EXERCISE QUESTIONS

CHAPTER - 4 MOVING CHARGES AND MAGNETISM

4.1 A circular coil of wire consisting of 100 turns, each of radius 8.0 cm carries a current of 0.40 A. What is the magnitude of the magnetic field B at the centre of the coil?

Ans - Number of turns, n = 100

Radius of coil, r = 8 cm

the magnetic field in the centre of a 100-turn circular coil

Using $B = \frac{\mu_0 n I}{2a}$, we get

$$B = \frac{4\pi \times 10^{-7} \times 100 \times 0\cdot 4}{2 \times 8 \times 10^{-2}}$$

$$= \pi \times 10^{-4}\,T = 3\cdot 142 \times 10^{-4}\,T$$

4.2 A long straight wire carries a current of 35 A. What is the magnitude of the field B at a point 20 cm from the wire?

Ans - Current through the wire, I = 35 A

Distance of point P from the wire, d = 20 cm

$$\text{Using } B = \frac{\mu_0 I}{2\pi a} = \frac{4\pi \times 10^{-7} \times 35}{2\pi \times 20 \times 10^{-2}}$$

$$= 3\cdot 5 \times 10^{-5}\,T$$

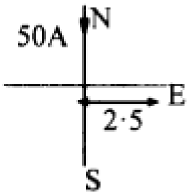
4.3 A long straight wire in the horizontal plane carries a current of 50 A in north to south direction. Give the magnitude and direction of B at a point 2.5 m east of the wire.

Ans - Let's start by deciding the normative directions on the paper plane.

Current through the wire, I = 50 A (North to South)

Distance of point P East of the wire, d = 2.5 m

$$B = \frac{\mu_0 I}{2\pi a} = \frac{4\pi \times 10^{-7} \times 50}{2\pi \times 2\cdot 5}$$



$= 2 \times 10^{-7} \times 20$

$= 4 \times 10^{-6}$ T vertically upward.

4.4 A horizontal overhead power line carries a current of 90 A in east to west direction. What is the magnitude and direction of the magnetic field due to the current 1.5 m below the line?

Ans - Standard instructions on a piece of paper can vary depending on the situation.

Current through the wire, I = 90 A (East to West)

Distance of point P below the wire, d = 1.5 m

$$B = \frac{\mu_0 I}{2\pi a} = \frac{4\pi \times 10^{-7} \times 90}{2\pi \times 1\cdot 5}$$

4.5 What is the magnitude of magnetic force per unit length on a wire carrying a current of 8 A and making an angle of 30° with the direction of a uniform magnetic field of 0.15 T?

Ans - Current in the wire, I = 8 A

Magnitude of the uniform magnetic field, B = 0.15 T

Angle between the wire and magnetic field, θ = 30°

Allow l to be the length of wire carrying an 8 A current at a 30° angle to the magnetic field.

Using $F = BIl \sin\theta$, we get

$$\frac{F}{l} = BI\sin\theta = 0\cdot15 \times 8 \times \sin 30$$

$$= 1\cdot2 \times \frac{1}{2} = 0\cdot6 \text{ N per unit length}$$

$$= 0\cdot6 \text{ N m}^{-1}$$

4.6 A 3.0 cm wire carrying a current of 10 A is placed inside a solenoid perpendicular to its axis. The magnetic field inside the solenoid is given to be 0.27 T. What is the magnetic force on the wire?

Ans - The solenoid's internal magnetic field runs parallel to its axis. The axis is parallel to the current in the wire.

I = 10 A, B = 0.27 T
1 = 3cm = 0.3m
and θ = 90°

F = BI 1 sin θ
=0.27×10 × 0.03 × sin90°
= 0.27×10 x 0.03 x 1
= 8.1 × 10-2N.

Hence, the magnetic force on the wire is 8.1×10^{-2} N. The direction of the force can be obtained from Fleming's left hand rule.

4.7 Two long and parallel straight wires A and B carrying currents of 8.0 A and 5.0 A in the same direction are separated by a distance of 4.0 cm. Estimate the force on a 10 cm section of wire A.

Ans - Current in wire A, IA = 8.0 A

Current in wire B, IB = 5.0 A

Distance between the conductors A and B, d = 4 cm

Force of attraction on two parallel wires conducting electricity in the same direction per unit length

Using $\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r} = \frac{4\pi\times10^{-7}\times8\times5}{2\pi\times4\times10^{-2}}$

or $F = (2\times10^{-7}\times2\times5\times10^{2})\,l$
$= 20\times10^{-5}\times10\times10^{-2}$
$= 2\times10^{-5}$ N, attractive.

