4 Magnetic Effect of Current

Facts that Matter

- In 1820 Oersted observed that when a magnetic compass is placed near to a current carrying conductor, it deflects which indicates that a current carrying conductor produces a magnetic field in the space surrounding it. He also discovered that when a conductor carrying in the direction south to north is placed over a magnetic compass, the needle of the compass deflects towards west. It is also known as 'SNOW' rule.
- The S.I. unit of magnetic field intensity or magnetic induction flux density is tesla or Wbm^{-2}.

• Biot-Savart law

The law states that the magnetic field (dB) due to a small current element of length '*dl*' carrying current *I* is directly proportional to the strength of current, perpendicular length of the conductor and inversely proportional to the square of the distance from the current element to the point where magnetic field is determined as shown in Fig. 4.1.

$$dB \propto I$$
$$\propto dl \sin\theta$$
$$\propto \frac{1}{r^2}$$

or $$dB \propto \frac{I\, dl \sin\theta}{r^2}$$

or $$dB = \frac{\mu_0}{4\pi}\frac{Idl \sin\theta}{r^2}$$

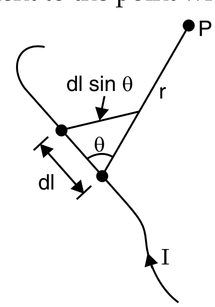

Fig. 4.1

where θ is the angle between line joining the point and current element and μ_0 is magnetic permeability of free space.

- In vector form,

$$\vec{dB} = \frac{\mu_0}{4\pi}\frac{I\vec{dl}\times\vec{r}}{|\vec{r}|^3}$$

- Magnetic field is a vector quantity and its direction can be determined by any one of the rule

(*i*) **Right hand thumb rule.** If a current carrying conductor is hold in right hand keeping the thumb in the direction of current, then curl of the fingers will represent the magnetic field lines and tangent drawn at a point on magnetic field line indicates the direction of magnetic field (Fig. 4.2).

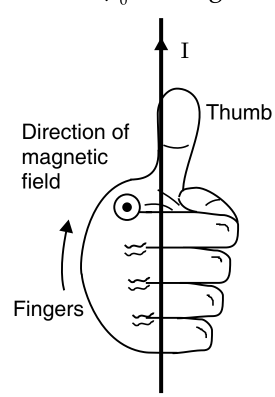

Fig. 4.2

(*ii*) **Right hand screw rule.** If we advance a screw by right hand in the direction of current, the grip of fingers rotating will represent the magnetic field lines and the tangent on field indicates the direction of field (Fig. 4.3).

(*iii*) **Right hand palm rule.** When we stretch the palm of our right hand keeping the thumb perpendicular to the fingers and if current is in direction of thumb fingers point towards the point where the direction of magnetic field is to be determined (Fig. 4.3).

- The direction field inward to the plane is represented by '*X*' and outward of the plane is represented by '•'.

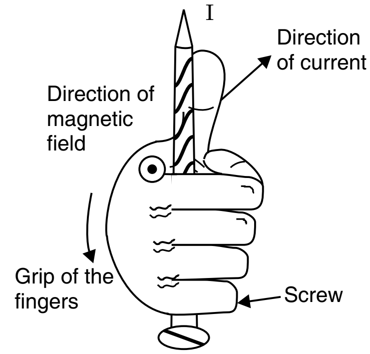

Fig. 4.3

• Magnetic field due to circular loop at its centre

Let there be a circular loop of radius *R* carrying current *I*. The magnetic field at the centre of the loop due to small element of length '*dl*',

$$dB = \frac{\mu_0 I dl \sin 90°}{4\pi R^2}$$

(applying Biot-Savart law)

The net magnetic field at the centre,

$$B = \frac{\mu_0 I}{4\pi R^2} \int dl$$

$$= \frac{\mu_0 I}{4\pi R^2}(2\pi R)$$

or
$$B = \frac{\mu_0 I}{2\pi R}$$

The SI unit of magnetic field is tesla.

- For clockwise current the direction of magnetic field will be inward the plane of loop and for anticlockwise current direction of field will be outward the plane.

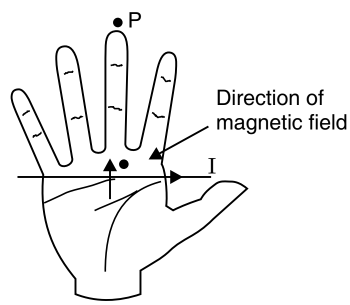

Fig. 4.4

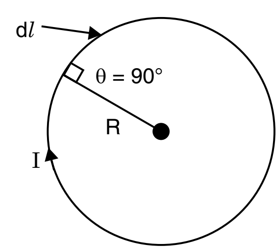

Fig. 4.5

• Magnetic field due to circular loop at axial point

Let there be a circular loop of radius *R*, carrying current *I* and an axial point *P* at the distance of *x* from its centre where magnetic field is to be determined. (Fig. 4.6). The magnetic field due to a small element of length '*dl*' at point *P*,

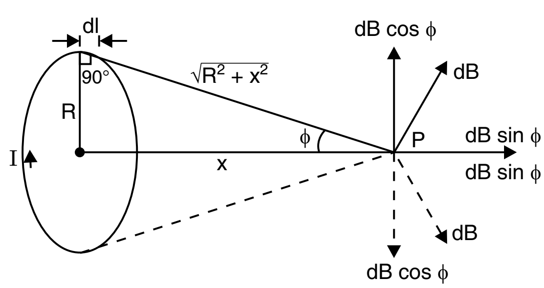

Fig. 4.6

$$dB = \frac{\mu_0 Idl \sin 90^\circ}{4\pi (R^2 + x^2)}$$

$$= \frac{\mu_0 Idl}{4\pi(R^2 + x^2)}$$

dB can be resolved in two rectangular components. The components $dB \cos \phi$ due counter part of the loop cancel each other, hence field due to 'dl' at P

$$= dB \sin \phi$$

$$= \frac{\mu_0 I\, dl \sin \phi}{4\pi (R^2 + x^2)}$$

$$= \frac{\mu_0 I\, dl\, R}{4\pi (R^2 + x^2)\sqrt{R^2 + x^2}} \qquad \left(\because \ \sin \phi = \frac{R}{\sqrt{R^2 + x^2}}\right)$$

$$= \frac{\mu_0 IR\, dl}{4\pi (R^2 + x^2)^{3/2}}$$

The net magnetic field at point P,

$$B = \frac{\mu_0 IR}{4\pi (R^2 + x^2)^{3/2}} \int dl$$

$$= \frac{\mu_0 IR\,(2\pi R)}{4\pi (R^2 + x^2)^{3/2}}$$

or $$B = \frac{\mu_0 IR^2}{2\,(R^2 + x^2)^{3/2}}$$

- The variation of magnetic field due to circular loop with the distance from its centre can be shown as given in Fig. 4.7.

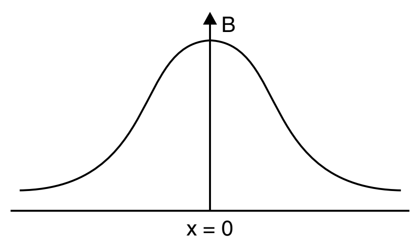

Fig. 4.7

- **Ampere's circuital law**

According to Ampere's circuital law, the line integral of the magnetic field $\vec{B}$ around any closed circuit is equal to μ_0 (permeability) times the total current I passing through the closed circuit or path

$$\therefore \qquad \oint \vec{B} \cdot \vec{dl} = \mu_0 I$$

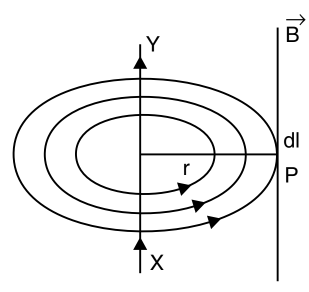

Fig. 4.8

Proof: Let us assume a straight conductor XY carrying current I from X to Y. The magnetic field is produced around the conductor in concentric rings.

The magnetic field at the point P at a distance r from the conductor is

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

The direction of $\vec{B}$ at every point is along the tangent to the circle.

Let us consider a small element $\vec{dl}$ of the circle of radius r at P. Then the line integral of $\vec{B}$ around the complete path of radius r is

$$\oint \vec{B}\cdot\vec{dl} = \oint B\,dl\cos\theta$$

Since $\vec{B}$ and $\vec{dl}$ are in the same direction then

$$\theta = 0°$$

$$\therefore \quad \cos\theta = \cos 0° = 1$$

$$\therefore \quad \oint \vec{B}\cdot\vec{dl} = \oint B\,dl = \oint \frac{\mu_0}{2\pi}\frac{I}{r}dl$$

$$= \frac{\mu_0}{2\pi}\frac{I}{r}\oint dl = \frac{\mu_0}{2\pi}\frac{I}{r}\cdot 2\pi r$$

Thus, $$\oint \vec{B}\cdot\vec{dl} = \mu_0 I \text{ (Ampere's Circuital Law)}$$

- **Magnetic field due to an infinitely long straight current carrying conductor**

Let there be an infinitely long straight conductor carrying current I and a point P at the distance (shortest) R from the conductor (Fig. 4.8) where magnetic field is to be determined. Applying the Ampere's circuital law,

$$\oint B dl = \mu_0(I)$$

$$B(2\pi R) = \mu_0 I$$

or $$B = \frac{\mu_0 I}{2\pi R}$$

- **Magnetic field due to a hollow cylindrical conductor**

Let there be a hollow cylindrical conductor of radius R carrying current I and a point P at the distance of x from the axis of the cylinder from magnetic field where magnetic field is to be determined as shown in Fig. 4.9. Applying Ampere's circuital law for

(*i*) $x < R$, current threading the *wp* = 0

$$\therefore \quad \oint B dl = \mu_0(0)$$

$$B(2\pi x) = 0$$

or $$B = 0$$

(*ii*) For $x = R$,

$$\oint B dl = \mu_0(I)$$

$$B(2\pi R) = \mu_0 I$$

or $$B = \frac{\mu_0 I}{2\pi R}$$

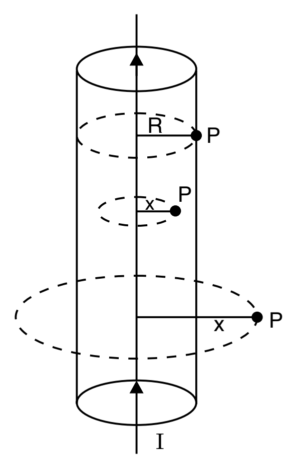

Fig. 4.9

(*iii*) For $x > R$

$$\oint B dl = \mu_0 (I)$$

$$B(2\pi x) = \mu_0 I$$

or $$B = \frac{\mu_0 I}{2\pi x}$$

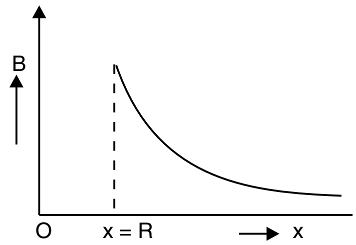

Fig. 4.10

- The variation of magnetic field due to hollow a cylindrical conductor with the distance from its axis is shown in Fig. 4.10.

- **Magnetic field due to a solid cylindrical conductor**

Let there be a solid cylindrical conductor of radius R carrying current I and a point P at the distance of x from its axis where magnetic field is to be determined as shown in Fig. 4.11.

Applying Ampere's circuital law

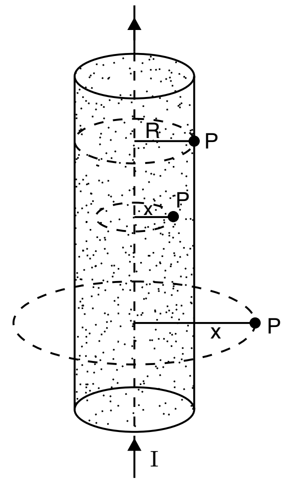

Fig. 4.11

(*i*) for $x < R$, current threading the loop $= \frac{I}{(\pi R^2)}(\pi x^2)$

$$= \frac{Ix^2}{R^2}$$

$\therefore$ $$\oint B dl = \mu_0 \left(\frac{Ix^2}{R^2}\right)$$

or $$B\ (2\pi x) = \frac{\mu_0 I x^2}{R^2}$$

or $$B = \frac{\mu_0 I(x)}{2\pi R^2}$$

(*ii*) For $x = R$

$$\oint B dl = \mu_0 (I)$$

or $$B(2\pi R) = \mu_0\ (I)$$

or $$B = \frac{\mu_0 I}{2\pi R}$$

(*iii*) For $x > R$

$$\oint B dl = \mu_0 (I)$$

or $$B(2\pi x) = \mu_0 I$$

or $$B = \frac{\mu_0 I}{2\pi x}$$

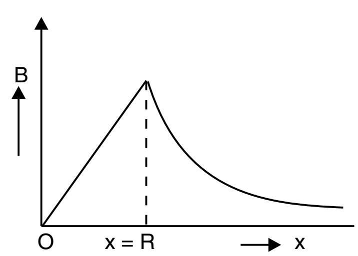

Fig. 4.12

- The variation of magnetic field due to a solid cylindrical conductor with the distance measured from its axis is shown in Fig. 4.12.

- **Magnetic field due to a solenoid (straight)**

Let there be a straight solenoid of turns N and infinitely large length L carrying current I as shown in Fig. 4.13.

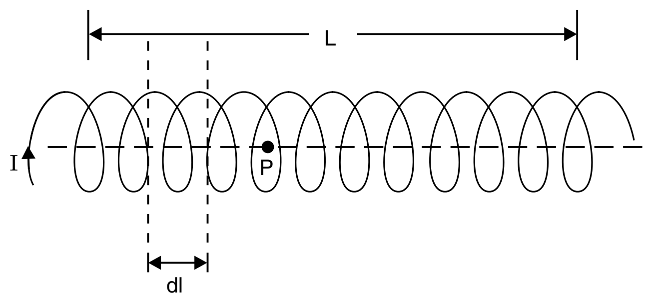

Fig. 4.13

There is a point P inside the solenoid at its axis where magnetic field is to be determined. The magnetic field due to small elementary length dl, according to Ampere' circuital law,

$$\oint Bdl = N(\mu_0)I$$

or $$B(L) = N\mu_0 I$$

or $$B = \left(\frac{N}{L}\right)\mu_0 I$$

or $$B = n\mu_0 I$$

where n is the number of turns per unit length.

- The magnetic field due to finite length solenoid at point P as shown in Fig. 4.14 can also be given as

$$B = \frac{N\mu_0 I}{2L}[\sin\alpha + \sin\beta]$$

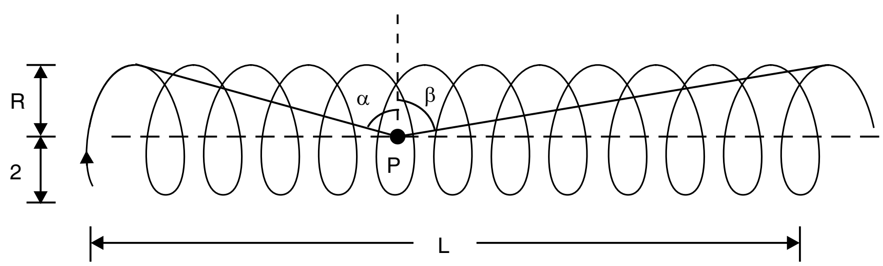

Fig. 4.14

For infinite length solenoid, $\alpha = \beta = 90°$

$\therefore$ $$B = \frac{N\mu_0 I}{2L}[1+1]$$

$$= \frac{N}{L}\mu_0 I = n\mu_0 I$$

- If the solenoid is of infinite length and the point P is near one end, $\alpha = 0$, $\beta = 90°$ and $B = \frac{N\mu_0 I}{2L}[0+1] = \frac{1}{2}n\mu_0 I$
- If the solenoid is of finite length and point is on the perpendicular bisector of its axis,

$$\alpha = \beta, \text{ and}$$

$$B = \frac{N\mu_0 I\,(2\sin\alpha)}{2L}$$

$$= \frac{N\,\mu_0 I\,L}{L\sqrt{L^2 + 4R^2}}$$

- If the solenoid is of finite length and the point is on its axis near one end, β = 0 and

$$B = \frac{N\mu_0 I}{2L}\,.\sin\alpha$$

$$= \frac{N\mu_0 I}{2L}\cdot\frac{L}{\sqrt{L^2 + R^2}}$$

- The variation of magnetic field with distance along the axis of a solenoid shown in Fig. 4.15 is shown in Fig. 4.15.

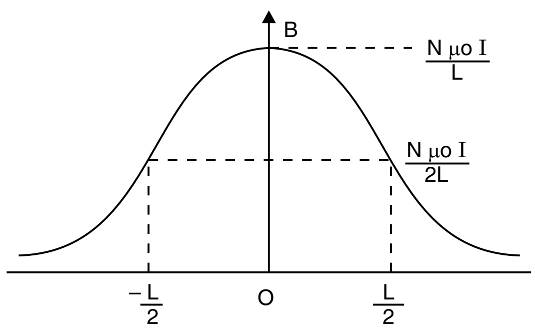

Fig. 4.15

• Magnetic field due to a torodial solenoid

Let there be a torodial solenoid of radius R, number of turns N and carrying current I. There be a point on its axis within the core where magnetic field is to be determined as shown in Fig. 4.16 Applying Ampere's circuital law,

$$\oint B\,dl = N\mu_0(I)$$

$$B(2\pi R) = N\mu_0(I)$$

or

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

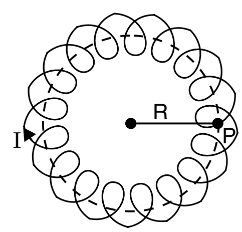

Fig. 4.16

- There is no magnetic field outside the solenoid and inside the toroid.

