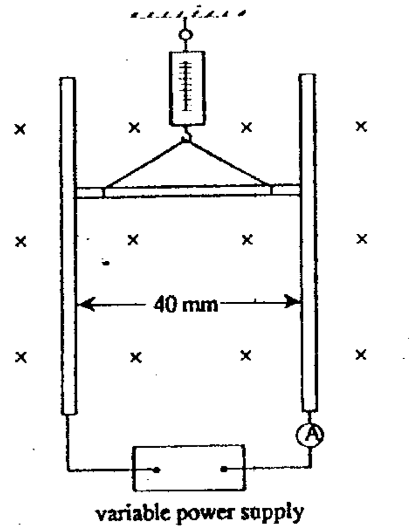
For equilibrium, sum of forces in the vertical direction must be zero.
$mg + F - 2T' = 0$

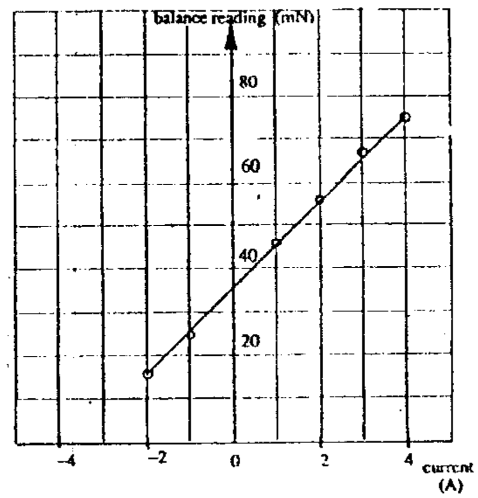
$F = 2kx' - mg$
$= 2(0.0981)(0.53) - (0.01)(9.81)$
$= 5.886 \times 10^{-3} = 5.89 \times 10^{-3}\ N$

$F = BIL$
$5.886 \times 10^{-3} = B(2)(0.05)$
$B = 0.05886\ T = 0.0589\ T$

D4. Equilibrium involving magnetic forces

Two smooth electrically conducting vertical tracks are joined by a horizontal metal slide of length 40 mm. The slide is supported by a sensitive spring balance and is free to move up and down the tracks in a uniform horizontal magnetic field, B, at right angles to its length as shown.





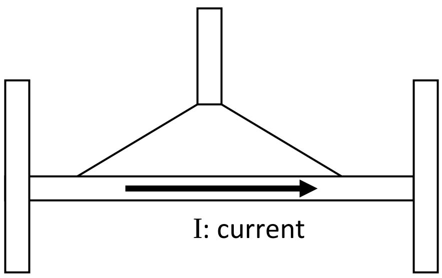
The spring balance, which is calibrated in milli-newton, reads zero when it is hanging vertically and supporting no load. The tracks are connected to a variable power supply which can provide a current in either direction through the circuit.
A student passes various currents through the circuit and notes corresponding readings on the spring. The results are shown in the graph above.

(a) Determine the mass of the slide [2]
(b) Determine the current flowing when the spring balance reads zero, [2]
(c) Indicate the direction of the current on the diagram when the spring balance reads zero [1]
(d) Draw a free body diagram showing all forces acting on the slide
(e) Calculate the value of the magnetic field B. [3]

(a) When no current, I = 0,
balance reading = 35 mN
Spring balance reading = weight of slide = mg
m = 35 x 10^{-3}/9.81 = 3.57 x 10^{-3} kg

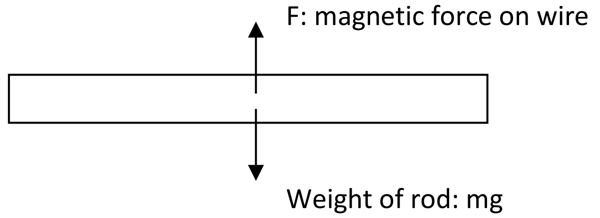
(b) Extrapolating onto the I-axis, I = - 3.6 A