4.8 A closely wound solenoid 80 cm long has 5 layers of windings of 400 turns each. The diameter of the solenoid is 1.8 cm. If the current carried is 8.0 A, estimate the magnitude of B inside the solenoid near its centre.
Ans - Length of solenoid, L = 80cm

Number of turns = number of layers × number of turns per layer

Number of turns, n = 5 × 400 = 2000

Radius of solenoid, r = Diameter/2 = 0.9 cm

It is possible to compute the total number of turns in a solenoid's 80 cm length.

Using $B = \frac{\mu_0 N I}{l}$, we get

$$B = \frac{4\pi \times 10^{-7} \times 400 \times 5 \times 8}{80 \times 10^{-2}}$$

$$= 8\,\pi \times 10^{-3}\ T$$

4.9 A square coil of side 10 cm consists of 20 turns and carries a current of 12 A. The coil is suspended vertically and the normal to the plane of the coil makes an angle of 30° with the direction of a uniform horizontal magnetic field of magnitude 0.80 T. What is the magnitude of torque experienced by the coil?

Ans - Length of side of square, L = 10 cm

Number of turns, n = 20

Current through the square coil, I = 12 A

torque felt by the current-carrying coil in the specified magnetic field.

Torque, τ = NI(A¯ x B¯)
= 20 x 12 x 100 x 10-4 x 0.8 x sin 30°1
= 20 x 12 x 100 x 10-4 x 0.8 x 12
= 0.96 Nm

4.10 Two moving coil meters, M1 and M2 have the following particulars:
R1 = 10 Ω, N1 = 30,
A1 = 3.6 × 10–3 m2 , B1 = 0.25 T
R2 = 14 Ω, N2 = 42,
A2 = 1.8 × 10–3 m2 , B2 = 0.50 T
(The spring constants are identical for the two meters).
Determine the ratio of
(a) current sensitivity and (b) voltage sensitivity of M2 and M1 .

Ans - For moving coil meter M1

Resistance of wire, R1 = 10Ω

Number of turns, N1 = 30

Area of cross-section, A1 = 3.6 × 10-3 m2

Magnetic field strength, B1 = 0.25 T

For moving coil meter M2

Resistance of wire, R2 = 14Ω

Number of turns, N2 = 42

Area of cross-section, A2 = 1.8 × 10-3 m2

The definition of a moving coil galvanometer's current sensitivity is

$$= \frac{30 \times 0 \cdot 25 \times 3 \cdot 6 \times 10^{-3}}{k} \quad \ldots (i)$$

***For M_2*,** Current sensitivity

$$= \frac{42 \times 0 \cdot 5 \times 1 \cdot 8 \times 10^{-3}}{k} \quad \ldots (ii)$$

Dividing *(ii)* by *(i)*

$$\frac{\text{Current sensitivity of } M_2}{\text{Current sensitivity of } M_1}$$

$$= \frac{42 \times 0 \cdot 5 \times 1 \cdot 8 \times 10^{-3}}{30 \times 0 \cdot 25 \times 3 \cdot 6 \times 10^{-3}} = 1 \cdot 4$$

Using ***Voltage sensitivity*** = NBA/*k*R

***For M_1*,** Voltage sensitivity

$$= \frac{30 \times 0 \cdot 25 \times 3 \cdot 6 \times 10^{-3}}{k \times 10} \quad \ldots (iii)$$

***For M_2*,** Voltage sensitivity

$$= \frac{42 \times 0 \cdot 5 \times 1 \cdot 8 \times 10^{-3}}{k \times 14} \quad \ldots (iv)$$

Dividing *(iv)* by *(iii)*, we get

4.11 In a chamber, a uniform magnetic field of 6.5 G (1 G = 10 –4 T) is maintained. An electron is shot into the field with a speed of 4.8 × 106 m s–1 normal to the field. Explain why the path of the electron is a circle. Determine the radius of the circular orbit. (e = 1.5 × 10–19 C, me = 9.1×10–31 kg)

Ans - Magnetic field strength, B = 6.5 G = 6.5 × 10-4T

Initial velocity of electron = 4.8 × 106 ms-1

The centripetal force required to maintain the circular route is provided by the magnetic force, quB, which acts perpendicular to the direction of motion.