• Force on a current carrying conductor in a magnetic field

Through experiments Ampere established that when a current element $\vec{dl}$ is placed in a magnetic field $\vec{B}$, it experiences a force

$$\vec{dF} = I\,\vec{dl} \times \vec{B}$$

and the magnitude force

$$dF = Idl\;B\;\sin\theta$$

or

$$F = IBl\;\sin\theta$$

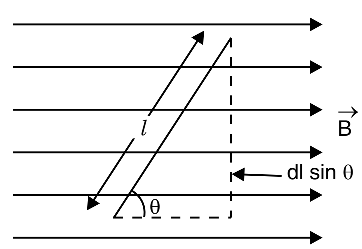

Fig. 4.17

- The direction of force is determined with the help of Fleming's left hand Rule according to which when we stretch the forefinger, central finger and thumb of left hand mutually perpendicular keeping forefinger in the direction of field, central finger in the direction of current, then force will be in the direction of thumb as shown in Fig. 4.18.

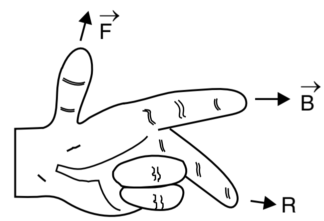

Fig. 4.18

• Force between two parallel conductors

Let there be two parallel conductors at separation d carrying current I_1 and I_2 respectively as shown in Fig. 4.19.

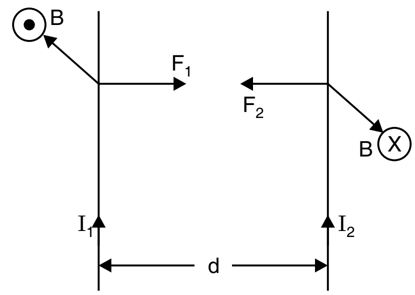

Fig. 4.19

Magnetic field due first conductor at second conductor,

$$B_1 = \frac{\mu_0 I_1}{2\pi d}$$

and force on second conductor in the magnetic field of first,

$$F_2 = I_2 B_1 l$$

$$= I_2 \frac{\mu_0 I_1}{2\pi d} l$$

or $$\frac{F_2}{l} = \frac{\mu_0 I I_2}{2\pi d} \quad ...(i)$$

Similarly the force on the first conductor in the magnetic field of second conductor,

$$F_1 = I_1 B_2 l$$

$$= I_1 \frac{\mu_0 I_2}{2\pi d} . l$$

$$\frac{F_1}{l} = \frac{\mu_0 I_1 I_2}{2\pi d} \quad ...(ii)$$

From Eqs. (i) and (ii), $\frac{F_1}{l} = \frac{F_2}{l} = \frac{F}{l}$ (say)

$\Rightarrow$ $$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi d}.$$

If $I_1 = I_2 = 1$ ampere and $d = 1$ m

then $$\frac{F}{l} = \frac{\mu_0}{2\pi} = \frac{4\pi \times 10^{-7}}{2\pi} = 2 \times 10^{-7} \text{ Nm}^{-1}$$

Hence one ampere is the current following through two parallel wires at the separation of 1 m which can produce a force of 2×10^{-7} N per unit length.

- The force between two parallel wires is of attraction if current is on same direction.
- The force between two parallel wire is of repulsion if current is in opposite direction.
- Force on a current loop in uniform magnetic field is always zero irrespective of its shape.

• Torque on a current loop in magnetic field

Let a current loop $ABCD$ carrying current I is placed in uniform magnetic field of strength B as shown in Fig. 4.20. The force on AB side of one loop.

$$F_{AD} = IBl \sin 90°$$
$$= IBl$$

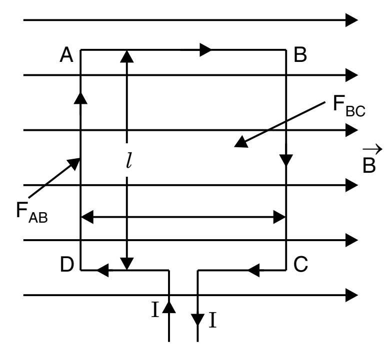

Fig. 4.20

Force on side AB,
$$F_{AB} = IBb \sin 0° = 0$$
Force on side BC,
$$F_{BC} = IBl \sin 90°$$
$$= IBl$$
$$F_{CD} = IBb \sin 0°$$
$$= 0$$
Due to pair of forces F_{AD} and F_{BC} being equal and opposite a torque acts on the loop.

$\therefore$ Torque = Force × ⊥ distance
$$= IBl \times b$$
$$= IBA$$
If α be the angle between the magnetic field and plane of the loop, then
$$\tau = IBl\, b \sin \alpha$$
$$= IBA \sin \alpha$$
If N be the number of turns in the loop,
$$\tau = N1BA \sin \alpha.$$

- **Moving Coil Galvanometer**

It is a device used to detect the electric current in the circuit. It is based upon the principle that when a current carrying coil is placed in a magnetic field, it experiences a torque. A galvanometer consists of a coil placed in radial magnetic field between the poles of a horseshoe magnet and pivoted on two springs S_1 and S_2. The coil is wound on a soft iron core and a pointer is attached to the coil as shown in Fig. 4.21. When current is passed through the coil it experiences a torque
$$\tau = N1AB \sin \alpha$$
and rotates in its plane. The pointer attached to the coil also rotates and the deflection of the pointer on the scale detects the current in the coil.

For maximum torque $\alpha = 90°$

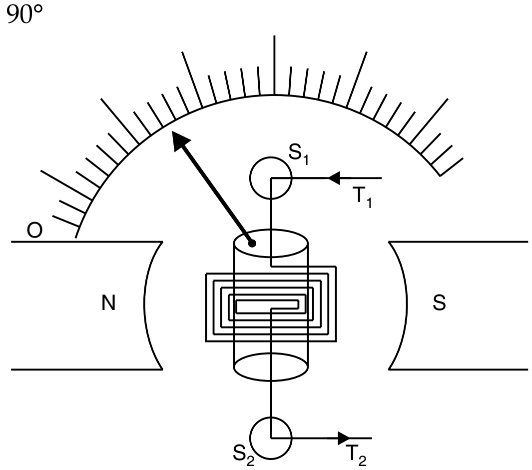

Fig. 4.21

$\therefore \qquad \tau = N1AB$

coil also experiences a restoring torque of the springs S_1 and S_2,

$$= C\theta$$

where C = coupling constant and θ is the deflection.

In equilibrium

$$NIAB = C\theta$$

or $$I = \frac{C}{NAB} . \theta$$

or $$R \propto \theta$$

- Current sensitivity of the galvanometer is the deflection per unit current *i.e.,*

$$\frac{\theta}{I} = \frac{NAB}{C}$$

- Voltage sensitivity is the deflection per unit volt *i.e.,*

$$\frac{\theta}{V} = \frac{\theta}{IR}$$

or $$\text{Voltage sensitivity} = \frac{\text{current sensitivity}}{\text{Resistance}}$$

- The galvanometer can be converted into ammeter by connecting a low resistance wire in its parallel (shunt). Let an ammeter consists of a galvanometer of resistance R_g and a shunt resistance R_s. The current to be measured and will distribute as I_g and $I - F_g$ through galvanometer and shunt wire respectively.

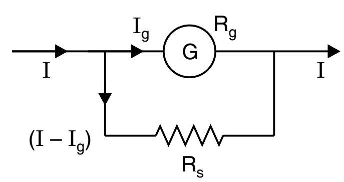

Fig. 4.22

$\therefore$ R_g and R_s are in parallel.

$$\therefore \qquad I_g R_g = (I - I_g)\ R_s$$

or resistance required to convert a galvanometer into ammeter,

$$R_S = I_g R_g / (I - I_g)$$

- The resistance of ammeter,

$$R_A = \frac{R_g \ . R_s}{(R_g + R_s)}$$

- The galvanometer can be converted into voltmeter by connecting a large resistance in its series. Let a voltmeter consists of a galvanometer of resistance R_g and large resistance in its series R_s. If current is passed through it, then potential difference across the element with which is connected,

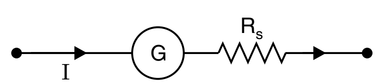

Fig. 4.23

$$V = I\ (R_g + R_s)$$

The resistance required to convert a galvanometer into voltmeter

$$R_s = \frac{V}{I} - R_g .$$

- The resistance of voltmeter,

$$R_V = R_g + R_s.$$

- The voltmeter is connected in parallel to the element across which a potential difference is to be measured.

- The ideal voltmeter has infinite resistance.
- The ammeter is connected in the series of the circuit.
- The ideal ammeter has zero resistance.
- The lower range ammeter has larger resistance.
- The lower range voltmeter has smaller resistance.

• Force on a moving charge particle in magnetic field

$\because \qquad F = IBl \sin\theta$

where, $\qquad I = \frac{q}{t}$ and $l = v.t$

$\therefore \qquad F = \frac{q}{t} Bv \, . \, t \sin\theta$

or $\qquad F = qBv \sin\theta$

This is the force on a charge particle q moving with velocity in magnetic field of strength B making an angle θ with direction of field.

Also, $\qquad \vec{F} = q\vec{v} \times \vec{B}$

$\therefore$ direction of this force will be perpendicular to the plane containing $\vec{v}$ and $\vec{B}$.

- If a charge particle q enters the perpendicular magnetic field of strength B moving with velocity v as shown in Fig. 4.24, then the force on q,

$$F = qvB \sin\theta$$

and according to Fleming's left hand rule or right hand screw rule the direction of F changes the direction of v as shown in Fig. 4.22 at point $ABCD$. Hence the charge particle follows the circular path. The direction of force remains perpendicular to $\vec{v}$ as well as $\vec{B}$.

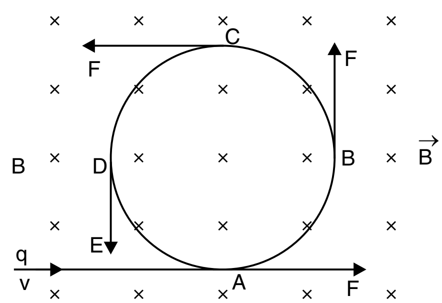

Fig. 4.24

- If charge particle moves along the direction of field, then force on it is zero.
- If charge particle makes an angle θ ($\neq 90° \neq 0°$) between $\vec{v}$ and $\vec{B}$, then it follows the helical path shown in Fig. 4.25.

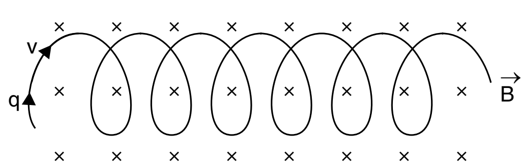

Fig. 4.25

- If charge particle is subjected to magnetic field as well as electric field then net force on the charge particle known as Lorntz force, is given by

$$\vec{F} = q\,[\vec{E} + \vec{v} \times \vec{B}]$$

- **Cyclotron**

The cyclotron is a device used to accelerate positively charged particle to high energies. Such charged particles are required to carry out nuclear reactions.

Principle

It works on the fact that

(*i*) when a charged particle moves at right angle to a uniform magnetic field it describes a circular path and

(*ii*) if the charged particle simultaneously and repeatedly crosses an electric field while moving in the direction of the electric field, it gets accelerated to a sufficiently high energy. Such an electric field is called an oscillating electric field.

Construction

The cyclotron consists of two D shaped hollow metallic semi-cylindrical chambers D_1 and D_2 called the dees, *enclosed in an evacuated steel box*. The dees are kept horizontally with a small gap separating them. An oscillator which produces an alternating potential difference of the order of 10^3 *volts* and frequency of the order of *mega cycles/sec* is applied across the dees. A strong magnetic field produced by a strong electromagnet acts perpendicular to the plane of the dees. A sources S of ions or positively charged particles is kept in the gap between the dees.

Theory of Working

Let m and q be the mass and charge of the ion or the particle to be accelerated. Let D_2 be negative and D_1 be positive when source(s) produces the particle.

The particle, therefore, gets attracted towards D_2, the electric field becomes zero. It is because the electric field inside a charged conductor is always zero. Thus, inside D_2, it moves with constant speed v at right angles to the magnetic field acting downward. As a result, the particle takes a semi-circular path inside D_2. Let r be the radius of the semi-circular path. Then

$$\frac{mv^2}{r} = qvB \quad \therefore\ r = \frac{mv}{qB}$$

$\therefore$ Time taken by particle to complete the semi-circular path

$$t = \frac{\pi r}{v}. \text{ But } v = \frac{qBr}{m}$$

$$t = \frac{\pi r m}{qBr} = \frac{\pi m}{qB}$$

Above relation shows that t is independent of both the radius of the circular path and the speed of the charged particle.

Cyclotron Frequency

The cyclotron works when the frequency of the applied alternating potential difference (V_o) is equal to the frequency of the revolving charged particle (v).

$$\therefore \qquad V_o = v = \frac{1}{T} = \frac{1}{2\times t} = \frac{qB}{2\pi m}$$

Thus, cyclotron angular frequency $\omega = 2\pi v$

$$= \frac{qB}{m}.$$

This frequency must conside the frequency of electric field applied.

- Charge particles of small mass cannot be accelerated by cyclotron because due to smaller mass it will acquire large velocity very soon due to which mass variation can take place and the frequency of charge particle will not concide with the frequency of electric field.
- The negative charge particle cannot be accelerated by cyclotron because these particles are of smaller mass and will acquire large velocity very soon and mass variation takes place due to which the frequency of particle in circular path does not concide with the frequency of electric source.

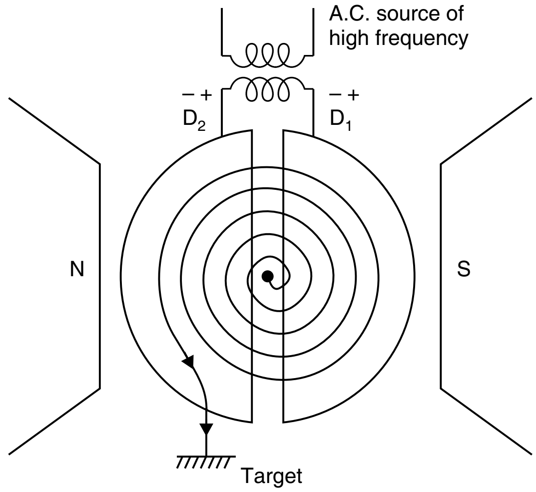

Fig. 4.26

QUESTIONS FROM TEXTBOOK

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?*

Sol. Given,

$$I = 0.40\ A,\ r = 8.0\ \text{cm} = 8 \times 10^{-2}\ \text{m}$$
$$n = 100$$

$$\boxed{B = \frac{\mu_0 n I}{2r}} = \frac{4\pi \times 10^{-7} \times 100 \times 0.4}{2 \times 8.0 \times 10^{-2}}\ \text{T}$$

$$= 3.1 \times 10^{-4}\ \text{T}.$$

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?*

Sol. Given,

$$I = 35\ \text{A},\ r = 20\ \text{cm} = 0.2\ \text{m}$$

$$\boxed{B = \frac{\mu_0 I}{2\pi r}} = \frac{4\pi \times 10^{-7} \times 35}{2\pi \times 0.20}\ \text{T}$$

$$= 3.5 \times 10^{-5}\ \text{T}.$$

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.*

Sol. Given,

$$I = 50\ \text{A},\ r = 2.5\ \text{m}$$
$$B = ?$$

As, $\boxed{B = \frac{\mu_0 I}{2\pi r}} = \frac{4\pi\times10^{-7}\times50}{2\pi\times2.5}$

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

Applying right hand thumb rule to find the direction of M.F. in east direction of wire it comes out upward direction.

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?*

Sol. $\boxed{B = \frac{\mu_0 I}{2\pi r}} = \frac{4\pi\times10^{-7}\times90}{2\pi\times1.5}T$

$= \frac{180}{1.5}\times10^{-7}\text{T} = 1.2\times10^{-5}\text{T}$

It is an example of magnetic field due to current in a wire of infinite length.

Applying the right-hand thumb rule, we find that the magnetic field at the observation point is directed towards south.

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?*

Sol. Given, $I = 8$ A, $B = 0.15$ T, $\theta = 30°$

Force acting on wire $\boxed{F = BIl.\sin\theta}$

Force per unit length $= \frac{F}{l} = BI\cdot\sin\theta$

$= 0.15 \times 8 \times \sin 30°$

$= 0.6$ N/m

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?*

Sol. Here, $l = 3.0$ cm $= 3 \times 10^{-2}$ m

$I = 10$ A, $B = 0.27$ T, $\theta = 90°$, F =?