(c)



Applying Fleming's Left Hand Rule.

d) At equilibrium, balance reading is zero (magnitude of current, I = 3.6 A)

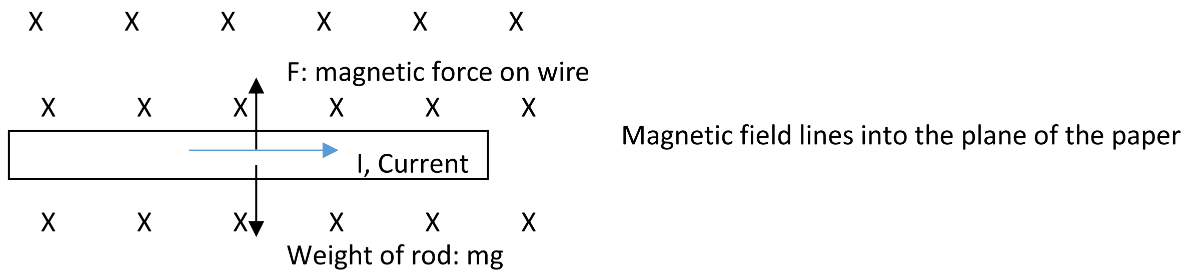


Weight of slide = Magnetic force acting on slide, F = BIL

mg = BIL

B = mg/IL = $35\text{x}10^{-3}$/ (3.6 x 0.040) = 0.24 T

D5. A straight horizontal rod X, of mass 50 g and length 0.5 m, is placed in a uniform horizontal magnetic field of 0.2 T perpendicular to X. Calculate the current in X if the force acting on it just balances its weight. Draw a sketch showing the directions of the current, field and force. [3]



For equilibrium, sum of forces in that direction must be zero.

(Magneticc force, F) - (Weight of rod, W) = 0 where F = BIL and W = mg

BIL = mg

$$I = \frac{50\times10^{-3}\times9.81}{0.2\times0.5}$$
$$= 4.9A$$

D6. Electric motor

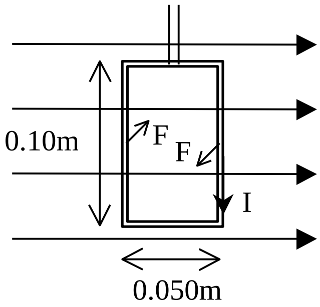
A narrow vertical rectangular coil is suspended from the middle of its upper side with its plane parallel to a uniform horizontal magnetic field of 0.020 T. The coil has 10 turn, and the lengths of its vertical and horizontal sides are 0.10 m and 0.050 m respectively. Calculate the torque on the coil when a current of 5.0 A is passed into it. Draw a sketch showing the directions of current, field and torque. [4]

F_B = NBIL

τ = F_B x d
= NBILd

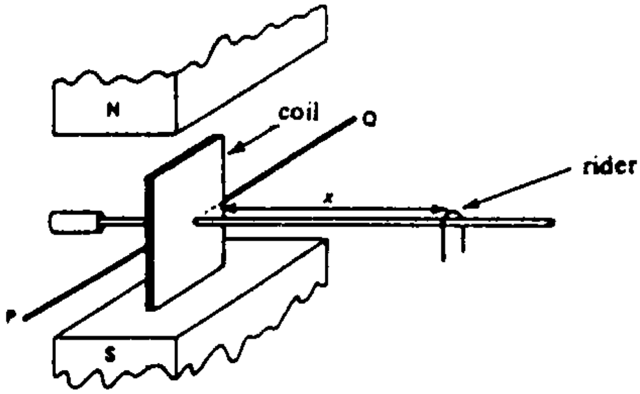
= (10)(0.020)(5)(0.10)(0.050)

= 5.0×10^{-3} Nm



D7.Current balance

A small 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 figure). 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.