Using $F = q\upsilon B\sin\theta$ and $F = \frac{m\upsilon^2}{r}$, we get

$$e\upsilon B\sin\theta = \frac{m\upsilon^2}{r} \quad \text{or} \quad r = \frac{m\upsilon}{Be} \qquad (\because \theta = 90°)$$

$$= \frac{(9\cdot1\times10^{-31})(4\cdot8\times10^{6})}{(6\cdot5\times10^{-4})(1\cdot6\times10^{-19})}$$

$$= 4\cdot2 \times 10^{-2} \text{ m or } r = 4\cdot2 \text{ cm.}$$

4.12 In Exercise 4.11 obtain the frequency of revolution of the electron in its circular orbit. Does the answer depend on the speed of the electron? Explain.

Ans - Magnetic field strength, B = 6.5 G = 6.5 × 10-4T

Initial velocity of electron = 4.8 × 106 ms-1

Electron speed has no effect on the frequency of its revolution.

Using $e\upsilon B = \frac{m\upsilon^2}{r}$, we get

$$eB = \frac{m\upsilon}{r} = \frac{m}{r} r\omega = m\omega = m\,(2\pi\,\nu)$$

i.e. $$\nu = \frac{eB}{2\pi m}$$

$$= \frac{(1\cdot6\times10^{-19})(6\cdot5\times10^{-4})}{2(3\cdot14)(9\cdot1\times10^{-31})}$$

$$= 18\cdot18 \times 10^{6} \text{ Hz} \simeq 18 \text{ MHz}$$

The answer does not depend upon speed of the electron because the relation $\nu = \frac{eB}{2\pi m}$ is independent of the speed of the electron.

4.13 (a) A circular coil of 30 turns and radius 8.0 cm carrying a current of 6.0 A is suspended vertically in a uniform horizontal magnetic field of magnitude 1.0 T. The field lines make an angle of 60°with the normal of the coil. Calculate the magnitude of the counter torque that must be applied to prevent the coil from turning.
(b) Would your answer change, if the circular coil in
(a) were replaced by a planar coil of some irregular shape that encloses the same area? (All other particulars are also unaltered.)

Ans - (a) The supplied coil is circular and suspended so that the field lines form a 60° angle with the coil normal. Similar amounts of torque are needed to stop the coil from rotating.

Using τ = NBIA sin 9, we get
τ= 30 X 1 x 6 x n (8 X 10-2)2 sin 60
= 180 x it (8 x 10-2)2 0.866
= 3.13 N m
The magnitude of the counter-torque is 3 .13 N m

(b) Answer will not change because torque does not depend upon the shape of the coil provided it encloses the same area.

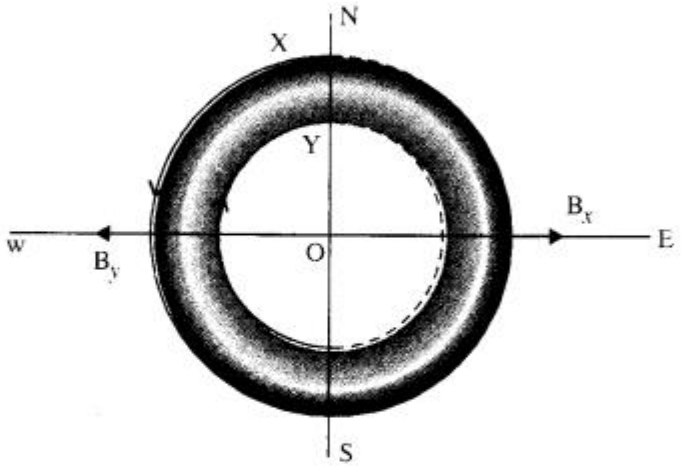
4.14 Two concentric circular coils X and Y of radii 16 cm and 10 cm, respectively, lie in the same vertical plane containing the north to south direction. Coil X has 20 turns and carries a current of 16 A; coil Y has 25 turns and carries a current of 18 A. The sense of the current in X is anticlockwise, and clockwise in Y, for an observer looking at the coils facing west. Give the magnitude and direction of the net magnetic field due to the coils at their centre.