By the formula

$\boxed{F = BIl\sin\theta}$

$= 0.27 \times 10 \times (3 \times 10^{-2}) \times \sin 90°$

$= 0.27 \times 10 \times 3 \times 10^{-2} \times 1$

or, $F = 8.1 \times 10^{-2}$ N

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.*

Sol. Given, $I_1 = 8.0$ A, $I_2 = 5$ A

$r = 4.0$ cm $= 4 \times 10^{-2}$ m

$l = 10$ cm $= 0.1$ m

$F = ?$

Force on length l,

$$F = \frac{\mu_0}{2\pi}\frac{I_1 I_2 l}{r}$$

$$= \frac{(4\pi \times 10^{-7}) \times 8 \times 5 \times 0.1}{2\pi \times 0.04} = 2 \times 10^{-5} \text{N}$$

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.*

Sol. Here, l = 80 cm = 0.80 m, N = 5 × 400 = 2000

I = 8.0 A, D = 1.8 cm, n = no. of turns per unit length

Magnitude of magnetic field inside a solenoid near its centre

$$n = \frac{\text{Total turn}}{\text{length}}$$

$$n = \frac{2000}{0.80}$$

$$B = \mu_0 n I = \frac{4\pi \times 10^{-7} \times 2000 \times 8.0}{0.80}$$

$$= 8\,\pi \times 10^{-3} \text{ T} = 2.5 \times 10^{-2} \text{ T.}$$

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?*

Sol. Here, l = 10 cm = 0.10 m, N = 20, I = 12 A

θ = 30°, B = 0.80 T, τ =?

Area, A = $l \times l$ = 0.1 × 0.1 = 0.01 m^2

$$\tau = NBIA \sin\theta$$

$$= 20 \times 0.80 \times 12 \times (0.1)^2 \times \sin 90°$$

$$= 0.96 \text{ Nm}$$

4.10. *Two moving coil meters, M_1 and M_2 have the following particulars:*

R_1 = *10 Ω; N_1 = 30,*

A_1 = *3.6 × 10^{-3} m^2, B_1 = 0.25 T*

R_2 = *14 Ω; N_2 = 42,*

A_2 = *1.8 × 10^{-3} m^2, B_2 = 0.50 T*

(The spring constants k are identical for the two meters).

Determine the ratio of (a) current sensitivity and (b) voltage sensitivity of M_2 and M_1.

Sol. (*a*) Current sensitivity of first meter

$$I_s = \frac{\theta}{I} = \frac{BAN}{k}$$

$$A = \frac{\theta}{I} = \frac{B_1 A_1 N_1}{k} = \frac{0.25 \times 3.6 \times 10^{-3} \times 30}{k}$$

$$= \frac{27 \times 10^{-3}}{k} \quad ...(i)$$

Current sensitivity of second meter

$$B = \frac{\theta}{I} = \frac{B_2 A_2 N_2}{k} = \frac{0.50 \times 1.8 \times 10^{-3} \times 42}{k}$$

$$= \frac{37.8 \times 10^{-3}}{k} \quad ...(ii)$$

Ratio of current sensitivity $\left(\frac{B}{A}\right) = \frac{37.8 \times 10^{-3}}{k} \Big/ \frac{27 \times 10^{-3}}{k} = 1.4$

(*b*) Voltage sensitivity of first meter

$$= \frac{\theta}{V} = \frac{\theta}{I \cdot R} = \frac{27 \times 10^{-3}}{k \times 10} = \frac{2.7 \times 10^{-3}}{k}$$

Voltage sensitivity of second meter

$$= \frac{\theta}{R.I} = \frac{37.8 \times 10^{-3}}{k \times 10} = \frac{2.7 \times 10^{-3}}{k}$$

Hence, the ratio of voltage sensitivity = 1.

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 × 10^6 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 = 1.6 × 10^{-19} C, m_e = 9.1 × 10^{-31} kg)*

Sol. Here, $B = 6.5 \times 10^{-4}$ T, $v = 4.8 \times 10^6$ m/s, $e = 1.6 \times 10^{-19}$ C;

$\theta = 90°$; $m = 9.1 \times 10^{-31}$ kg; r =?

(*i*) Force on the moving electron due to magnetic field will be, $F = evB \sin \theta$.

The direction of this force is perpendicular to $\vec{v}$ as well as $\vec{B}$ therefore, this force will only change the direction of motion of the electron without affecting its velocity *i.e.*, this force will provide the centripetal force to the moving electron and hence, the electron will move on the circular path. If r is the radius of circular path traced by electron, then

$$evB \sin 90° = mv^2/r \quad \text{or} \quad r = \frac{mv}{Be} = \frac{(9.1 \times 10^{-31}) \times (4.8 \times 10^6)}{(6.5 \times 10^{-4}) \times (1.6 \times 10^{-19})}$$

$$= 4.2 \times 10^{-2} \text{ m} = 4.2 \text{ cm}$$

4.12. *In Question 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.*

Sol. Frequency is given by

$$v = \frac{Bq}{2\pi m} = \frac{6.5 \times 10^{-4} \times 1.6 \times 10^{-19}}{2 \times 3.14 \times 9.1 \times 10^{-31}}$$

$$v = \frac{10.4 \times 10^{-23}}{51.148 \times 10^{-31}}$$

$$= 0.18198 \times 10^8$$

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

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 to 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).

Sol. Given, $N = 30, I = 6.0 \text{ A}, B = 1.0 \text{ T}, \alpha = 60°$

$$r = 8.0 \text{ cm} = 8 \times 10^{-2} \text{ m.}$$

Area of the coil, $A = \pi r^2$

$$= \frac{22}{7} \times \left(8 \times 10^{-2}\right)^2$$

$$A = 2.01 \times 10^{-2} \text{ m}^2$$

(*a*) Now, $\boxed{\tau = NBIA \sin \alpha}$

$$= 30 \times 6.0 \times 1.0 \times (2 \times 10^{-2}) \times \sin 60°$$

$$\tau = 30 \times 6 \times 1 \times 2 \times \frac{\sqrt{3}}{2} \times 10^{-2} = 3.12 \text{ Nm.}$$

(*b*) If the area of the loop is the same, the torque will remain unchanged as the torque on the planar loop does not depend upon the shape.

4.14. *Two concentric 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 current in X is anti clockwise and in Y, clockwise, for an observer looking at the coil facing west. Give the magnitude and direction of the net magnetic field due to the coils at their centre.*

Consider X, X′ axis in East, West directions respectively and Y, Y′ in North, South direction. Plane of coil is in Y–Z axis plane M.F. due to coil X is in East, and due to coil Y is in west direction.

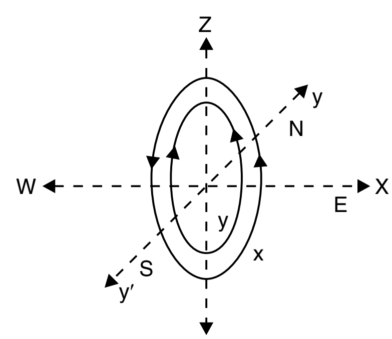

Fig. 4.27

Sol. Given, for coil X

$$r_x = 16 \text{ cm} = 0.16 \text{ m}$$

$$N_x = 20, I_x = 16 \text{ A}$$

Magnetic field at the centre of coil X is

$$\boxed{B_x = \frac{\mu_0 I_x N_x}{2r_x}}$$

$$= \frac{4\pi \times 10^{-7} \times 16 \times 20}{2 \times 0.16}$$

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

The current in the coil X is anticlockwise, the field B_x is directed towards east.

Given, for coil Y

$$r_y = 10\ \text{cm} = 0.10\ \text{m},\ N_y = 25,\ I_y = 18\ \text{A}$$

Magnetic field at the centre of coil Y is

$$\boxed{B_y = \frac{\mu_0 I_y N_y}{2r_y}}$$

$$= \frac{4\pi \times 10^{-7} \times 18 \times 25}{2 \times 0.10} = 9\pi \times 10^{-4}\ \text{T}$$

The direction of magnetic field induction B_y is towards west.

$$\text{Net magnetic field} = B_y - B_x$$
$$= 9\pi \times 10^{-4} - 4\pi \times 10^{-4}$$
$$= 5\pi \times 10^{-4}$$
$$= 1.6 \times 10^{-3}\ \text{T (Towards west).}$$

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} m^2. 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.*

Sol. Given, $B = 100\ G = 10^{-2}$ T

$I = 15\ A,\ n = 1000\ \text{m}^{-1}$

Magnetic field inside a solenoid is

$$\boxed{B = \mu_0\, nI}$$

$$nI = \frac{B}{\mu_0} = \frac{10^{-2}}{4\pi \times 10^{-7}} = \frac{10^5}{4\pi} = 7955$$

We may have $I = 10\ A$ and $n = 800$

The solenoid may have length 50 cm and cross section 5×10^{-3} m^2 (five times given values) so as to avoid *edge effects* etc.

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,*

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

(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,*

$$B = 0.72 \frac{\mu_0 NI}{R}, \text{ approximately.}$$

[Such an arrangement to produce a nearly uniform magnetic field over a small region is known as Helmholtz coils.]

Sol. (a) Given, that $$B = \frac{\mu_0 I R^2 N}{2(x^2 + R^2)^{3/2}} \quad \text{(axial line)}$$

Putting $x = 0$ (centre of coil)

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

or $$B = \frac{\mu_0 IN}{2R}$$

which is same as the standard result.

(b) In figure, O is a point which is mid-way between the two coils X and Y.

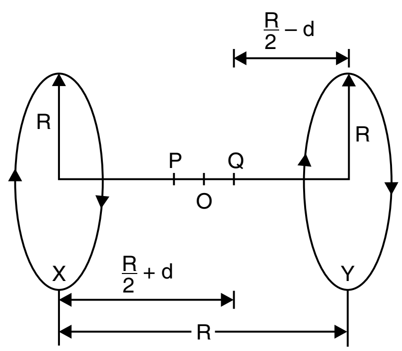

Fig. 4.28

Let B_x be the magnetic field at Q due to coil X.

Then, $$B_x = \frac{\mu_0 NIR^2}{2\left[\left(\frac{R}{2} + d\right)^2 + R^2\right]^{3/2}}$$

If B_y is the magnetic field at Q due to coil Y, then

$$B_y = \frac{\mu_0 NIR^2}{2\left[\left(\frac{R}{2} - d\right)^2 + R^2\right]^{3/2}}$$

The currents in both the coils X and Y are flowing in the same direction. So, the resultant field is given by

$$B = B_x + B_y$$

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

$$B = \frac{\mu_0 NIR^2}{2}\left[\frac{1}{\left[\left(\frac{R}{2}+d\right)^2 + R^2\right]^{3/2}} + \frac{1}{\left[\left(\frac{R}{2}-d\right)^2 + R^2\right]^{3/2}}\right]$$

$$B = \frac{\mu_0 NIR^2}{2}\left[\frac{1}{\left[\frac{R^2}{4} + d^2 + Rd + R^2\right]^{3/2}} + \frac{1}{\left[\frac{R^2}{4} + d^2 - Rd + R^2\right]^{3/2}}\right]$$

$$B = \frac{\mu_0 NIR^2}{2}\left[\frac{1}{\left[\frac{5R^2}{4} + Rd\right]^{3/2}} + \frac{1}{\left[\frac{5R^2}{4} - Rd\right]^{3/2}}\right] \qquad \because \quad d^2 << R^2$$

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

$$= \frac{\mu_0 NIR^2}{2\left(\frac{5}{4}\right)^{3/2} R^3}\left[\left[1 - \frac{3}{2}\times\frac{4}{5}\times\frac{d}{R}\right] + \left[1 + \frac{3}{2}.\frac{4}{5}.\frac{d}{R}\right]\right]$$

$$= \frac{\mu_0 NI \,.\, \cancel{2}}{\cancel{2}\left(\frac{5}{4}\right)^{3/2} R}$$

$$= \frac{\mu_0 NI}{R}\left(\frac{5}{4}\right)^{3/2}$$

$$= 0.72\,\frac{\mu_0 NI}{R} \text{ (approx.)}$$

4.17. *A toroid has a core (non-ferromagnetic material) of inner radius 25 cm and outer radius 26 cm around which 3500 turns of 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 (c) in the empty space surrounded by the toroid?*

Sol. Given, $r_1 = 0.25$ m, $r_2 = 0.26$ m N = 3500

$I = 11$ A

(*i*) The magnetic field is zero outside the toroid.

(*ii*) Magnetic field inside the core of the toroid, $B = \mu_0 nI$

or $$B = \frac{\mu_0 NI}{l} \qquad \left(\because n = \frac{N}{l} \rightarrow \text{Number of turns per unit length}\right)$$

$$l = 2\pi\left(\frac{r_1 + r_2}{2}\right)$$

$$= \pi(r_1 + r_2) = \pi(0.25 + 0.26) = \pi \times 0.51 \text{ m}$$

Putting the values

$$B = \frac{(4\pi \times 10^{-7}) \times 3500 \times 11}{\pi \times 0.51} = 3.02 \times 10^{-2} \text{ T}$$

(*iii*) The magnetic field is zero in the empty space surrounded by the toroid.

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.*

Sol. (*a*) The force on a charged particle moving in a magnetic field is given by

$$F = qvB \sin\theta.$$

The charged particle will travel undeflected along a straight path with constant speed in a magnetic field if no force act on it *i.e.*, $F = 0$.

It is possible only when $\sin\theta = 0$

or $\theta = 0°, 180°$

i.e., initial velocity v is either parallel or anti-parallel to $\vec{B}$.

(*b*) Yes, because magnetic force can change the direction of $\vec{v}$, not its magnitude. The direction of force due to magnetic force on moving charge is perpendicular to v and *BSO* force component in the direction of v is zero. So charge zero is also zero.

(*c*) The electrostatic field is directed towards south. Since the electron is a negatively charged particle, therefore, the electrostatic field shall exert a force directed towards north. So, if the electron is to be prevented from deflection from straight path, by the magnetic force on the electron should be directed towards south. Now $\vec{F}_m = -e\left(\vec{v}\times\vec{B}\right)$.

$\vec{F}_m$ is towards south, $\vec{v}$ is due east. Applying Fleming's Left-Hand Rule, we find that magnetic field $\vec{B}$ should be in the vertically downward 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.*

Sol. Given, V = 2 kilo volt = 2000 volt

B = 0.15 T

(*a*) If magnetic field is transverse to initial velocity of electron. In this particular case, the velocity vector has no component in the direction of magnetic field.

$\therefore$ Force on electron $= Bev \sin 90°$

$= Bev$

This force acts as the centripetal force:

$$\therefore \quad Bev = \frac{mv^2}{r}$$

$$\text{or} \quad r = \frac{mv}{eB} \quad \text{...(I)}$$

$$\text{But} \quad \frac{1}{2}mv^2 = eV \quad \text{...(II)}$$

$$\text{or} \quad v = \sqrt{\frac{2eV}{m}}$$

$$\therefore \quad r = \frac{m}{eB}\sqrt{\frac{2eV}{m}} \quad \text{[From I, II]}$$

$$\text{or} \quad v = \frac{1}{B}\sqrt{\frac{2mV}{e}}$$

$$= \frac{1}{0.15}\sqrt{\frac{2\times 9.1\times 10^{-31}\times 2000}{1.6\times 10^{-19}}} \text{ m}$$

$$= 10^{-3} \text{ m} = 1.0 \text{ mm.}$$

The electron would move in a circular trajectory of radius 1.0 mm. The plane of the trajectory is normal to B.

(*b*) If v makes an angle 30° with the direction of magnetic field, the velocity can be resolved into $v_\perp$ and $v_\parallel$ *i.e.*, $v \cos 30°$ and $v \sin 30°$ respectively.

Due to $v_\perp$ the electron will move on a circular path. The resultant path will be a combination of straight line motion and circular motion which is called helical.

$$\text{Thus,} \quad evB \sin\theta = \frac{m(v\sin\theta)^2}{r_n}$$

for circular motion of radius r_n

$$ev_{\perp} \times B = \frac{mv_{\perp}^2}{r_n}$$

$$v_{\perp} = v \sin\theta$$

or $$r_n = \frac{mv\sin\theta}{eB}$$

$$r_n = \frac{9.1\times10^{-31}\times2.65\times10^{7}\times\sin 30}{1.6\times10^{-19}\times0.15}$$

$$= 0.49 \times 10^{-3} \text{ m} = 0.49 \text{ mm} \simeq 0.5 \text{ mm}$$

The linear velocity $= v\cos\theta$

$$= 2.65 \times 10^7 \times \cos 30°$$

$$= 2.65 \times 10^7 \times \frac{\sqrt{3}}{2}$$

$$= 2.3 \times 10^7 \text{ ms}^{-1}$$

Thus, the electron moves in a helical path of radius 0.49 mm with a velocity component of 2.3×10^7 ms^{-1} in the direction of magnetic field.

4.20. *A magnetic field set up using Helmholtz coils 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 Vm^{-1}, make a simple guess as to what the beam contains. Why is the answer not unique?*

Sol. Given, $$\frac{1}{2}mv^2 = eV$$

$$\frac{e}{m} = \frac{v^2}{2V}$$

$$\frac{e}{m} = \frac{1.2\times10^{6}\times1.2\times10^{6}}{2\times15\times10^{3}}$$

$$\frac{e}{m} = \frac{0.24}{5}\times10^{9}$$

$$\frac{e}{m} = 0.048 \times 10^9$$

$$\frac{e}{m} = 4.8 \times 10^7 \text{ coulomb/kg}$$

This charge to mass ratio is equivalent to charge to mass ratio of proton so the charge particle may be deuterons. However, the answer is not unique. This is because $He^{++}\left(\frac{2e}{2m}\right)$ and $Li^{++}\left(\frac{3e}{3m}\right)$ have also the same value of $\frac{e}{m}$.