(a) Starting from the definition of magnetic flux density, show that *B* is given by the expression $B = \dfrac{Mgx}{IL^2 N}$ [4]

(b) The current is supplied by a battery of constant e.m.f. , E, and negligible internal resistance.

(i) Show that the current in the coil is given by the expression $I = \dfrac{EA}{\rho(4NL)}$

Hint: use $R = \dfrac{\rho L}{A}$

(ii) Hence, discuss the effect on *x* if the coil is replaced by one with:

(1) sides of length *L* with 2*N* turns,
(2) *N* turns with sides of length *L*/2. [4]

(a) Force acting on vertical sides = 0
Force acting on each horizontal side,
F_B = NBIL
Torque about PQ, τ = $NBIL^2$

For equilibrium,

$NBIL^2$ = Mgx

$B = \frac{Mgx}{IL^2 N}$ (Shown) Eqn (2)

(b)(i) Resistance of the coil depends on the total length of the coil wire.

$I = \frac{E}{R} = \frac{EA}{\rho(4NL)}$ Eqn (1)

(b)(ii) By combining Eqn 1 and Eqn 2, we have:

$$x = \frac{BL^2 N}{Mg} \times \frac{EA}{\rho(4NL)} = \frac{BEA}{4\rho Mg} L$$

Using the equation we have derived, $x = \frac{BEA}{4\rho Mg} L$, we can conclude the following:

(1) no effect (as x does not depend on N)
(2) halved (as x is directly proportional to L)

D8. Particles moving in magnetic field.

(a) There are two situations in which a charged particle in a magnetic field does not experience a magnetic force. State these two situations. [2]

(b) A beam of protons of speed is 6.0 x 10^6 ms^{-1} enters a region of uniform magnetic field of flux density 0.18 T. The region is evacuated and the magnetic field is normal to the direction of the motion of the protons.

(i) Sketch the path of the protons within and beyond the magnetic field and show the direction of the field. [2]

(ii) Calculate
1. the force on an individual proton. [2]
2. the acceleration of the proton. [1]
3. the radius of the path of the protons within the magnetic field. [2]

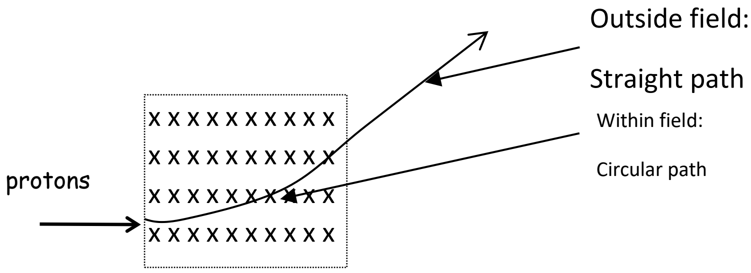
(iii) Measurement of this radius can be used as a means to determine the kinetic energy of the protons. State and explain what happens to the radius if the kinetic energy of the protons were to be reduced. [3]

(a) *The two situations are:*
The charged particle is stationary (v = 0). Hence there is no magnetic force acting on the charged particle (F = Bqvsin θ = 0).

The charge particle is moving parallel to the magnetic field, θ = 0.

Hence, F = Bqv sin 0 = 0

(b) (i)



(ii)1. $F = Bqv = 0.18 \times 1.6 \times 10^{-19} \times 6 \times 10^{6}$
$= 1.73 \times 10^{-13}$ N

(ii)2. $a = F / m = 1.04 \times 10^{14}$ ms^{-2}

(ii)3. $r = v^2 / a = (6 \times 10^6)^2 / 1.04 \times 10^{14}$
$= 0.348$ m

(iii) By Newton's 2nd Law, $F_{net} = ma$
Magnetic force (F_B) provides the centripetal force (F_C) so that the circular motion can take place .