Ans - North to south is the direction of the concentric coils. Let's decide the directions in a paper plane with all the comforts.

Here, we need to determine the overall magnetic field generated by the system, thus we'll first calculate the magnetic field due to each coil with its direction before adding them in accordance with the vector addition formula. We can forecast the direction of the induced magnetic field in both coils using the right-hand thumb rule.

Using $B = \frac{\mu_0 n I}{2a}$, we get

$$B_x = \frac{4\pi \times 10^{-7} \times 20 \times 16}{2 \times 16 \times 10^{-2}}$$



i.e. $B_x = 4\pi \times 10^{-4}$ T towards east.

For Coil Y

$$B_y = \frac{4\pi \times 10^{-7} \times 25 \times 18}{2 \times 10 \times 10^{-2}}$$

$= 9\pi \times 10^{-4}$ T, towards west

Net magnetic field $= B_y - B_x$

$= 9\pi \times 10^{-4} - 4\pi \times 10^{-4}$

$= 5\pi \times 10^{-4}$ T

$= 1{\cdot}6 \times 10^{-3}$ T towards west.

4.15 A magnetic field of 100 G (1 G = 10–4 T) is required which is uniform in a region of linear dimension about 10 cm and area of cross-section about 10–3 m2 . The maximum current-carrying capacity of a given coil of wire is 15 A and the number of turns per unit length that can be wound round a core is at most 1000 turns m–1. Suggest some appropriate design particulars of a solenoid for the required purpose. Assume the core is not ferromagnetic.

Ans - The Required Magnetic field B = 100 G = 100 × 10–4 = 10–2 T

Maximum Number of turns per unit length, n = 1000/m

Maximum Current flowing in the coil, I = 15 A

100 G of magnetic field must be applied across a 10 cm length. Therefore, the solenoid should be longer than 10 cm. Wire can carry up to 15 A of current, hence no more than that much should run through it. the present

$$B \approx \mu_0 nI \text{ or } nI = \frac{B}{\mu_0} = \frac{100 \times 10^{-4}}{4\pi \times 10^{-7}} = 7955 \approx 8000$$

4.16 For a circular coil of radius R and N turns carrying current I, the magnitude of the magnetic field at a point on its axis at a distance x from its centre is given by,

$$B = \frac{\mu_0 I R^2 N}{2(x^2 + R^2)^{3/2}}$$

(a) Show that this reduces to the familiar result for field at the centre of the coil.

(b) Consider two parallel co-axial circular coils of equal radius R, and number of turns N, carrying equal currents in the same direction, and separated by a distance R. Show that the field on the axis around the mid-point between the coils is uniform over a distance that is small as compared to R, and is given by, 0 0.72 NI B R μ = , approximately. [Such an arrangement to produce a nearly uniform magnetic field over a small region is known as Helmholtz coils.]

Ans -

(a) If the magnetic field at the centre of the coil is considered, then $x = 0$.

$$\therefore B = \frac{\mu_0 I R^2 N}{2R^3} = \frac{\mu_0 I N}{2R}$$

This is the familiar result for magnetic field at the centre of the coil.

(b) The south pole of the loop is where the current appears to flow clockwise, and the north pole is where the current appears to flow counterclockwise. The magnetic field runs from the south pole to the north pole.

$$B = \frac{\mu_0 N I R^2}{2\left[\left(\frac{R}{2}+d\right)^2 + R^2\right]^{\frac{3}{2}}} + \frac{\mu_0 N I R^2}{\left[\left(\frac{R}{2}-d\right)^2 + R^2\right]^{\frac{3}{2}}}$$

$$= \frac{\mu_0 N I R^2}{\left(\frac{5}{4}R^2\right)^{\frac{3}{2}}}\left[\frac{1}{\left(1+\frac{4d}{5R}\right)^{\frac{3}{2}}} + \frac{1}{\left(1-\frac{4d}{5R}\right)^{\frac{3}{2}}}\right]$$

4.17 A toroid has a core (non-ferromagnetic) of inner radius 25 cm and outer radius 26 cm, around which 3500 turns of a wire are wound. If the current in the wire is 11 A, what is the magnetic field
(a) outside the toroid,
(b) inside the core of the toroid, and
(c) in the empty space surrounded by the toroid.