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.) $g = 9.8\ m\ s^{-2}$.

Sol. Given, $l = 0.45$ m, m = 60 g = 60×10^{-3} kg

$I = 5.0$ A

(*a*) Force needed to balance the weight of the rod,

$$\boxed{F = mg} = 0.06 \text{ kg} \times 9.8 = 0.588 \text{ N}$$

By the formula,

$$\boxed{F = BIl}$$

$$B = \frac{F}{Il} = \frac{0.588}{5.0 \times 0.45} = 0.26 \text{ T}$$

If the direction of current in horizontal conductor is from right to left then the direction of magnetic field is horizontal and normal to the conductor, the force due to magnetic field will be upwards by Fleming's left hand rule.

(*b*) 'BIl' and 'mg' will act vertically downwards if direction of current is reversed.

Total tension in the wires = $BIl + mg$

= 0.588 + 0.588 = 1.176 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?*

Sol. Given, $I_1 = 300\ A$, $I_2 = 300\ A$, $r = 1.5$ cm

$= 1.5 \times 10^{-2}$ m

By using formula $\boxed{F = \frac{\mu_0 I_1 I_2 l}{2\pi r}}$

or force per unit length $= \frac{F}{l} = \frac{4\pi \times 10^{-7} \times 300 \times 300}{2\pi \times 0.015}$

$= 1.2\ \text{Nm}^{-1}$

The total force between the wires is

$F = fl$

$= 1.2 \times 0.70$ N = 0.84 N.

The force is repulsive since the current will flow in opposite direction in the two wires connecting the battery to the starting motor.

4.23. *A uniform magnetic field of 1.5 T exists in a cylindrical region of radius 10.0 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?

Sol. (*a*) Diameter of cylindrical region

$= 20 \text{ cm} = 0.20 \text{ m}$

Clearly, $l = 0.20$ m. Also, $\theta = 90°$

$F = BIl \sin\theta = 1.5 \times 7 \times 0.20 \sin 90° \text{ N}$

$= 2.1 \text{ N}$

Using Fleming's left-hand rule, we find that the force is directed vertically downwards.

(*b*) If l_1 is the length of the wire in the magnetic field, then,

$F_1 = BIl_1 \sin 45°$

But $l_1 \sin 45° = l$

$\therefore \quad F_1 = BIl = 1.5 \times 7 \times 0.20 \text{ N} = 2.1 \text{ N}$

The force is directed vertically downwards by Fleming's left hand rule.

(*c*) When the wire is lowered by 6 cm, the length of the wire in the cylindrical magnetic field is $2x$.

Now, $x^2 = 10^2 - 6^2$

$x = \sqrt{64} = 8 \text{ cm}$

$\therefore \quad 2x = 16 \text{ cm}.$

$F_2 = BIl_2 = 1.5 \times 7 \times 0.16 \text{ N}$

$= 1.68 \text{ N}$

The force is directed vertically downwards.

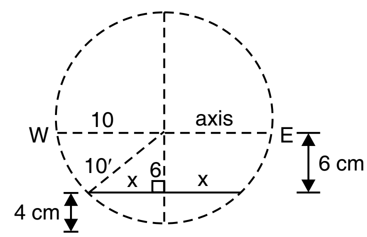

Fig. 4.29

The result is true for any angle between current and direction of $\vec{B}$. This is because $l \sin\theta$ remains constant i.e., 20 cm.

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 12A. What is the torque on the loop in the different cases shown in the figure below. What is the force on each case? Which case corresponds to stable equilibrium?*

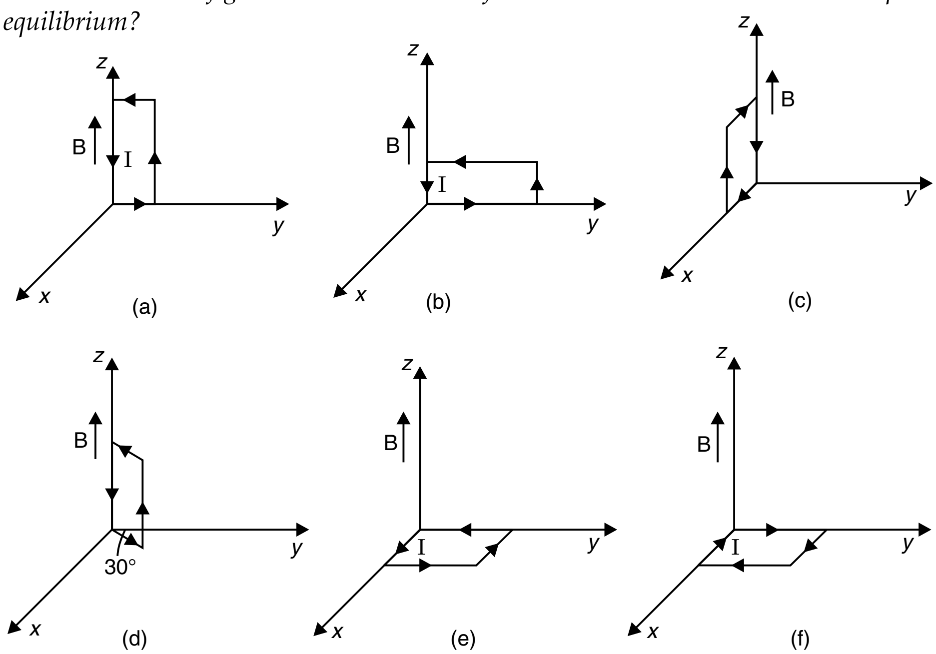

Fig. 4.30

Sol. (*a*) Torque on the loop,

$$\boxed{\tau = BIA \cos \theta}$$

where θ is the angle between the plane of loop and direction of magnetic field.

Here, $\theta = 0°,\ B = 3000$ gauss

$= 3000 \times 10^{-4}$ T

$= 0.3$ T

$I = 12$ A, $A = 10 \times 10^5$ cm^2 $= 50 \times 10^{-4}$ m^2

$\tau = 0.3 \times 12 \times 50 \times 10^{-4} = 1.8 \times 10^{-2}$ Nm.

The direction of torque or force on arm 5 cm, lower arm $+x$ axis upper arm $-x$ axis by Fleming's left hand rule.

(*b*) Similar to (*a*) but torque act on side of 10 cm.

(*c*) $\tau = 1.8 \times 10^{-2}$ Nm along $-x$ direction of torque on lower arm of 5 cm towards $-y$ axis.

(*d*) This case is similar to (c). Direction of torque is 60°.

(*e*) zero. (∵ angle between plane of loop and direction of magnetic field is 90°)

(*f*) zero.

Force is zero in each case. Stable equilibrium is corresponded by case (*e*).

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} m^2, and the free electron density in copper is given to be about 10^{-29} m^{-3}.)

Sol. Given, $N = 20,\ r = 10$ cm $= 10 \times 10^{-2}$ m

$B = 0.10$ T, $I = 5.0$ A

$\theta = 0°$ (angle between field and normal to the coil)

Area of the coil,

$$A = \pi r^2 = \pi \times (10 \times 10^{-2})^2 = \pi \times 10^{-2} \text{ m}^2$$

(*a*) Torque $\tau = NIBA \sin \theta$

$= 20 \times 5.0 \times 0.10 \times \pi \times 10^{-2} \sin 0°$

$= 20 \times 5.0 \times 0.10 \times \pi \times 10^{-2} \times 0 = 0$

(*b*) Net force on a planer current loop in a magnetic field is always zero, as net force due to couple of force is zero.

(*c*) If v_d is the drift velocity of electron

$$F = qv \times B$$

$$= ev_d \,.\, B \sin 90°$$

Force on one electron $= Be\, v_d = Be \dfrac{I}{neA} = \dfrac{BI}{nA}$

Here, $n = 10^{29}$ m^{-3}, $A = 10^{-5}$ m^2

∴ Force on one electron $= \dfrac{0.10 \times 5.0}{10^{29} \times 10^{-5}} = 5 \times 10^{-25}$ 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 the 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 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? $g = 9.8\ ms^{-2}$.*

Sol. Given, for solenoid, $l = 60\text{ cm} = 0.60\text{ m}$

$N = 3 \times 300 = 900$

For wire, $l_1 = 2.0\text{ cm} = 0.02\text{ m, m}$

$2.5\text{ g} = 2.5 \times 10^{-3}\text{ kg}$

$I_1 = 6.0\text{ A}$

Let current I be passed through the solenoid windings, the magnetic field produced inside the solenoid due to current is

$$B = \frac{\mu_0 NI}{l}$$

Force on wire $= I_1 l_1 B = I_1 l_1 \frac{\mu_0 NI}{l}$

The wire can be supported if the force on wire is equal to the weight of wire, *i.e.*,

$$I_1 l_1 = \frac{\mu_0 NI}{l} = mg$$

or
$$I = \frac{mgl}{I_1 l_1 \mu_0 N} = \frac{2.5 \times 10^{-3} \times 9.8 \times 0.6}{(6.0) \times (0.02) \times \left(4\pi \times 10^{-7}\right)} \times 900$$

$= 108.27\text{ A}$

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?*

Sol. Given, $G = 12\ \Omega$, $I_g =$

$3\text{ mA} = 3 \times 10^{-3}\text{ A}$

$V = 18\ v$, $R = ?$

By using formula,

$$V = I_g (R + R_g)$$

or
$$\frac{V}{I_g} = R + R_g$$

or
$$R = \frac{V}{I_g} - R_g = \frac{18}{3 \times 10^{-3}} - 12$$

$$R = 6 \times 10^3 - 12 = 5988\ \Omega$$

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?*

Sol. Given, $G = 15\ \Omega$, $I_g = 4\text{ mA} = 4 \text{ x } 10^{-3}\text{ A}$

$I = 6\text{ A}$

Using formula,

$$S = \frac{I_g \cdot G}{I - I_g}$$

Putting values,

$$S = \frac{4 \times 10^{-3} \times 15}{6 - 0.004}$$

$$= \frac{60 \times 10^{-3}}{5.996} = 10 \times 10^{-3}\ \Omega$$

or $S = 10\ \text{m}\ \Omega$

MORE QUESTIONS SOLVED

I. VERY SHORT ANSWER TYPE QUESTIONS

Q. 1. *An electron does not suffer any deflection while passing through a region of uniform magnetic field. What is the direction of the magnetic field?*

Ans. The direction of magnetic field $\vec{B}$ is parallel to the velocity $\vec{v}$ of electron.

As $F = q\left(\vec{v} \times \vec{B}\right) = 0$ since $\vec{V} \,||\, \vec{B}$

Q. 2. *What are the units of magnetic permeability?*

Ans. Tesla metre/ampere (TmA^{-1}).

Q. 3. *Magnetic field lines can be entirely confined within the core of a toroid, but not within a straight solenoid. Why?*

Ans. Because the magnetic field induction outside the toroid is zero.

Q. 4. *The coils, in certain galvanometers, have a fixed core made of a non-magnetic matallic materials. Why does the oscillating coil come to rest so quickly such a core?*

Ans. The restoring torque due to eddy current in core try to restore the coil back to its original position.

Q. 5. *Two circular coils made of similar wires but of radii 20 cm and 40 cm are connected in parallel. What will be the ratio of the magnetic field at their centres?*

Ans. Magnetic field at the centre of circular coil of radius r, turns N, and current I passing in coil is

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

$$B = \frac{\mu_0 N}{2r}\frac{V}{R} \qquad [R = \text{resistance of coil}]$$

$$B = \frac{\mu_0 N}{2r}\frac{V}{2\pi r x} \qquad [x \text{ is resistance per unit length}]$$

$$B = \frac{\mu_0 NV}{4\pi x r^2}$$

As coils are is parallel so potential difference 'V' are equal in both coils

$\therefore \qquad V \propto \frac{1}{r^2}$

or $$\frac{B_1}{B_2} = \frac{r_2^2}{r_1^2}$$

$$\frac{B_1}{B_2} = \left(\frac{40}{20}\right)^2$$

$$\frac{B_1}{B_2} = 4 \quad \text{or} \quad B_1 : B_2 = 4 : 1$$

Q. 6. *What is the direction of the force acting on a charged particle q, moving with a velocity $\vec{v}$ in a uniform magnetic field $\vec{B}$?*

Ans. $\because \vec{F} = q\left(\vec{v}\times\vec{B}\right)$

Magnetic force is always normal to plane of $\vec{V}$ and $\vec{B}$.

Q. 7. *Magnetic lines of force are endless. Comment.*

Ans. This is because magnetic lines of force are continuous closed loops and mono pole is not possible.

Q. 8. *An electron is moving along +ve x-axis in the presence of uniform magnetic field along +ve y-axis. What is the direction of force acting on it?*

Ans. The direction of the force is along –ve z-axis.

Q. 9. *A magnetic dipole is situated in the direction of a magnetic field. What is its potential energy? If it is rotated by 180°, then what amount of work will be done?*

Ans. $P.E.$ of dipole $= -MB \cos 0° = -MB$

Work done $= MB (\cos 0° - \cos 180°) = MB (1 + 1) = 2\,MB$.

Q. 10. *Define magnetic flux. Give its SI unit.*

Ans. The total number of magnetic lines of force crossing the surface A in a magnetic field $\vec{B}$ is termed as magnetic flux.

$$\phi = BA \cos \theta$$

Its SI unit is Weber. It is a scalar quantity.

Q. 11. *What is the approximate distance upto which earth's magnetic field extends?*

Ans. The magnetic field of earth extends to nearly five times the radius of the earth *i.e.,* $5 \times (6.4 \times 10^3)$ km $= 3.2 \times 10^4$ km.

Q. 12. *An electron moving through a magnetic field does not experience any force. Under what condition is this possible?*

Ans. *As* $F = qvB \sin \theta$

So either electron is moving parallel to the direction of the magnetic field or it is at rest.

Q. 13. *An electron moving with a velocity of 107 m/s enters a uniform magnetic field of 1 T along a direction parallel to the field. What would be its trajectory?*

Ans. Straight line as $F = qvB \sin \theta$ here $\theta = 0$

Q. 14. *Write one condition under which an electric charge does not experience a force in a magnetic field.*

Ans. $\because \quad F = qvB \sin \theta$

When the electric charge is either at rest ($v = 0$) or parallel ($\theta = 0$) to magnetic field, it does not experience force in magnetic field.

Q. 15. *What is a shunt? State its SI unit.*

Ans. A small resistance connected in parallel with a galvanometer to convert it into ammeter is called shunt. Its SI unit is ohm.

Q. 16. *Write SI unit of magnetic field $\vec{B}$.*

Ans. SI unit of magnetic field is tesla (T).

Q. 17. *A charge q is moving in a region where both the magnetic field $\vec{B}$ and electric field $\vec{E}$ are simultaneously present. What is the Lorentz force acting on the charge?*

Ans. Lorentz force, $\vec{F} = q\vec{E} + q\left(\vec{v}\times\vec{B}\right)$

or $\vec{F} = q\left(\vec{E}+\vec{v}\times\vec{B}\right)$

Q. 18. *In the diagram below is shown a circular loop carrying current I. Show the direction of the magnetic field with the help of lines of force.*

Ans. The magnetic force lines of a circular loop carrying current *I* are shown as follows.

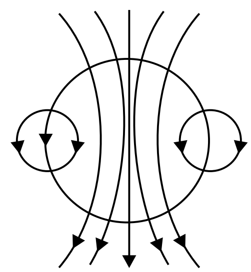

Fig. 4.31

Q. 19. *The force $\vec{F}$ experienced by a particle of charge 'q' moving with a velocity 'v' in a magnetic field 'B' is given by $\vec{F} = q\left(\vec{v}\times\vec{B}\right)$. Which pairs out of these vectors are always at right angles to each other?*

Ans. $\vec{F}\perp\vec{v}$ and $\vec{F}\perp\vec{B}$.

Q. 20. *A certain proton moving through a magnetic field region experiences maximum force. When does this occur?*

Ans. When proton moves perpendicular to the magnetic field, $\theta = 90°$. $\vec{v}\times\vec{B}$ is maximum.

Q. 21. *Under what conditions is the force acting on a charge moving through a uniform magnetic field minimum?*

Ans. When a charge moves parallel or antiparallel to the direction of the magnetic field, the force acting on it is zero or minimum.

Q. 22. *What is the nature of magnetic field in a moving coil galvanometer?*

Ans. It is radial in nature.

Q. 23. *Two wires of equal lengths are bent in the form of two loops. One of the loops is square shaped whereas the other loop is circular. These are suspended in a uniform magnetic field and the same current is passed through them. Which loop will experience greater torque? Give reasons.*

Ans. For a wire of given length, the circular loop has greater area than the square loop. So the circular loop will experience greater torque in the magnetic field, because torque $\propto$ area of the loop.

Q. 24. *Write the SI unit of (i) magnetic pole strength (ii) magnetic dipole moment of a bar magnet.*

Ans. (*i*) The SI unit of magnetic pole strength is Am.

(*ii*) The SI unit of magnetic dipole strength is Am^2.

Q. 25. *Give two factors by which the current sensitivity/voltage sensitivity of a moving coil galvanometer can be increased.*

Ans. (*i*) Increasing the number of turns in the galvanometer coil.