$F_B = F_C$
$Bqv = mv^2 / r$
$r = mv / Bq$

From the equation above, if E_k is reduced, the radius will become smaller.

D9 α-particles, each of speed v and mass m, are travelling in a narrow beam in a vacuum, as shown in Fig.2.1. The α-particles enter a region where there is a uniform magnetic field of flux density B. The α-particles in the magnetic field move along the arc of a circle of radius r.

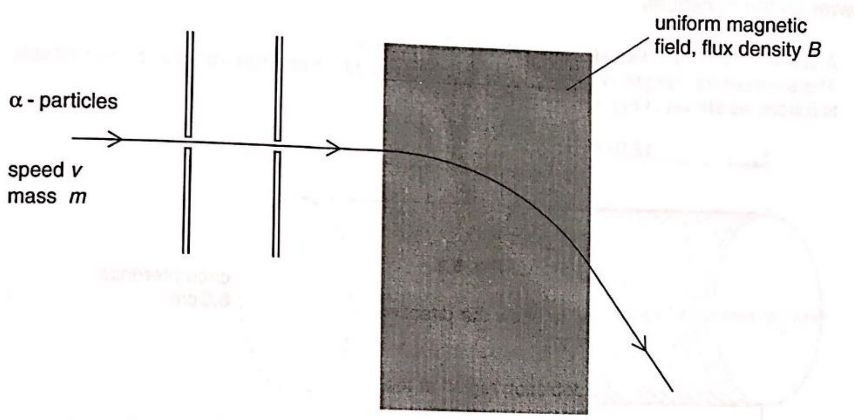


Fig. 2.1

(a) State the direction of the magnetic field. [1]
The direction of the magnetic field is pointing normally out of the plane of the page.

(b) Show that, for an α-particle in this beam,
(i) The magnitude p of its momentum is given by the expression

$$P = 2\,Ber,$$

where e is the elementary charge, [2]

Magnetic force, F_B, acting on the particle provides the centripetal force for the particle's circular motion.

Using Newton's 2nd Law, $F_{net} = ma$
$F_B = Bqv = mv^2/r$

$r = mv/Bq$

$P = mv$ and $q = 2e$ (Alpha particle has 2 protons, hence $q = 2e$)

$r = P/B2e$

$P = 2Ber$ (shown)

(ii) The kinetic energy Ek is given by the expression

$$E_k = \frac{2(Ber)^2}{m}$$ [1]

$E_k = ½\, mv^2$
$E_k = P^2/2m$
$= (2Ber)^2/2m$
$= 4(Ber)^2/2m$
$= (Ber)^2/m$

(c) On Fig. 2.2, sketch the part of an α-particle that has a speed greater than v. [2]

(2007 P2Q4)

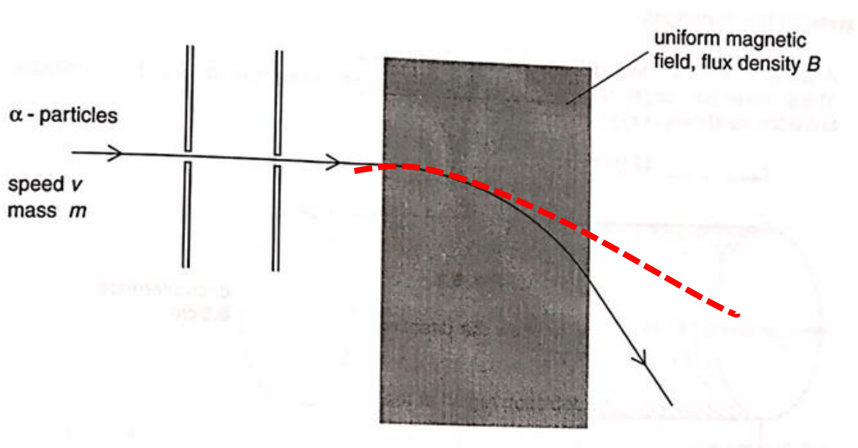


Fig. 2.1

High v imply high P. Hence using r = P/Bq, r is proportional to P when B and q are constant. Hence r is larger.