Ans - There are 3500 total turns in the toroid.
(i) There is no magnetic field outside of the toroid.

$$(ii)\ B = \mu_0 n I = \frac{\mu_0 N I}{l}$$

$$l = 2\pi\left(\frac{r_1 + r_2}{2}\right) = 2\pi\left(\frac{0{\cdot}25 + 0{\cdot}26}{2}\right) = 0{\cdot}51\pi\,\text{m}$$

$$\therefore B = \frac{\mu_0 N I}{l} = \frac{4\pi \times 10^{-7} \times 3500 \times 11}{0{\cdot}51\,\pi} = 3{\cdot}02 \times 10^{-2}\ \text{T}$$

(*iii*) Zero.

4.18 Answer the following questions:
(a) A magnetic field that varies in magnitude from point to point but has a constant direction (east to west) is set up in a chamber. A charged particle enters the chamber and travels undeflected along a straight path with constant speed. What can you say about the initial velocity of the particle?
(b) A charged particle enters an environment of a strong and non-uniform magnetic field varying from point to point both in magnitude and direction, and comes out of it following a complicated trajectory. Would its final speed equal the initial speed if it suffered no collisions with the environment?
(c) An electron travelling west to east enters a chamber having a uniform electrostatic field in north to south direction. Specify the direction in which a uniform magnetic field should be set up to prevent the electron from deflecting from its straight line path.
Ans - (A) A charged particle will move undeflected if it moves parallel or antiparallel to the magnetic field since no magnetic force will act on it. Therefore, under the circumstances, either the charged particle enters from the east or the west.

(b) Because a magnetic force acts normally in the direction of speed, it can only modify the direction of a charged particle's motion, never its magnitude. Therefore, even though a charged particle's journey may be complex, its speed never changes.

(c) The electron will be redirected toward the north by the electrostatic field (towards the positive plate). If the magnetic field's force is directed southward, it won't be deflected. The magnetic Lorentz force expression, F m=e(v B), states that the magnetic field B should be applied vertically and downwardly because the electron's velocity, y, is from west to east. The Fleming left-hand rule can be used to determine the magnetic field's direction.

4.19 An electron emitted by a heated cathode and accelerated through a potential difference of 2.0 kV, enters a region with uniform magnetic field of 0.15 T. Determine the trajectory of the electron if the field
(a) is transverse to its initial velocity,
(b) makes an angle of 30° with the initial velocity.

Ans - A 2.0 kV potential difference will accelerate an electron by 2000 eV in terms of kinetic energy.

$$\frac{1}{2} m v^2 = eV$$

$$\text{or } v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times 1{\cdot}6 \times 10^{-19} \times 2 \times 10^3}{9{\cdot}1 \times 10^{-31}}}$$

$$= 2.67 \times 10^7 \text{ m s}^{-1}$$

(*a*) Force acting on electron due to transverse magnetic field,

$$\left|\vec{F}\right| = \left|-e\left(\vec{v} \times \vec{B}\right)\right| = e\ v\ B.$$ This force acts perpendicular to both $\vec{v}$ and $\vec{B}$ and hence electron moves in a circular path of radius r. The magnetic force $e\,v\,B$ provides the necessary centripetal force to the electron to move in the circular path. Therefore, $e\,v\,B = \frac{mv^2}{r}$

$$\text{or } r = \frac{mv}{eB} = \frac{9{\cdot}1 \times 10^{-31} \times 2{\cdot}67 \times 10^7}{1{\cdot}6 \times 10^{19} \times 0{\cdot}15} = 10^{-3} \text{m} = 1 \text{mm}$$

(b)The electron's trajectory turns helical when the magnetic field and beginning velocity are at an angle of 30°. The helical path's radius is

the velocity of electron parallel to $\vec{B}$ and $v \sin\theta$ is

the velocity of electron perpendicular to $\vec{B}$. The electron moves in a straight line due to $v \cos\theta$ and in a circular path due to $v \sin\theta$. Hence, the resultant path of electron is helical path of radius r. Now

$$e\ (v \sin\theta)\ B = \frac{mv(\sin\theta)^2}{r}$$

$$\text{or } r = \frac{m\,v \sin\theta}{e\,B} = \frac{9{\cdot}1 \times 10^{-19} \times 2{\cdot}67 \times 10^{-7} \times \sin 30°}{1{\cdot}6 \times 10^{-19} \times 0{\cdot}15}$$

$$= 0{\cdot}5 \times 10^{-3} \text{m} = 0{\cdot}5 \text{ mm}$$

4.20 A magnetic field set up using Helmholtz coils (described in Exercise 4.16) is uniform in a small region and has a magnitude of 0.75 T. In the same region, a uniform electrostatic field is maintained in a direction normal to the common axis of the coils. A narrow beam of (single species) charged particles all accelerated through 15 kV enters this region in a direction perpendicular to both the axis of the coils and the electrostatic field. If the beam remains undeflected when the electrostatic field is 9.0 × 10–5 V m–1, make a simple guess as to what the beam contains. Why is the answer not unique?