(*ii*) Decreasing the torsion constant of the suspension fibre.

II. SHORT ANSWER TYPE QUESTIONS

Q. 1. *A beam of protons with a velocity 4×10^5 m/s enters a uniform magnetic field of 0.3 T at an angle 60° to the magnetic field. Find the radius of the helical path taken by the proton beam. Also find the pitch of the helix mp = 1.67×10^{-27} kg.*

Ans. ∵

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

$$r = \frac{1.67 \times 10^{-27} \times 4 \times 10^5 \sin 60}{1.6 \times 10^{-19} \times 0.3}$$

$$= 1.2 \times 10^{-2} = 1.2 \text{ cm}$$

$$T = \frac{2\pi r}{v \sin\theta} = 2.175 \times 10^{-7} \text{ S}$$

∴ $$P = v \cos \theta . T$$

or, $$= 4 \times 10^5 \times \frac{1}{2} \times 2.175 \times 10^{-7} = 4.35 \text{ cm}$$

Q. 2. *An electron moves around the nucleus in a hydrogen atom of radius 0.51 Å, with a velocity of 2 x 105 m/s. Calculate the following:*

(i) the equivalent current due to orbital motion of electron,

(ii) the magnetic field produced at the centre of the nucleus

(iii) the magnetic moment associated with the electron.

Ans. Given, $$v = 2 \times 10^5 \text{ m/s}$$

$$r = 0.51 \text{ Å} = 0.51 \times 10^{-10} \text{ m}$$

(*i*) Equivalent current

$$\boxed{I = \frac{e}{t}} = \frac{e}{2\pi r / v} = \frac{ev}{2\pi r}$$

or $$I = \frac{1.6 \times 10^{-19} \times 2 \times 10^5}{2 \times 3.14 \times 0.51 \times 10^{-10}}$$

or, $$I = \frac{3.2 \times 10^{-4}}{3.2028} = 0.99 \times 10^{-4} = 10^{-4} \text{ A}$$

(*ii*) Magnetic field

$$\boxed{B = \mu n I}$$

$$B = 4\pi \times 10^{-7} \times 1 \times 10^{-4}$$

or, $$B = 4 \times 3.14 \times 10^{-11} = 12.56 \times 10^{-11} = 1.256 \times 10^{-10} \text{ T.}$$

(*iii*) Magnetic moment,

$$\boxed{M = IA} = I(\pi r^2)$$
$$= 10^{-4} \times 3.14 \times (0.51 \times 10^{-10})^2$$
$$= 3.14 \times 0.2601 \times 10^{-4} \times 10^{-20}$$

or, $$M = 0.816 \times 10^{-24} = 8.16 \times 10^{-25} \text{ Am}^2$$

Q. 3. *Three long straight and parallel wires, carrying currents, are arranged as shown in the figure below. Find the force experienced by a 25 cm length of wire C.*

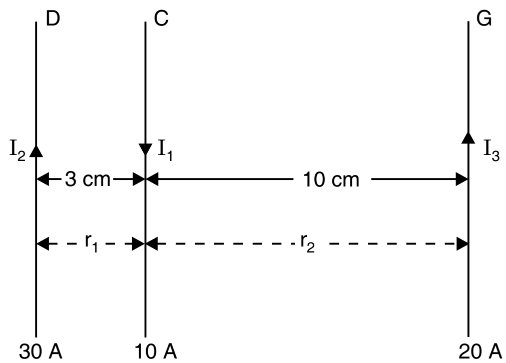

Fig. 4.32

Ans. As the direction of current in *C* and *D* wires are in opposite direction so force of repulssion *F* acts on *C* towards right side. Similarly due to *G* it will be in left hand side so resultant force on *C* due to wires *D* and *G* will be *F*

$$F = F_1 - F_2$$
$$= \frac{\mu_0 I_1 I_2 l}{2\pi r_1} - \frac{\mu_0 I_1 I_3 l}{2\pi r_2}$$
$$= \frac{\mu_0 I_1 l}{2\pi}\left[\frac{I_2}{r_1} - \frac{I_3}{r_2}\right]$$
$$= \frac{4\pi \times 10^{-7} \times 10 \times 25}{2\pi}\left[\frac{30}{0.03} - \frac{20}{0.10}\right]$$
$$= 5 \times 10^{-7} \times 80$$
$$= 400 \times 10^{-7}$$
$$F_c = 4 \times 10^{-5} \text{ N towards left side.}$$

Q. 4. *The wire shown in figure below carries a current of 60 A. Find the magnetic field B at P.*

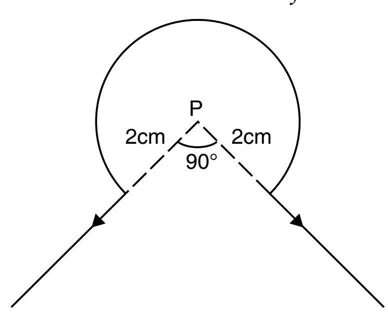

Fig. 4.33

Ans. The field at P arises from 3/4th of the circular loop only because P lies on the straight wires themselves. Thus

$$B = \frac{\mu_0}{4\pi}\frac{2\pi I}{r}\frac{\theta}{360}$$

$$\theta = 270$$

$$= \frac{3\times10^{-7}\times2\pi\times60}{4\times0.02}$$

$$= 1.4 \times 10^{-3}\text{ T (directed out of the page)}$$

Q. 5. *What is the toroid? Using Ampere's circuital law calculate the magnetic field inside the toroid.*

Ans. When a solenoid is in the form of a ring then it is treated as toroid.

Consider a toroid carrying current I and has N turns. The magnetic field is set up inside the turns of the toroid. The magnetic lines of force inside the toroid are concentric circles. By symmetry the magnitude of the field $\vec{B}$ is same at all points on the circle of radius r and is directed tangentially to the circle at any point

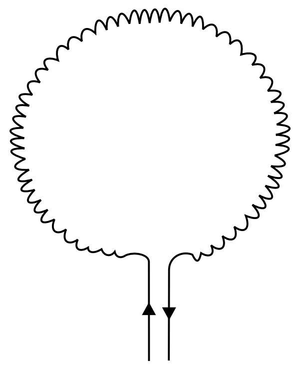

Fig. 4.34

$$\therefore \quad \oint \vec{B}\cdot\vec{dl} = \oint B\,dl\cos\theta°$$

$$\oint \vec{B}\cdot\vec{dl} = \oint B\,dl\cos 0°$$

$$\text{or,} \quad \oint \vec{B}\cdot\vec{dl} = B\;2\pi r$$

By applying Ampere's circuital law,

$$\oint \vec{B}\cdot\vec{dl} = \mu_0 \times \text{total current passing through circle of radius } r.$$

$$B\;2\pi r = \mu_0 \times N \times 2\pi r l$$

$$\therefore \quad B = \mu_0 NI$$

Q. 6. *A 50 turn coil as shown in the figure below carries of 2 A in a magnetic field B = 0.25 Wb m^{-2}. Find the torque acting on the coil. In what direction will it rotate?*

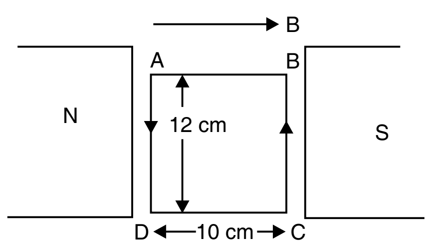

Fig. 4.35

Ans. The sides AB and DC are along the field lines: hence the force on each side is zero. The force on each vertical wire is given as

$$\tau = B1NA\sin\theta$$

$$\tau = 0.25 \times 2 \times 50 \times 0.12 \times 0.1 \sin\theta$$

$$= 0.3\text{ N-m clockwise}$$

Q. 7. *Define current sensitivity and voltage sensitivity of a galvanometer. Increasing the current sensitivity may not necessarily increase the voltage sensitivity of galvanometer. Justify.*

Ans. The definitions of current sensitivity and voltage sensitivity are given in the text. (No. 17).

→ Let the deflection produced in applying voltage V is α then

$$\text{voltage sensitivity} = \frac{\alpha}{v} = \frac{NBA}{kR}$$

The voltage sensitivity may be increased by (*i*) increasing N, B, A (*ii*) decreasing k and

$$\text{current sensitivity} = \frac{NBA}{k}$$ can be increased by

(*i*) increasing NBA (*ii*) decreasing k.

Hence increasing the current sensitivity may not necessarily increase the voltage sensitivity of a galvanometer.

Q. 8. *In an exercise to increase current sensitivity of a galvanometer by 25%, its resistance is also increased 1.5 times. How will the voltage sensitivity of the meter be affected ?*

Ans. Here,

$$I'_s = I_s + \frac{25}{100}I_s = \frac{125}{100}I_s = \frac{5}{4}I_s$$

$$R' = 1.5\ \text{R}$$

$$V_S = \frac{I_s}{R} \text{ and } V_s' = \frac{I_s'}{R'} = \frac{(5/4)I_s}{1.5R} = \frac{5}{6}V_s$$

$$\%\ \text{increase in voltage sensitivity} = \left(1 - \frac{V_s'}{V_s}\right) \times 100$$

$$= \left(1 - \frac{5}{6}\right) \times 100 = 16.7\%$$

Q. 9. *A charge 'q' moving along the –X-axis with a velocity $\vec{v}$ is subjected to a uniform magnetic field B acting along the Z-axis as it crosses the origin O.*

(*i*) *Trace its trajectory.*

(*ii*) *Does the charge again kinetic energy as it enters the magnetic field? Justify your answer.*

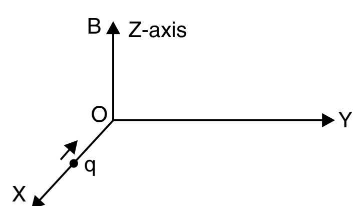

Fig. 4.36

Ans. (*i*) The trajectory of charge q moving along –X-axis will be helical.

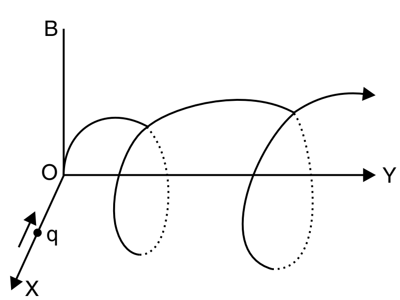

Fig. 4.37

(*ii*) The speed and kinetic energy of the particle remain constant but the velocity of the charged particle changes only in direction.

Q. 10. *Two straight wires A and B of lengths 10 m and 12 m carrying currents of 4.0 A and 6.0 A respectively in opposite directions lie parallel to each other at a distance of 0.03 m. Estimate the force on a 15 cm section of the wire B near its centre.*

Ans. The ratio of the lengths of the wires to the separation between them is large (more than 300). So one can estimate approximately the force on a section of either of the two wires (near their centres) by using exact result for force per unit length for two infinitely long wires carrying currents I_1 and I_2.

Force per unit length $\boxed{\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}\,\text{Nm}^{-1}}$

$$= \frac{4\pi \times 10^{-7} \times 4 \times 6}{2\pi \times 0.03} = 1.6 \times 10^{-4}\ \text{Nm}^{-1}$$

Force on 15 cm section of wire *B* (near its centre) = $1.6 \times 10^{-4} \times 0.15$ N = 2.4×10^{-5} N

The force is repulsive as the currents are in opposite directions; the direction of force is normal to the wire away from *A*.

Q. 11. *Derive an expression for the torque acting on a loop of N turns, area A, carrying current I, when held in a uniform magnetic field.*

With the help of circuit, show how a moving coil galvanometer can be converted into an ammeter of given range. Write the necessary mathematical formula.

Ans. Let I = current through the loop *PQRS*

a, b = sides of the rectangular loop

A = ab = area of the loop

N = number of turns in the loop

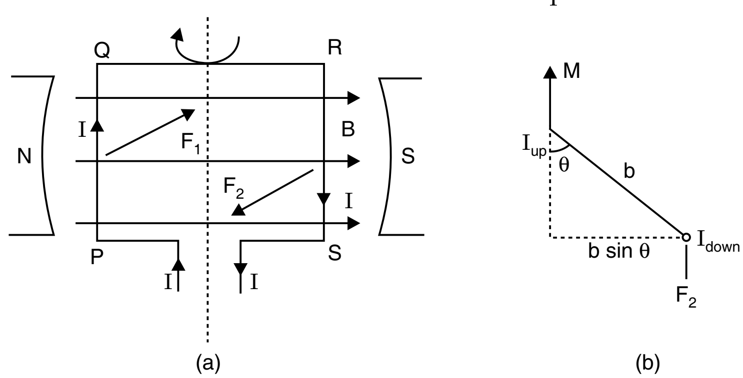

Fig. 4.38

According to Fleming's left-hand rule, the side *PQ* experiences a normal inward force, $F_1 = IaB$ and side *SR* experiences a normal outward force, $F_2 = IaB$. These two equal and opposite forces form a couple which exerts a torque given by

$$\tau = \text{Force} \times \text{Perpendicular distance}$$
$$= IaB \times b \sin\theta$$
$$= IB\,(ab) \sin\theta$$
$$= IBA \sin\theta \qquad [\because A = ab]$$

As the coil has N turns, so

$$\tau = NBA \sin\theta$$

Conversion of galvanometer into ammeter: A galvanometer can be converted into an ammeter by connecting a low resistance S in parallel with it. This low resistance is called shunt.

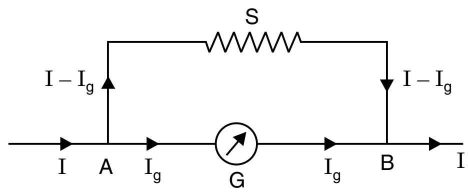

Fig. 4.39

Let I_g be the current with which the galvanometer gives full scale deflection. As galvanometer and shunt are connected in parallel, so

$P.D.$ across the galvanometer = $P.D.$ across the shunt

or $$I_g R_g = (I - I_g) R_s$$

or $$R_s = \frac{I_g}{I - I_g} \times R_g$$

Hence by connecting a shunt of resistance R_s across the galvanometer, we get an ammeter of desired range.

Q. 12. *A circular coil of 200 turns, radius 5 cm carries a current of 2.5 A. It is suspended vertically in a uniform horizontal magnetic field of 0.25 T, with the plane of the coil making an angle of 60° with the field lines. Calculate the magnitude of the torque that must be applied on it to prevent it from turning.*

Ans. Given, $N = 200$, $r = 5 \times 10^{-2}$ m

Area of coil, $A = \pi r^2$

$$= \frac{22}{7} \times 5 \times 10^{-2} \times 5 \times 10^{-2}$$

$$= 7.857 \times 10^{-3} \text{ m}^2$$

$I = 2.5\ A$, $B = 0.25\ T$, $\theta = 60°$

Since, $\tau = NBIA \cos\theta$

where θ is the angle between the plane of the coil and the direction of the magnetic field.

Now, $$\tau = 200 \times 0.25 \times 2.5 \times 7.857 \times 10^{-3} \times \cos 60° \text{ Nm}$$

$$= 0.49 \text{ Nm}$$

An opposite and equal torque is required in order to prevent the coil from turning. Thus, the magnitude of the applied torque should be 0.49 m.

Q. 13. *Draw the field lines of (a) a bar magnet (b) a current carrying finite solenoid, and (c) an electric dipole.*

What basic difference do you notice between the magnetic and electric field lines? How do you explain this difference?

Ans. The magnetic field lines.

The field lines of (*a*) a bar magent, (*b*) a current carrying finite solenoid and (*c*) electric dipole. At large distances, the field lines are very similar. The curves labelled (*i*) and (*ii*) are closed Gaussian surfaces.

There is a basic difference between magnetic and electric field lines. In case of the electric field of an electric dipole, the electric lines of force originate from positive charge and end at the negative charge.

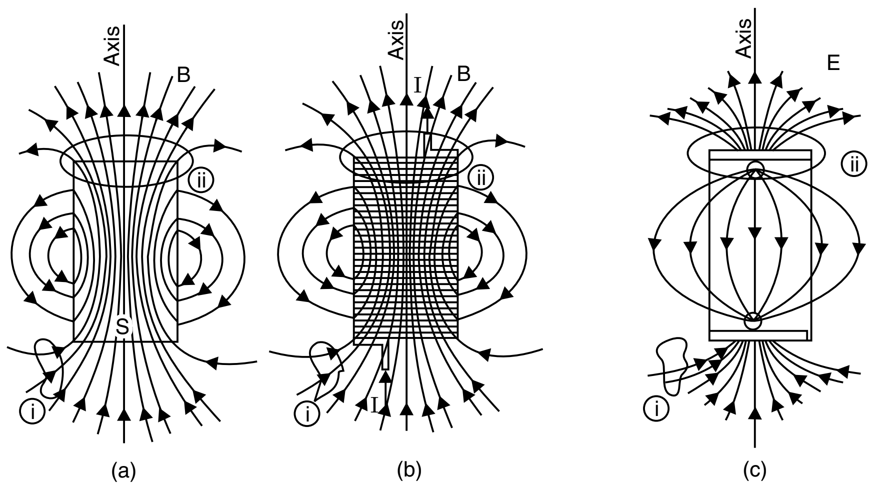

Fig. 4.40

In case of a bar magnet, the magnetic field lines are closed loops, *i.e., magnetic field lines do not start or end anywhere.*

Q. 14. *Two long parallel straight wires X and Y separated by a distance of 5 cm in air carry currents of 10 A and 5 A respectively in opposite directions. Calculate the magnitude and direction of the force on a 20 cm length of the wire Y.*

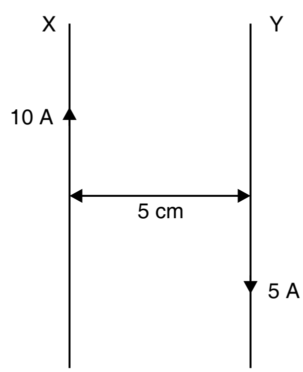

Fig. 4.41

Ans. By using formula,

$$F = \frac{\mu_0 I_1 I_2 \, l}{2\pi r}$$

$$= \frac{4\pi \times 10^{-7} \times 10 \times 5 \times 0.20}{2\pi \times 0.05} = 4 \times 10^{-5} \text{ N}.$$

The direction of force is perpendicular to the length of wire Y and acts away from X (repulsion).