Assignment

A1 A student makes a solenoid with insulated copper wire. The solenoid has length 12.0 cm and the average length of one turn of wire on the solenoid is 8.8 cm, as shown in Fig. 1.1.

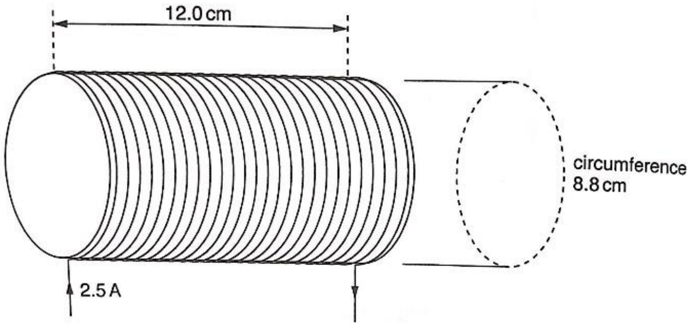


Fig. 1.1

The copper wire has a circular cross-section of diameter 0.60 mm. The resistivity of copper is 1.6×10^{-8} Ωm.

It is found that the current in the solenoid is 2.5 A when the potential difference across its terminal is 4.5 V.

(a) **(i)** Calculate, for the solenoid, the resistance of the wire. [1]

Using $E = IR$
$4.5 = 2.5 (R)$
$R = 1.8\ \Omega$

(ii) Use your answer in **(i)** in order to calculate the total number of turns of wire on the solenoid. [3]

$R = \rho NL/A$ where N is the number of turns and L is the circumference of 1 turn.
$1.8 = 1.6 \times 10^{-8} \times N \times (0.088) / \pi (0.6 \times 10^{-3}/2)^2$
$N = 361.46 = 360$ turns.

(iii) Use your answers in **(ii)** to show that the number of turns per unit metre length of the solenoid is 3000. [1]

Number of turns per unit metre = N/0.12 = 360/0.12 = 3000 shown.

(b) The magnetic flux density B (in Tesla) inside the solenoid and parallel to its axis is given by the expression

$$B = \mu_o nI$$

Where n is the number of turns per metre length of the solenoid, I is the current in the solenoid expressed in amperes and μ_o is the permeability of free space.

(i) Define the tesla. [3]
(ii) Calculate the magnetic flux density in the solenoid. [1]

(i) refer to lecture notes
(ii)

$B = \mu_o nI$

B= 4πx10^{-7} x 3000 x 2.5
= 9.42 m T

(c) The solenoid in (b) is in a vacuum. An electron is injected into the field of the solenoid with a speed of 4.0 x10^{7} ms^{-1} at an angle of 30^{o} to its axis, as shown in Fig.1.2.

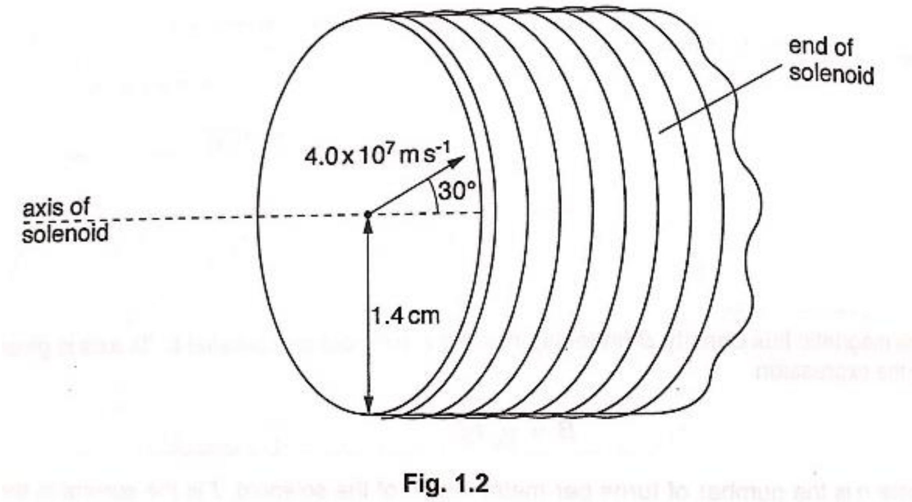


Fig. 1.2

Calculate the magnitude of the component of the velocity of the electron's velocity