Ans - The magnetic and electric forces are perpendicular to one another, and a narrow beam of charged particles stays unaffected by them. Magnetic force therefore counterbalances electric force. qE = quB Charged particle motion speed

Using $eE = Bev$, we get

$$v = \frac{E}{B} = \frac{9 \times 10^5}{0 \cdot 75}$$
$$= 1 \cdot 2 \times 10^6 \text{ m s}^{-1}$$

Also $\frac{1}{2}mv^2 = eV$

or $$\frac{e}{m} = \frac{1}{2}\frac{v^2}{V} = \frac{(1 \cdot 2 \times 10^6)^2}{2 \times 15 \times 10^3}$$
$$= 4 \cdot 8 \times 10^7 \text{ C kg}^{-1}$$

4.21 A straight horizontal conducting rod of length 0.45 m and mass 60 g is suspended by two vertical wires at its ends. A current of 5.0 A is set up in the rod through the wires.
(a) What magnetic field should be set up normal to the conductor in order that the tension in the wires is zero?
(b) What will be the total tension in the wires if the direction of current is reversed keeping the magnetic field same as before? (Ignore the mass of the wires.) g = 9.8 m s–2 .

Ans - (a) Tension in the strings and magnetic force |B| balance the weight of wire. 2 T + |B| = mg
The tension in the wire is zero if the force on the current-carrying wire due to current is equal and opposite to the weight of the wire. This is, BIl= mg

i.e. $$B = \frac{mg}{Il} = \frac{(60 \times 10^{-3})9 \cdot 8}{5 \times 0 \cdot 45}$$
$$= 0 \cdot 26 \text{ T.}$$

(b) In case the current is reversed, the tension is equal to the force acting on the wire due to the magnetic field plus the weight of the wire. This is,
T = BIL + mg

= 0.26 x 5 x 0.45 + 60 x 10-3 x 9.8
= 1.18 N.

4.22 The wires which connect the battery of an automobile to its starting motor carry a current of 300 A (for a short time). What is the force per unit length between the wires if they are 70 cm long and 1.5 cm apart? Is the force attractive or repulsive?

Ans - Two cables carrying a 300 A current in the opposite direction link an automobile's battery to the starting motor. The force between them is hence repellent. per unit of length, force