Q. 15. *A charge 2Q is spread uniformly over an insulated ring of radius R/2. What is the magnetic moment of the ring if it is rotated with an angular velocity ω with respect to normal axis?*

Ans. Charge on the element of length dl of the ring is $d_q = \lambda \cdot dl$

$$dq = \frac{2Q}{2\pi(R/2)}dl = \frac{2Q}{\pi R}dl$$

Current due to circular motion of this charge is

$$dI = dq \times v = \frac{2Q}{\pi R}dl \times \frac{\omega}{2\pi} \qquad (\because \omega = 2\pi v)$$

Magnetic moment due to current dl

$$dM = dI \times \pi (R/2)^2 = \frac{2Q}{\pi R}dl \times \frac{\omega}{2\pi} \times \pi (R/2)^2$$

or,
$$M = \frac{Q\omega R}{4\pi}\int dl = \frac{Q\omega R}{4\pi} \cdot 2\pi R = \frac{1}{2}Q\omega R^2 .$$

Q. 16. *A galvanometer with a coil of resistance 120 ohm shows full scale deflection for a current of 2.5 mA. How will you convert the galvanometer into an ammeter of range 0 to 7.5 A? Determine the net resistance of the ammeter. When an ammeter is put in a circuit, does it read slightly less or more than the actual current in the original circuit? Justify your answer.*

Ans.
$$R_g = 120\ \Omega,\ I_g = 2.5\ \text{mA} = 0.0025\ \text{A}$$
$$I = 7.5\ \text{A}$$

$$R_s = \frac{I_g}{I - I_g} \times R_g = \frac{0.0025}{7.5 - 0.0025} \times 120 = 0.04\ \Omega$$

By connecting a shunt of 0.04 Ω across the given galvanometer, we get an ammeter of range of 0 to 7.5 A.

Net resistance of the ammeter

$$= \frac{120 \times 0.04}{120 + 0.04} = 0.03998\ \Omega$$

When an ammeter is put in a circuit, it reads slightly less than the actual current. An ammeter has a small resistance. When it is connected in the circuit, it decreases the current by a small amount.

Q. 17. *An electron of 45 eV energy is revolving in a circular path in a magnetic field of intensity 9×10^{-5} Wb m^{-2}. Determine (i) the speed of the electron (ii) radius of the circular path.*

Ans.
$$\frac{1}{2}mv^2 = 45 \times 1.6 \times 10^{-19}$$

or,
$$v = \sqrt{\frac{2 \times 45 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}}}\ \text{ms}^{-1} = 3.98 \times 10^6\ \text{ms}^{-1}$$

Now,
$$Bev = \frac{mv^2}{r} \quad \text{or} \quad r = \frac{mv}{Be}$$

or,
$$r = \frac{9.1 \times 10^{-31} \times 3.98 \times 10^6}{9 \times 10^{-5} \times 1.6 \times 10^{-19}}\ \text{m} = 0.25\ \text{m}$$

Q. 18. *State Biot-Savart law. A current I flows in a conductor placed perpendicular to the plane of the paper. Indicate the direction of the magnetic field due to a small element $\vec{dl}$ at point P situated at a distance $\vec{r}$ from the element as shown in the figure.*

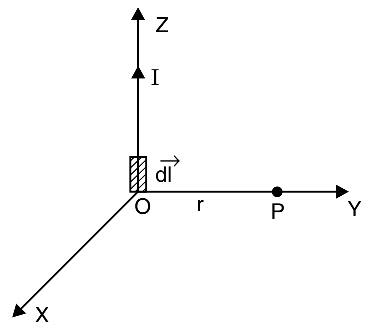

Fig. 4.41

Ans. Biot-Savart law states that the magnitude of magnetic field induction at a point due to a current element of length *dl*, carrying current *I*, at a point *r* from the element is given by

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{I\, dl \sin\theta}{r^2}$$

Vector form: $$|\vec{dB}| = \frac{\mu_0}{4\pi} \cdot \frac{|dl \times I|}{r^3}$$

The direction of magnetic field $\vec{dB}$ is perpendicular to the plane containing $\vec{dl}$ and $\vec{r}$ and is directed inward.

III. LONG ANSWER TYPE QUESTIONS

Q. 1. *An iron core is inserted into a solenoid 0.5 m long with 400 turns per unit length. The area of cross-section of the solenoid is 0.01 m2. (a) Find the permeability of the core when a current of 5 A flows through the solenoid winding. Under these conditions, the magnetic flux through the cross-section of the solenoid is 1.6×10^{-3} Wb. (b) Find the inductance of the solenoid under these conditions.*

Ans. The magnetic induction on the axis of the solenoid is given by

$$B = \mu\, [\mu_0 n I]$$

$$B = \mu \left(\frac{\mu_0}{4\,\pi}\right) 4\,\pi n i$$

where μ is the permeability of the medium, *n* the number of turns per unit length and *i* is the current.

(*a*) Magnetic flux $\boxed{\phi = BA,}$ since the normal to the area is along the direction of the field.

Given, $\phi = 1.6 \times 10^{-3}$ Wb, $A = 0.001 = 10^{-3}$ m^2

Therefore, $$B = \frac{\phi}{A} = \frac{1.6 \times 10^{-3}}{10^{-3}} = 1.6 \text{ Wb m}^{-2}$$

Since $n = 400$, $i = 5$ A and $\frac{\mu_0}{4\pi} = 10^{-7}$ Hm^{-1}

We have $1.6 = \mu \times 10^{-7} \times 4\pi \times 400 \times 5$

which gives, $\mu = \dfrac{1.6 \times 10^{7}}{4\pi \times 5 \times 400} = 636.7 \approx 637$

(*b*) Total number of turns in the solenoid is given by

$$N = n \times l = 400 \times 0.5 = 200$$

Total flux through the solenoid is

$$N\phi = 200 \times 1.6 \times 10^{-3} = 0.32 \text{ Wb}$$

Self inductance $\boxed{L = \dfrac{N\phi}{i}} = \dfrac{0.32}{5} = 0.064 \text{ H} = 64 \text{ mH}$

Alternatively,

$$\boxed{L = \frac{\mu\,\mu_0 N^2 A}{l}} = \mu\,\mu_0 n^2 l\, A$$

$$= 637 \times (4\pi \times 10^{-7}) \times 400 \times 400 \times 0.5 \times 10^{-3}$$

$$= 6.4 \times 10^{-2} \text{ H} = 64 \text{ mH}$$

Q. 2. *(a) Using Biot-Savart's law, derive an expression for the magnetic field at the centre of a circular coil of radius R, number of turns N, carrying current i.*

(b) Two small identical circular coils marked 1, 2 carry equal currents and are placed with their geometric axes perpendicular to each other as shown in the figure. Derive an expression for the resultant magnetic field at 0.

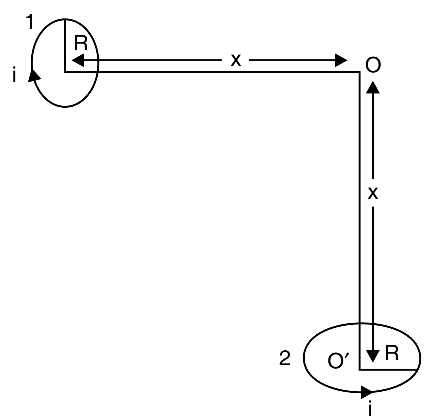

Fig. 4.42

Ans. As per Biot-Savart law, the magnetic field due to a current element $\vec{dl}$ at the observation point whose position vector $\vec{r}$ is given by

$$\vec{dB} = \frac{\mu_0 I}{4\pi} \cdot \frac{\vec{dl} \times \vec{r}}{r^3}$$

where, μ_0 is the permeability of free space.

Consider a circular loop of wire of radius *r* carrying a current *I* and also a current element *dl* of the loop.

The direction of *dl* is along the tangent, so $dl \perp r$. From Biot-Savart law, magnetic field at the centre O due to this current element is

$$dB = \frac{\mu_0 I}{4\pi}\frac{dl \sin 90°}{r^3} = \frac{\mu_0 I}{4\pi}\frac{dl}{r^2}$$

The magnetic field due to all such current elements will point into the plane of paper at the centre O. Hence the total magnetic field at the centre O is given by

$$B = \int dB = \int \frac{\mu_0 I\, dl}{4\pi r^2}$$

or, $$B = \frac{\mu_0 I}{4\pi r^2}\int dl = \frac{\mu_0 I}{4\pi r^2}\cdot l$$

$$= \frac{\mu_0 I}{4\pi r^2}\cdot 2\pi r \text{ or } B = \frac{\mu_0 I}{2r}$$

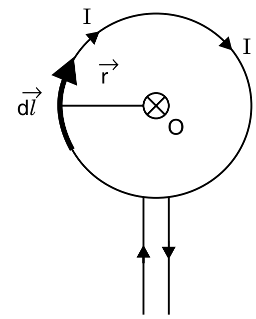

Fig. 4.43

For a coil of N turns, $B = \frac{\mu_0 NI}{2r}$

(*b*) Magnetic field at 0 due to loop 1.

$$B_1 = \frac{\mu_0 i R^2}{2\left(x^2+R^2\right)^{3/2}} \text{ acting towards left}$$

Magnetic field at O due to loop 2.

$$B_2 = \frac{\mu_0 i R^2}{2\left(x^2+R^2\right)^{3/2}} \text{ acting vertically upwards}$$

Here R is the radius of each loop.
Resultant field at O will be

$$B = \sqrt{B_1^2+B_2^2} = \sqrt{2B_1} \qquad (\because B_1 = B_2)$$

$$= \frac{\mu_0}{\sqrt{2}}\frac{i R^2}{\left(x^2+R^2\right)^{3/2}}$$

This field acts at an angle of 45° with the axis of loop 1.

Q. 3. *Two long parallel wires carrying currents 2.5 ampere and I ampere in the same direction (directed into the plane of the paper) are held at P and Q respectively such that they are perpendicular to the plane of paper. The points P and Q are located at a distance of 5 metre and 2 metre respectively from a collinear point R (see figure).*

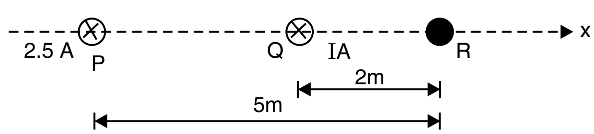

Fig. 4.44

(*i*) *An electron moving with a velocity of 4×10^5 m/s along the positive x-direction experiences a force of magnitude 3.2×10^{-20} N at the point R. Find the value of I.*

(*ii*) *Find all the positions at which a third long parallel wire carrying a current of magnitude 2.5 amperes may be placed so that the magnetic induction at R is zero.*

Ans. (*i*) Magnetic field B_1 due to P at R

$$B_1 = \frac{\mu_0 I}{2\pi r} = \frac{\mu_0}{2\pi}\left(\frac{2.5}{5}\right)$$

Magnetic field B_2 due to Q at B

$$B_2 = \frac{\mu_0}{2\pi}\frac{I}{r} = \frac{\mu_0}{2\pi}\left(\frac{I}{2}\right)$$

Resultant magnetic field at R

$$B = B_1 + B_2 = \frac{\mu_0}{2\pi}\left(\frac{2.5}{5} + \frac{I}{2}\right) \quad ...(i)$$

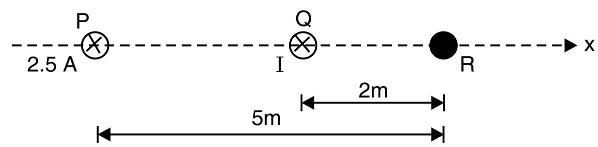

Fig. 4.45

This field B at R acts ● downwards and perpendicular to PX. Force experienced by electron moving along PX is

$$\vec{F} = e\left(\vec{v} \times \vec{B}\right) \qquad \theta = 90°$$

$\vec{F}$ is perpendicular to both $\vec{v}$ and $\vec{B}$. Because of the negative charge of electron (*i.e.*, q = negative) the force F acts perpendicular to the plane of *paper directed upwards*.

Now, $F = evB$

$$\therefore \qquad B = \frac{F}{ev} = \frac{3.2 \times 10^{-20}}{1.6 \times 10^{-19} \times 4 \times 10^5} = 0.5 \times 10^{-6} \quad ...(ii)$$

Equating this to (1), we get

$$\frac{\mu_0}{2\pi}\left[\frac{2.5}{5} + \frac{I}{2}\right] = 0.5 \times 10^{-6}$$

which gives

$$I = 2\left[\frac{2\pi}{\mu_0}\left(0.5 \times 10^{-6}\right) - \frac{2.5}{5}\right] = 2\left[\frac{2\pi \times \left(0.5 \times 10^{-6}\right)}{4\pi \times 10^{-7}} - \frac{2.5}{5}\right]$$

$$= 2\left[\frac{2.5}{1} - \frac{2.5}{5}\right] = 4\text{A}$$

(*ii*) In this case, we consider the following alternatives:

(*a*) When the current 2.5 A is directed *into the plane* of paper. If r is the distance of this current wire from R. We have $B_3 = \left(\frac{\mu_0}{2\pi}\right)\left(\frac{2.5}{r}\right)$

Now, $B_1 + B_2 + B_3 = 0$ we get,

$$\frac{\mu_0}{2\pi}\left(\frac{2.5}{5}+\frac{4}{2}+\frac{2.5}{r}\right) = 0$$

which gives $r = -1$ m

Thus the third wire is located at 1 m from R on RX.

(*b*) When the current 2.5 A is directed *out from the plane* of paper upwards.

Here $I_3 = -2.5$ A

Hence we will similarly have

$$\frac{\mu_0}{2\pi}\left(\frac{2.5}{5}+\frac{4}{2}+\frac{2.5}{r}\right) = 0$$

which gives $r = 1$ m *i.e.*, the third wire is located 1 m from R on RQ.

Q. 4. *Two parallel co-axial circular coils of equal radius 'R' and equal number of turns 'N', carry equal currents 'I' in the same direction and are separated by a distance '2R'. Find the magnitude and direction of the net magnetic field produced at the mid-point of the line joining their centres.*

Ans. Magnetic field at the mid-point due to loop 1.

$$B_1 = \frac{\mu_0 \, i \, R^2}{2\left(R^2+R^2\right)^{3/2}}\text{, acting towards right}$$

Magnetic field at the mid-point due to loop 2.

$$B_2 = \frac{\mu_0 \, i \, R^2}{2\left(R^2+R^2\right)^{3/2}}\text{, acting towards right}$$

∴ Total magnetic field at the mid-point

$$B = B_1 + B_2$$

or,

$$B = \frac{\mu_0 \, i \, R^2}{\left(2R^2\right)^{3/2}}$$

which is acting towards right.

Q. 5. *Depict the magnetic field lines due to two straight, long parallel conductors carrying currents I_1 and I_2 in the same direction. Hence deduce on expression for the force acting per unit length on one conductor due to the other. Is this force attractive or repulsive?*

Figure shows a rectangular current carrying loop placed 2 cm away from a long, straight, current carrying conductor. What is the direction and magnitude of the net force acting on the loop?

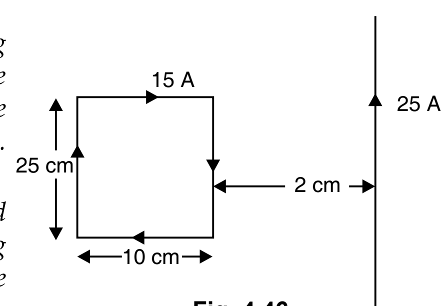

Fig. 4.46

Ans. Two infinitely long conductors AB and CD with currents I_1 and I_2 in same direction respectively, placed parallel to each other and separated by distance r.

Magnetic field produced by current I_1 at any point of CD is

$$B_1 = \boxed{\frac{\pi_0\, I_1}{2\pi r}}$$

This field acts perpendicular to CD and into the plane of paper. It exerts a force on wire CD carrying current I_2.

Force exerted on unit length of CD is

$$F = B_1 I_2 l = \frac{u_0\, I_1}{2\pi r} \times I_2 \times 1$$

or, $$F = \frac{\mu_0\, I_1 I_2}{2\pi r} \text{ or } \frac{\mu_0}{4\pi}\cdot\frac{2 I_1 I_2}{r}$$

According to Fleming's left hand rule, this force acts on CD towards AB. Similarly, conductor CD also exerts an equal force AB towards itself. Hence the two wires get attracted towards each other.