(i) Along the axis of the solenoid, [1]
(ii) Normal to the axis of the solenoid. [1]

(i) Velocity along the axis, $V_{//}$ = 4.0x10^{7} cos 30^{o} = 34.6 x10^{6} m s^{-1}

(ii) Velocity normal to the axis of the solenoid, $V\perp$ = 4.0x10^{7} sin 30^{o} = 2.0 x10^{7} m s^{-1}

(d) A particle of mass m and charge q is moving with speed v normal to a magnetic field of flux density B. Show that the particle will move in a circular path of radius r given by the expression

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

Explain your working. [3]

Magnetic force, FB, acting on the particle provides the centripetal force for the particle's circular motion.

Using Newton's 2nd Law, Fnet = ma
$F_B = Bqv = mv^2/r$

r= mv/Bq

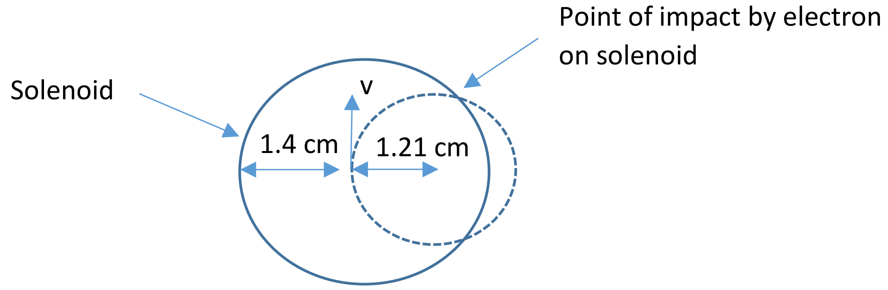
(e) The radius of the cross-section of the solenoid in **(c)** is 1.4 cm. Use the data from **(c)** and **(d)** to determine quantitatively whether the electron will travel down the length pf the solenoid or will collide with its wall. [3]

(2009 P3 2)

r= mv/Bq

$= 9.11\text{x}10^{-31} \text{ x } 2\text{x}10^{7} /(9.42\text{x}10^{-3} \text{ x } 1.6\text{x}10^{-19})$
$= 1.21 \text{ x}10^{-2}$ m
= 1.21 cm

As the electron enters the solenoid at the centre, it will move along a partial circular path. It will hit the solenoid before it can complete a circle as shown in the diagram below because the diameter of its circular path lies outside the solenoid. The diameter of the circle formed is 2.42 cm.



Answer Keys

1	A
2	B
3	B
4	B
5	C
6	C
7	D

D2	C
D3	b. 0.0981Nm^{-1}
	c. 0.0589 T
D4	a. 3.7×10^{-3} kg
	b. -3.6A
	e. 0.25 T
D5	4.9 A
D6	5x10-3 Nm
D8	b.ii.1. 1.73×10^{-13} N
	b.ii.2. 1.03×10^{14} m s^{-2}
	b.ii.3. 0.348 m

Past year A-level MCQs from Google Drive

Magnetic Fields due to currents
3, 4, 6, 7, 8, 9

Force on current carrying conductors
21, 22, 25, 26, 28,29,32,24

Force on parallel conductors
48, 50, 53, 54, 56,59

Charge particles
1,2,4,7,9,11,28,29,31,32,50,53,54,58