$$\text{Using, } F = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r}$$

$$= \frac{10^{-7} \times 2 \times 300 \times 300}{1{\cdot}5 \times 10^{-2}}$$

$$= 1{\cdot}2 \text{ N m}^{-1}$$

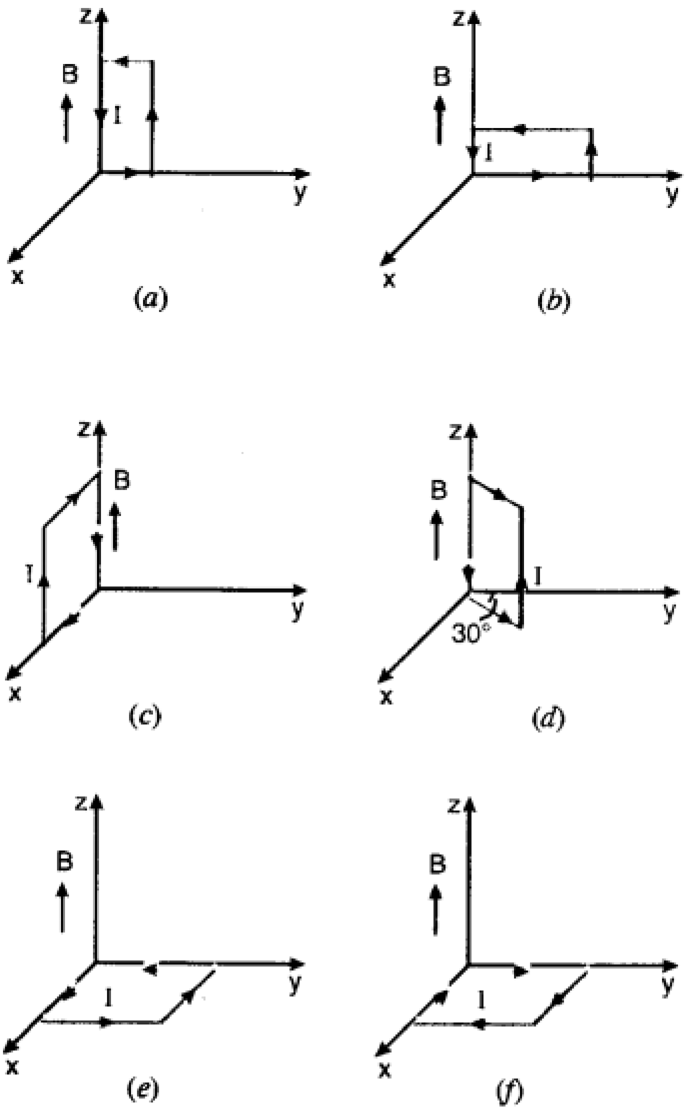
4.23 A uniform magnetic field of 1.5 T exists in a cylindrical region of radius10.0 cm, its direction parallel to the axis along east to west. A wire carrying current of 7.0 A in the north to south direction passes through this region. What is the magnitude and direction of the force on the wire if,
(a) the wire intersects the axis,
(b) the wire is turned from N-S to northeast-northwest direction,
(c) the wire in the N-S direction is lowered from the axis by a distance of 6.0 cm?

Ans - East to west is the direction of the magnetic field, which is located in a 10-cm-diameter cylinder.
(A) An axis is intersected by a wire conveying current. F = |B| = IB (2r) = 7 1.5 2 1 10-2 F = 2.1 N for force on wire. Downwards

(b) The force is maintained at 2.1 N by rotating the wire by an angle of 45° in both the NE and NW directions. Downwards

(c) The wire is now lowered by 6.0 cm from the axis.

4.24 A uniform magnetic field of 3000 G is established along the positive z-direction. A rectangular loop of sides 10 cm and 5 cm carries a current of 12 A. What is the torque on the loop in the different cases shown in Fig. 4.28? What is the force on each case? Which case corresponds to stable equilibrium?



Ans - let us discuss each case individually

$\vec{\tau} = I\vec{A} \times \vec{B}$ and $\vec{F} = I(\vec{l} \times \vec{B})$

(*a*) $I\vec{A} = (12 \times 50 \times 10^{-4})\hat{i} = (0{\cdot}06\,\hat{i})Am^2$,

$\vec{B} = 3000G = (3000 \times 10^{-4}T)\hat{k} = (0{\cdot}3T)\hat{k}$

$\therefore \vec{\tau} = (0{\cdot}06 \times 0{\cdot}3)\ (\hat{i} \times \hat{k}) = 1{\cdot}8 \times 10^{-2}\ Nm(-\hat{j})$

$\therefore \tau = 1{\cdot}8 \times 10^{-2}$ Nm along negative *y*-axis.

Force = 0

(*b*) Same as (*a*)

(*c*) $I\vec{A} = (12 \times 50 \times 10^{-4})(-\hat{j})$

$= (-0.06\,\hat{j})\ Am^2, \vec{B} = (0{\cdot}3T)\hat{k}$

$\because \vec{\tau} = (0{\cdot}06 \times 0{\cdot}3)\ (-\hat{j} \times \hat{k}) = (1{\cdot}8 \times 10^{-2}\ Nm)\ (-\hat{i})$

$\because \tau = 1{\cdot}8 \times 10^{-2}$ Nm along negative *x*–axis. F = 0

(*d*) Same as (*c*) but direction of torque is 60° anticlockwise with negative *x* axis or 240° with positive *x*-axis.

(*e*) $I\vec{A} = (0{\cdot}06\,\hat{k})Am^2$ and $\vec{B} = (0{\cdot}3T)\hat{k}$. Therefore,

$\vec{\tau} = 0$ and F = 0.

The loop is in stable equilibrium as $I\vec{A}(=\vec{m})$ is parallel to $\vec{B}$.