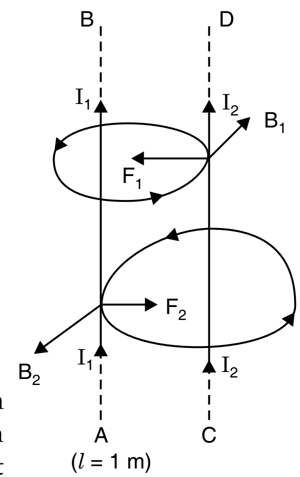

Fig. 4.47

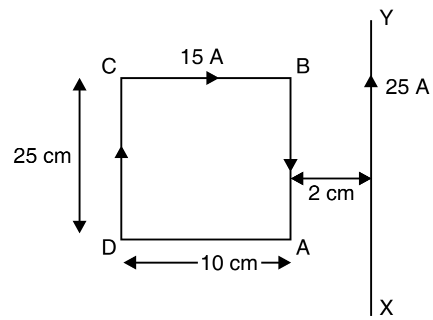

Fig. 4.48

Numerical:

Force on AB, $$F_1 = \frac{\mu_0}{4\pi}\cdot\frac{2I_1I_2}{r_1} \times \text{length of } AB$$

or, $$F_1 = \frac{10^{-7} \times 2 \times 15 \times 25}{2 \times 10^{-2}} \times 25 \times 10^{-2}$$

$= 9.375 \times 10^{-4}$ N (attractive, towards XY)

Force on CD, $$F_2 = \frac{\mu_0}{4\pi}\cdot\frac{2I_1I_2}{r_2} \times \text{length of } CD$$

$$= \frac{10^{-7} \times 2 \times 15 \times 25}{2 \times 10^{-2}} \times 25 \times 10^{-2}$$

$= 1.5625 \times 10^{-14}$ N (repulsive, away from XY)

Net force on the loop,

$F = F_1 - F_2 = (9.375 - 1.5625) \times 10^{-4}$

$= 7.8125 \times 10^{-4}$ (attractive towards XY).

Q. 6. *A circular coil of 25 turns and radius 6.0 cm, carrying a current of 10 A, is suspended vertically in a uniform magnetic field of magnitude 1.2 T. The field lines run horizontally in the plane of the coil. Calculate the force and torque on coil due to the magnetic field. In which direction should a balancing torque be applied to prevent the coil from turning?*

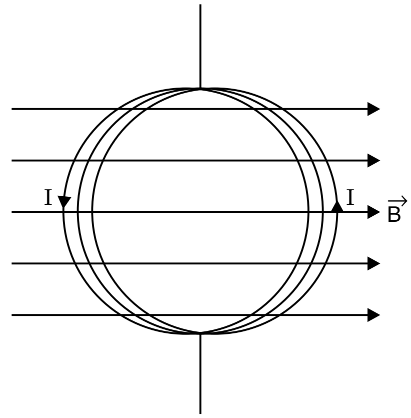

Fig. 4.49

Ans. Consider any element $\vec{dl}$ of the wire. The force on this element is $I\left(\vec{dl}\times\vec{B}\right)$. For each element $\vec{dl}$, there is another length element $-\vec{dl}$ on the closed loop give by $-\vec{dl}$. Since $\vec{B}$ is uniform, therefore, the forces cancel for each pair of such elements. So, the net force on the coil is zero.

The torque $\vec{\tau}$ on a plane loop of any shape carrying a current I in a magnetic field B is given by

$$\vec{\tau} = IA\ \hat{n}\times\vec{B}$$

where $\hat{n}$ is a unit vector normal to the plane of the loop (direction of motion of a right-handed screw rotating in the sense of current). For a circular coil of radius r and N turns, $A = N \times \pi r^2$

In the given problem, the angle between $\hat{n}$ and $\vec{B}$ is 90°.

Now, $\tau = BIA \sin\alpha$

$$= 1.2 \times 10 \times 25 \times \pi(0.06)^2 \sin 90° = 3.39 \text{ N m}$$

The direction of $\vec{\tau}$ is vertically upwards. To prevent the coil from turning, an equal and opposite torque must be applied.

Q. 7. *State and prove Ampere's circuital law.*

Ans. Refer to Page 227.

Q. 8. *A rectangular coil of sides 8 cm and 6 cm having 2000 turns and carrying a current of 200 mA is placed in a uniform magnetic field of 0.2 T directed along the positive x-axis. (a) What is the maximum torque the coil can experience? In which orientation does it experience the maximum torque? (b) For which orientations of the coil is the torque zero? When is this equilibrium stable and unstable.*

Ans. We know that a current loop, having n turns, each of area A, carrying current I, when placed in a magnetic field $\vec{B}$, experience a torque whose magnitude is given by

$$\tau = nIAB \sin\alpha \qquad ...(i)$$

where α is the angle which the normal on the plane of the current loop makes with the direction of magnetic field, *i.e.*, angle between $\vec{A}$ and $\vec{B}$.

Here, $N = 2000$,

$I = 200 \text{ mA} = 200 \times 10^{-3}\ A$,

$A = 8 \times 6 \text{ sq. cm} = 48 \times 10^{-4} \text{ m}^2$;

$B = 0.2$ T.

(*a*) Torque acting on the coil will be maximum when

$$\sin\alpha = 1$$

or $$\alpha = 90°$$

$\therefore$ Maximum torque, $\tau_{max} = NIAB$

$$= 2000 \times (2.0 \times 10^{-3}) \times (48 \times 10^{-4}) \times 0.2$$

$$= 0.384 \text{ N–m}$$

In this situation, the plane of the coil is parallel to the direction of magnetic field *i.e.,* the plane of the coil is in the direction of *X*-axis.

(*b*) Torque on the coil will be zero, if $\sin\alpha = 0$ or $\alpha = 0°$ or $180°$. It will be so if plane of the coil is perpendicular to the direction of magnetic field *i.e.,* the plane of the coil is along *Y* or *Z*-axis.

The coil will be in stable equilibrium when $\vec{A}$ is parallel to $\vec{B}$ and is unstable equilibrium when $\vec{A}$ is antiparallel to $\vec{B}$.

Q. 9. (*i*) *What is the relationship between the current and the magnetic moment of a current carrying circular loop? Use the expression to derive the relation between the magnetic moment of an electron moving in a circle and its related angular momentum?*

(*ii*) *A muon is a particle that has the same charge as an electron but is 200 times heavier than it. If we had an atom in which the muon revolves around a proton instead of an electron, what would be the magnetic moment of the muon in the ground state of such an atom?*

Ans. Let us assume that an electron of mass m_e and charge *e* revolves in a circular orbit of radius *r* around the positive nucleus in anticlockwise direction.

The angular momentum of the electron due to its orbital motion is given by

$$L = m_e vr \quad ...(i)$$

Let the period of orbital motion of the electron is *T*. Then, the electron crosses any point on its orbit after every *T* seconds.

Therefore, orbital motion of electron is equivalent to a current.

$$I = e\cdot\left(\frac{1}{T}\right)$$

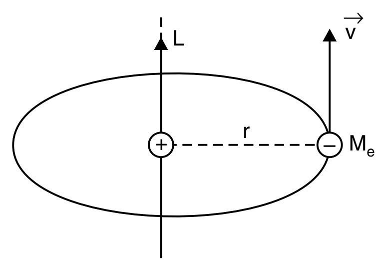

Fig. 4.50

The period of revolution of the electron is given by

$$T = \frac{2\pi r}{v}$$

$\therefore$ $$I = e\left(\frac{1}{2\pi r / v}\right) = \frac{ev}{2\pi r}$$

The area of the electron orbit, $A = \pi r^2$

The magnetic dipole moment of the atom is $\boxed{M = IA}$

$$M = \frac{ev}{2\pi r}\times \pi r^2 = \frac{evr}{2} \quad ...(ii)$$

$\therefore$ Using the equation (*i*) we have

$$M = \left(\frac{e}{2m_e}\right)L \quad \text{[From I]}$$

In vector rotation

$$\vec{M} = -\left(\frac{e}{2m_e}\right)\vec{L}$$

which tells that the magnetic dipole moment vector is directed in a direction opposite to that of angular momentum vector.

(*ii*) Given, $e = 1.6 \times 10^{-19}$ C (charge on muon)

$$m = 200\, m_e \text{ (mass of muon)}$$
$$= 200 \times 9.1 \times 10^{-31} \text{ kg}$$
$$= 18.2 \times 10^{-29} \text{ kg}$$

For ground state $n = 1$

∴ Magnetic moment of muon is

$$M = n\left(\frac{en}{4\pi m_e}\right)$$

or, $$M = \frac{1 \times 1.6 \times 10^{-19} \times 6.6 \times 10^{-34}}{4 \times 3.14 \times 18.2 \times 10^{-29}}$$

or, $$M = \frac{10.56 \times 10^{-53}}{228.592 \times 10^{-29}}$$

or, $$M = 0.046 \times 10^{-24}$$

or, $$M = 4.6 \times 10^{-26} \text{ Am}^2$$

QUESTIONS ON HIGH ORDER THINKING SKILLS (HOTS)

Q. 1. *A coil in the shape of an equilateral triangle of side 0.02 m is suspended from a vertex such that it is ranging in a vertical in plane magnetic field of 5 × 10⁻² T. Find the couple acting on the coil when a current of 0.1 ampere is passed through it and the magnetic field is parallel to its plane.*

Ans. As the coil is in the form of an equilateral triangle, its area

$$A = \frac{\sqrt{3}}{4} \times 0.02 \times 0.02$$
$$A = \sqrt{3} \times 10^{-4} \text{ m}$$
$$= \sqrt{3} \times 10^{-4} \text{ m}^2$$

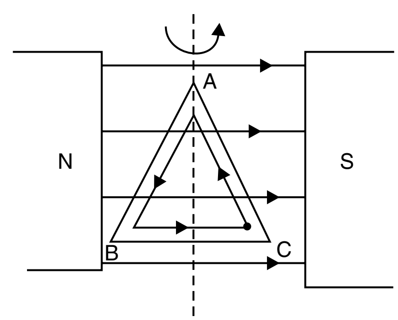

Fig. 4.51

Torque on current carring coil in magnetic field is

$$\tau = BINA \sin\alpha$$
$$\alpha = 90°$$
$$N = 1$$
$$\tau = BIA$$
$$= 5 \times 10^{-2} \times 0.1 \times \sqrt{3} \times 10^{-4} \text{ N-m}$$
$$= 0.5 \times \sqrt{3} \times 10^{-6}$$
$$= 5\sqrt{3} \times 10^{-7}$$

Q. 2. *A solenoid of length 0.4 m and having 500 turns of wire carries a current of 3 A. A thin coil having 10 turns of wire and of radius 0.01 m carries a current of 0.4 A. Calculate the torque required to hold the coil in the middle of the solenoid with its axis perpendicular to the axis of the solenoid.*

Ans. The torque acting on a current loop of turn N and current i in a magnetic field of induction B due to a solenoid is given by

$$\tau = (N\ i\ A)\ B \sin\theta$$

where i is the current flowing in N turns of the loop with face area A and making an angle θ with the field. $N\ i\ A$ can be regarded as the magnetic dipole moment M. The magnetic dipole moment M of the loop lies along the axis of the loop. Magnetic field B due to a *solenoid* is given by

$$\boxed{B = \mu_0\, n\, i_0}$$

where n is the number of turns per unit length of the solenoid and i_0 is the current in the solenoid. The direction of B is along its axis. Therefore, when the small coil is held with its axis perpendicular to the axis of the solenoid, the torque becomes

$$\boxed{\tau = \mu_0\, n i_0\, N\, i\, A}$$

Here $N = 10,\ n = \dfrac{500}{0.4} = 1250,\ i_0 = 3\ A,\ i = 0.4\ \text{A}$

$A = \pi r^2 = \pi\ (0.01)^2 = \pi \times 10^{-4}\ \text{m}^2,\ \mu_0 = 4\ \pi \times 10^{-7}$

$\therefore$ $\tau = 4\ \pi \times 10^{-7} \times 1250 \times 3 \times 10 \times 0.4 \times \pi \times 10^{-4}$ N-m

$= 5.922 \times 10^{-6}$ N-m

Q. 3. *A current carrying coil of 200 turns has an area of cross-section $1 \times 10^{-4}\ m^2$. When suspended freely through its centre, it can turn in a horizontal plane. What is the magnetic moment of the coil for a current of 5 A? Also calculate the net force and torque on coil if a uniform horizontal field of 10×10^{-2} T is set up at an angle of 30° with axis of coil when it is carrying the same current.*

Ans. Here, $N = 200,\ A = 1 \times 10^{-4}\ \text{m}^2,\ I = 5\ \text{A}\ ;\ M = ?$

$M = N\,IA = 200 \times 5 \times 10^{-1} = 10^{-1}\ \text{JT}^{-1}$

In a uniform horizontal field $B = 10 \times 10^{-2}\ T$, the ends of coil experience equal and opposite forces. Therefore, net force on the coil = zero.

Torque, $\tau = MB \sin\theta = 10^{-1} \times 10 \times 10^{-2} \sin 30°$

$= 10^{-2} \times \dfrac{1}{2} = 0.5 \times 10^{-2}$ Nm

Q. 4. *A galvanometer of resistance 50 Ω gives full scale deflection for a current of 0.05 A. Calculate the length of the shunt wire required to convert the galvanometer into an ammeter of range 0 to 5 A. The diameter of the shunt wire is 2 mm and its resistivity is 5×10^{-7} Ω m.*

Ans. By using the formula,

$$\boxed{S = \frac{G\,I_g}{I - I_g}}$$

Putting the values,

$$S = \frac{50 \times 0.05}{5 - 0.05}\,\Omega = \frac{50}{99}\,\Omega$$

Now, $S = p\dfrac{1}{\pi r^2}$ or $l = \dfrac{\pi r^2 S}{p}$

putting the values,

$$l = \frac{22}{7} \times \left(1 \times 10^{-3}\right)^2 \times \frac{50}{99} \times \frac{1}{5 \times 10^{-7}} = 3.175 \text{ m.}$$

Q. 5. *Two parallel wires Q and R carry currents 5 A and 10 A respectively in opposite directions. A plane lamina ABCD intersects the wires at right angles at points Q and R. Find the magnitude of the total magnetic induction at point P located in the lamina as shown in the figure.*

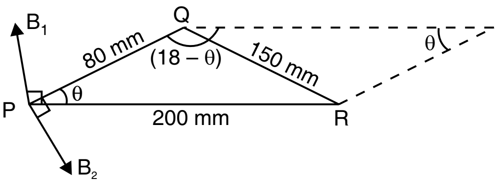

Fig. 4.52

Ans. The magnetic induction at P due to the 10 A current,

$$B_1 = \frac{\mu_0 I_1}{2\pi r_1} = \frac{4\pi \times 10^{-7} \times 10}{2\pi \times 200 \times 10^{-3}} T = 10\ \mu T$$

The magnetic induction at P due to the 5 A current,

$$B_2 = \frac{\mu_0 I_2}{2\pi r_2}$$

$$B_2 = \frac{\cancel{4}^{2}\ \pi \times 10^{-7} \times 5}{2\pi \times \cancel{80}_{40} \times 10^{-3}}$$

$$B_2 = \frac{5 \times \cancel{100} \times 10^{-7}}{\cancel{100}}$$

$= 125 \times 10^{-1} \times 10^{-6}$

$= 12.5 \times \mu T$

Resultant magnetic induction,

$$B = \sqrt{B_1^2 + B_2^2 + 2B_1B_2 \cos(180° - \theta)}$$

where $QR^2 = PQ^2 + PR^2 - 2PQ.\ PR \cos\theta$

$$\cos\theta = \frac{-150^2 + 80^2 + 200^2}{2 \times 80 \times 200} = +0.7469$$

$$B = 10^{-6}\sqrt{10^2 + 12.5^2 - 2 \times 10 \times 12.5 \times 0.7469} = 8.34 \times 10^{-6}\ T$$

$= 8.34\ \mu T$

Q. 6. *Two concentric coplanar semi-circular conductors form part of two current loops as shown in the figure. If their radii are 11 cm and 4 cm, calculate the magnetic induction at the centre.*

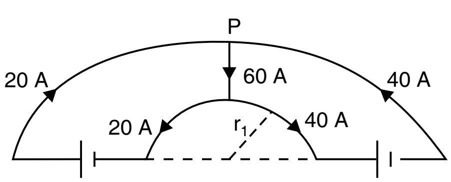

Fig. 4.53

Ans. Magnetic field due to circular loop at centre

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

Magnetic induction at 0 due 4 quadrant of wire

$$= \frac{1}{4}\frac{\mu_0}{2}\left(\frac{40}{r_1} - \frac{40}{r_2}\right) - \frac{1}{4}\frac{\mu_0}{2}\left(\frac{20}{r_1} - \frac{20}{r_2}\right)$$

$$= \frac{4\pi \times 10^{-7}}{8}\left[20\left(\frac{1}{r_1} - \frac{1}{r_2}\right)\right]$$

$$= \frac{4\pi \times 10^{-7}}{8}\left[20\left(\frac{1}{4 \times 10^{-2}} - \frac{1}{11 \times 10^{-2}}\right)\right]$$

$= 5 \times 10^{-5}$ weber/m^2 (inward)

Q. 7. *Derive an expression for the maximum force experienced by a straight conductor of length l, carrying current I and kept in a uniform magnetic field, B.*

Ans. Consider a straight conductor PQ of length l, area of cross section A carrying current I placed in a uniform magnetic field $\vec{B}$. Suppose the conductor is placed along x-axis and magnetic field acts along y-axis. Current I flows from end P to Q and electrons drift from Q to P.