(*f*) $I\vec{A} = (-0{\cdot}06\,\hat{k})Am^2$, $\vec{B} = (0{\cdot}3T)\hat{k}$. Therefore,

$\vec{\tau} = 0$ and F = 0.

Loop is in unstable equilibrium as $(I\vec{A} = \vec{m})$ is anti-parallel to $\vec{B}$.

4.25 A circular coil of 20 turns and radius 10 cm is placed in a uniform magnetic field of 0.10 T normal to the plane of the coil. If the current in the coil is 5.0 A, what is the

(a) total torque on the coil,

(b) total force on the coil,
(c) average force on each electron in the coil due to the magnetic field? (The coil is made of copper wire of cross-sectional area 10–5 m2 , and the free electron density in copper is given to be about 1029 m–3.)

Ans - The coil's plane is parallel to the magnetic field, which results in the minimal torque situation.

(*a*) $\tau = NIAB \sin \theta$

$= NIAB \sin 0 = 0$

(*b*) Total force is zero.

(*c*) Using $F = Bq\upsilon$, we get $F = Be\upsilon_d$

$$= Be\frac{I}{neA} = \frac{BI}{nA}$$

$$= \frac{0{\cdot}1 \times 5}{10^{29} \times 10^{-5}} = 5 \times 10^{-25} \text{ N}$$

4.26 A solenoid 60 cm long and of radius 4.0 cm has 3 layers of windings of 300 turns each. A 2.0 cm long wire of mass 2.5 g lies inside the solenoid (near its centre) normal to its axis; both the wire and the axis of the solenoid are in the horizontal plane. The wire is connected through two leads parallel to the axis of the solenoid to an external battery which supplies a current of 6.0 A in the wire. What value of current (with appropriate sense of circulation) in the windings of the solenoid can support the weight of the wire? g = 9.8 m s–2 .

Ans - A current of 7 = 6.0 A is flowing through a wire that is suspended inside the solenoid. To allow the magnetic force to balance the wire's weight

Step 1. Magnetic field of a solenoid is given by,

$$B = \mu_0 \frac{N}{l} I = (4\pi \times 10^{-7})\frac{(300 \times 3)}{(2 \times 10^{-2})} \times I$$

$= (6\pi \times 10^{-4})I$ tesla

Step 2. Force on wire,

$F = BI'l = (6\pi \times 10^{-4})I \times 6(2 \times 10^{-2})$

$= 2{\cdot}26 \times 10^{-4}$ I newton.

Step 3. As per given condition, $F = mg$

i.e. $(2{\cdot}26 \times 10^{-4})I$

$= (2{\cdot}5 \times 10^{-3}) \times 9{\cdot}8$ or $I = 108$ A.

4.27 A galvanometer coil has a resistance of 12 Ω and the metre shows full scale deflection for a current of 3 mA. How will you convert the metre into a voltmeter of range 0 to 18 V?

Ans - G = 12 is the galvanometer resistance. By connecting a high series resistance R to the galvanometer, a voltmeter with a range of 0 to V (here, V = 18 V) can be created.

Galvanometer resistance, G = 12 Ω
The galvanometer can be converted into the voltmeter of range 0 to V (here V = 18 V) by connecting a high series resistance R given by

$$R = \frac{V}{I} - G = \frac{18}{3\times10^{-3}} - 12$$

$$= 6000 - 12 = 5988\ \Omega.$$

4.28 A galvanometer coil has a resistance of 15 Ω and the metre shows full scale deflection for a current of 4 mA. How will you convert the metre into an ammeter of range 0 to 6 A?

Ans - The amount of shunt needed to transform a galvanometer into an ammeter with the desired range can be estimated.

Here, galvanometer resistance

$G = 15\ \Omega$, $I = 6$ A

and $I_g = 4$ mA $= 4 \times 10^{-3}$ A

To convert a galvanometer, a very small resistance S called the shunt resistance is to be connected in parallel with the galvanometer. The value of S is given by

$$S = \frac{I_g.G}{I - I_g} = \frac{4\times10^{-3}\times15}{6-4\times10^{-3}} = \frac{60\times10^{-3}}{6-0{\cdot}004}$$

$$= \frac{60\times10^{-3}}{5{\cdot}996} = 0{\cdot}001\ \Omega$$

$$= 0{\cdot}001 \times 10^3\ m\Omega = 10\ m\Omega.$$