Let $\overrightarrow{v_d}$ = drift velocity of electron

$-e$ = charge on each electron

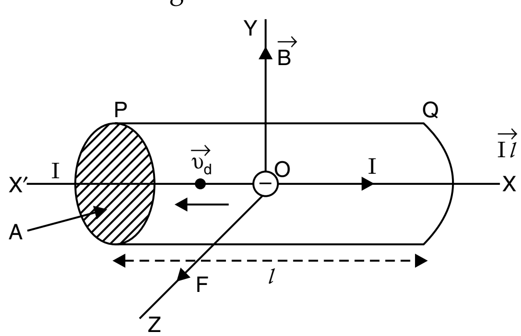

Fig. 4.54

Magnetic Lorentz force on an electron is given by

$$\vec{f} = -e(\vec{v}_d \times \vec{B}) \qquad \left[\because F = q(\vec{v} \times \vec{B})\right]$$

If n is the number of free electrons per unit volume of the conductor, then total number of free electrons in the conductor will be

$$N = n(Al) = nAl$$

$\therefore$ Total force on the conductor is

$$\vec{F} = N\vec{f} = nAl\left[-e(\vec{v}_d \times \vec{B})\right]$$

$$= -nAle(\vec{v}_d \times \vec{B}) \qquad ...(i)$$

But the current through a conductor is related with drift velocity be the relation.

$$\boxed{I = n\,A\,e\,v_d}$$

$\therefore$ $$Il = n\,A\,e\,v_d l$$

We represent $I\vec{l}$ as current element vector. It acts in the direction of flow of current *i.e.,* along *OX.* Then have $I\vec{l}$ and $\vec{v}_d$ opposite directions. So

$$\boxed{I\vec{l} = -n\,Ale\,\vec{v}_d} \quad ...(ii)$$

From (*i*) and (*ii*), we have

$$\vec{F} = I\left(\vec{l}\times\vec{B}\right)$$

Magnitude of

$$F = I\,l\,B\sin\theta$$

When $\pi = 90°$, $F_{max} = I\,l\,B$.

Fleming's left hand rule: This rule gives the direction of force on current carring conductor placed in magnetic field per pendicularly. If we stretch the fore finger, central finger and the thumb of our left hand mutually perpendicular to each other such that the fore finger points in the direction of magnetic field, central finger in the direction of current, then the thumb gives the direction of force experienced by the conductor.

Q. 8. *A straight horizontal conducting rod of length 0.60 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 wire.*

(a) What magnetic field should be set up normal to the conductor in order that the tension in the wire is zero?

(b) What will be total tension in the wires if the direction of current is reversed, keeping the magnetic field same as before (Ignore mass of the wire), $g = 10\ ms^{-2}$.

Ans. Given, $l = 0.60$ m, m = 60 g = 60×10^{-3} kg

$I = 5.0$ A

(*a*) Tension in the wire is zero if the force on the wire carrying current due to magnetic field is equal and opposite to the weight of wire, *i.e.,*

$$BIl = mg$$

or $$B = \frac{mg}{I\,l} = \frac{\left(60\times10^{-3}\right)\times10}{5.0\times0.60} = 0.20\ \text{T}$$

The force on the conductor due to magnetic field will be upwards if the direction of magnetic field is horizontal and normal to the conductor.

(*b*) When direction of current is reversed, *BIl* and *mg* will act vertically downwards, the effective tension in the wires,

$$T = BIl + mg$$
$$= 0.2 \times 5.0 \times 0.60 + (60 \times 10^{-3}) \times 10$$
$$= 1.2\ \text{N}.$$

Q. 9. *An electron beam passes through a magnetic field of* 4×10^{-3} *weber/m²* *and an electric field of* $2 \times 104\ Vm^{-1}$, *both acting simultaneously. The path of electron remaining undeviated, calculate the speed of the electrons. If the electric field is removed, what will be the radius of the electron path?*

Ans. Given, $B = 4 \times 10^{-3}$ weber/m^2

$E = 2 \times 10^4$ V/m

The force on the moving electron due to electric field is equal and opposite to the force on moving electron due to magnetic field since the path of moving electron is undeviated, *i.e.,*

$$\boxed{eE = evB}$$

or, $$v = \frac{E}{B} = \frac{2\times10^4}{4\times10^{-3}} = 5\times10^6 \text{ m/s}.$$

When electron moves perpendicular to magnetic field, the radius r of circular path traced by electron is

$$\boxed{r = \frac{mv}{eB}} = \frac{(9.1\times10^{-31})\times(5\times10^6)}{(1.6\times10^{-19})\times4\times10^{-3}}$$

$$= 7.11 \times 10^{-3} \text{ m} = 7.11 \text{ mm}$$

Q. 10. *A current I flows along the length of an infinitely long, thin walled pipe. Then what will be the magnetic field at*

(i) a point inside the pipe (ii) a point on the axis of the pipe (iii) a point out side the pipe.

Ans. Refer to Page 227.

Q. 11. *A narrow stream of protones and deuterons, having the same momentum values, enter a region of uniform magnetic field directed perpendicular to their common direction of motion. What would be the ratio of the radii of the circular paths, described by the protons and deutrons?*

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

$\therefore$ $$\frac{r_p}{r_D} = \frac{q_D}{q_p} = \frac{2q}{q} = 2$$

Q. 12. *Find the magnitude of the force on each segment of the wire shown, if a magnetic field of 0.30 T, is applied parallel to AB and DE take the value of current flowing in the wire, as 1 ampere.*

Ans. $$F = IBl \sin\theta$$

$\therefore$ For segment

AB and *DE*, $\theta = 0$

$\therefore$ force on these segments is zero

The force on *BC*

$$= IBl \sin 90°$$
$$= 1\,(B)\,8 \times 10^{-2} = 0.08\,B \text{ tesla.}$$

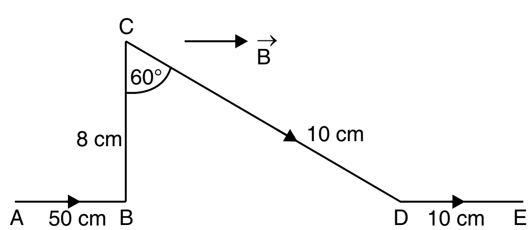

Fig. 4.55

The force on *CD* segment,

$$F = (1)\,(B)\,(10 \times 10^{-2}) \sin 30°$$
$$= 0.05B \text{ tesla.}$$

Q. 13. *Write the relation for current sensitivity and voltage sensitivity of a moving coil galvanometer? Using these relations, explain the fact that increasing the current sensitivity may not necessary increase the voltage sensitivity.*

Ans.

$$\text{Current sensitivity} = \frac{\theta}{I}$$

$$\text{Voltage sensitivity} = \frac{\theta}{V} = \frac{\theta}{IR} = \frac{\text{Current sensitivity}}{\text{Resistance}}$$

If current sensitivity increases and the resistance also increases in same order, the voltage sensitivity will remain unchanged.

Q. 14. *A wire AB is carrying a current of 12A and is lying on the table. Another wire CD, carrying current 5A is arranged just above AB at a height of 1 mm. What should be the weight per unit length of this wire so that CD remains suspended at its position? Indicate the direction of current in CD and the nature of force between two wires.*

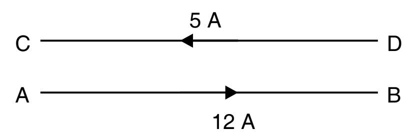

Fig. 4.56

Ans. Weight of the wire will be balanced by the force of repulsion between the wires *AB* and *CD*.

$$\because \quad \frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

$$\therefore \quad \frac{mg}{l} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

or weight per unit length,

$$= \frac{4\pi \times 10^{-7} \times 12 \times 5}{2\pi \times 1 \times 10^{-3}} \text{ Nm}^{-1}$$

$$= 120 \times 10^{-4} = 0.12 \text{ Nm}^{-1}$$

The direction of current is *CD* will be opposite to that of *AB*.

Q. 15. *Two circular loops of radii r and 2r have current I and I/2 flowing through them clockwise and anticlockwise sense respectively. If their equivalent magnetic moments are M_1 and M_2 respectively, state the relation between M_1 and M_2.*

Ans.

$$M_1 = I(\pi r^2)$$

and

$$M_2 = \frac{I}{2}[\pi(2r)^2]$$

$$\therefore \quad \frac{M_1}{M_2} = \frac{I\pi r^2}{I\pi 2r^2} = \frac{1}{2}$$

or

$$M_1 = \frac{1}{2} M_2$$

Q. 16. *A small magnet of magnetic moment M is placed at a distance r from the origin O with its axis parallel to x-axis as shown. A small coil of one turn, is placed on the x-axis, at the same distance from the origin, with the axis of the coil coinciding with x-axis. For what value of current in the coil does a small magnetic needle, kept at origin remain undeflected? What is the direction of current in the coil?*

Ans. For a needle to remain undeflected the magnetic field due to magnet and current loop must be equal and opposite.

The magnetic field of magnet at origin

$$= \frac{\mu_0}{4\pi} \cdot \frac{M}{r^3}$$

The magnetic field of the small coil at origin

$$= \frac{\mu_0}{4\pi} \frac{I\pi x^2}{(r^2 + x^2)^{3/2}}$$

(x = radius of the loop)

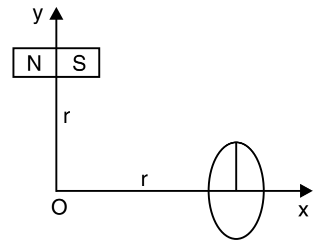

Fig. 4.57

$$\therefore \quad \frac{\mu_0}{4\pi} \cdot \frac{M}{r^3} = \frac{\mu_0}{4\pi} \frac{I\pi x^2}{(r^2 + x^2)^{3/2}}$$

or $$I = \frac{M (r^2 + x^2)^{3/2}}{\pi x^2}$$

The direction of the current in the loop must be anticlockwise.

MULTIPLE CHOICE QUESTIONS

1. If electron velocity is $2\hat{i} + 3\hat{j}$ and it is subjected to magnetic field of $4\hat{k}$, then its

(*a*) path will change (*b*) speed will change
(*c*) both (*a*) and (*b*) (*d*) none of the above

2. An electron having energy 10 eV is circulating in path having magnetic field of 10^{-4} T. The speed of the electron will be

(*a*) 3.8×10^6 m/s (*b*) 1.9×10^{12} m/s (*c*) 3.8×10^{12} m/s (*d*) 1.9×10^6 m/s

3. A particle having charge 100 times that of an electron is revolving in a circular path by radius 0.8 m with one rotation per second. The magnetic field produced at the centre is:

(*a*) $10^{-17}\ \mu_0$ (*b*) $10^{-17}\ \mu_0$ (*c*) $10^{-16}\ \mu_0$ (*d*) $10^{-15}\ \mu_0$

4. A particle of mass m and charge q is placed at rest in a uniform electric field E and then released. The kinetic energy attained by the particle after moving a distance y is

(*a*) qEy^2 (*b*) qE^2y (*c*) qEy (*d*) q^2Ey.

5. A galvanometer of resistance 25 Ω is shunted by a 2.5 Ω wire. The part of total current that flows through the galvanometer is given by

(*a*) $\frac{I}{I_0} = \frac{1}{11}$ (*b*) $\frac{I}{I_0} = \frac{2}{11}$ (*c*) $\frac{I}{I_0} = \frac{3}{11}$ (*d*) $\frac{I}{I_0} = \frac{4}{11}$

6. The resistance of a galvanometer is 50 Ω and the current required to give full scale deflection is 100 μA. In order to convert it into an ammeter for reading up to 10 A, it is necessary to put a resistance of

(*a*) 5×10^{-3} Ω (*b*) 5×10^{-4} Ω (*c*) 5×10^{-5} Ω (*d*) 5×10^{-2} Ω.

7. The resistance of the coil of ammeter is R. The shunt resistance required to increase its range four fold should have a resistance

(*a*) $R/3$ (*b*) $R/4$ (*c*) $4R$ (*d*) $R/5$

8. Two long parallel wires P and Q are held perpendicular to the plane of the paper with distance of 5 m between them. If P and Q carry current of 2.5 A and 5A respectively in the same direction, then the magnetic field at a point half way between the wire is

(*a*) μ_0/π (*b*) $\sqrt{3}\mu_0/\pi$ (*c*) $\mu_0/2\pi$ (*d*) $3\mu_0/2\pi$

9. A wire of length 2m carries a current of 1 ampere is bend to form a circle. The magnetic moment of the coil is

(*a*) 2π (*b*) $\pi/2$ (*c*) $\pi/4$ (*d*) $1/\pi$

10. The magnetic field of given length of wire for single turn coil at its centre is B, then its value for two turns coil for the same wire is

(*a*) $B/4$ (*b*) $B/2$ (*c*) $4/B$ (*d*) $2B$.

11. When a charged particle enters in a uniform magnetic field, its kinetic energy.

(*a*) remains constant (*b*) increases (*c*) decreases (*d*) becomes zero

12. The deflection in moving coil galvanometer falls from 50 divisions to 10 divisions, when a shunt of 12 Ω is applied, the resistance of galvanometer coil is

(*a*) 12 Ω (*b*) 24 Ω (*c*) 48 Ω (*d*) 50 Ω

13. If the number of turns, area and current through a coil is given by n, A and I respectively, then its magnetic moment will be

(*a*) nIA (*b*) n^2IA (*c*) nIA^2 (*d*) $nI/\sqrt{A}$

14. The scale of a galvanometer of resistance 100 Ω contains 25 divisions. It gives a deflection of one division on passing a current of 4×10^{-4} A. The resistance in ohms to be added to it, so that it may become a voltmeter of range 2.5 volt is

(*a*) 100 (*b*) 150 (*c*) 250 (*d*) 300

15. The electric current in a circular coil of two turns produces a magnetic induction of 0.2 T at its centre. The coil is unwound and is rewound into a circular coil of four turns. The magnetic induction at the centre of the coil now is, in tesla (if same current flows in the coil)

(*a*) 0.2 (*b*) 0.4 (*c*) 0.6 (*d*) 0.8

Answers

1. (*a*)	**2.** (*d*)	**3.** (*a*)	**4.** (*c*)	**5.** (*a*)
6. (*b*)	**7.** (*a*)	**8.** (*c*)	**9.** (*d*)	**10.** (*c*)
11. (*a*)	**12.** (*c*)	**13.** (*a*)	**14.** (*b*)	**15.** (*d*).

TEST YOUR SKILLS

1. State Biot-Savart law Using Biot-Savart law, derive an expression for the magnetic field at the centre of a circular coil of number of turns 'N', radius 'r' carrying a current 'I'. A semi-conductor arc of radius 20 cm carries a current of 10A, calculate the magnitude of the magnetic field at the centre of arc.
2. A proton and an α-Particle of same kinetic energy in turn move through a uniform magnetic field B in a plane normal to the field. Compare the radii of the paths of the two particles.
3. Define the SI unit of magnetic field. "A charge moving at right angles to a uniform magnetic field does it undergo change in kinetic energy". Why?
4. Give the principle of a cyclotron. Draw a labelled diagram of cyclotron and explain how a positively charged particle is accelerated in it?

5. Obtain an expression for the magnetic moment associated with the orbital motion of an electron.

6. What is the effect of current flowing in the same direction in two long straight and parallel conductors? Give the defination of 'ampere' based on this effect.

7. Derive the expression for the torque on a rectangular coil of area A, carrying a current I, placed in a magnetic field B. The angle between the direction of B and the vector perpendicular to the plane of the coil is θ.

8. What is the resistance of shunt required to increase the range of a galvanometer by n times? What is the resistance of converted ammeter?

9. An electron of kinetic energy 25 keV moves perpendicular to the direction of a uniform magnetic field of 0.2 millitesla. Calculate the time period of rotation of the electron in the magnetic field.

10. What is the magnetic moment associated with a coil of 1 turn, area of cross-section 10^{-4} m^2 carrying a current of 2A?

11. How can a moving coil galvanometer by converted into an ammeter? To increase the current sensitivity of a moving coil galvanometer by 50%, its resistance is increased so that the new resistance becomes twice its initial resistance. By what factor does its voltage sensitivity change?

12. An electron is projected with a speed of 10^5 ms^{-1} at right angles to a magnetic field of 0.019 G. Calculate the radius of the circle described by the electron.

13. Write the relation for the force F acting on a charge carrier q moving with a velocity v through a magnetic field B in vector notation. Using this relation, deduce the conditions under which this force will be (*i*) maximum (*ii*) minimum.

14. Draw a labelled diagram of a moving coil galvanometer, Explain the principal on which it works. Deduce an expression for the torque acting on a rectangular current carrying loop kept in uniform magnetic field. Write two factors on which the current sensitivity of a moving coil galvanometer depend.

15. Two identical conducting wires AOB and COD are placed at right angles to each other. The wire AOB carries an electric current I_1 and COD carries a current I_2. What will be the magnetic field on point lying at a distance d from O, in a direction perpendicular to the plane of the wires AOB and COD?

16. A charge particle moves through a magnetic field perpendicular to its direction. Which of following quantity will change or remain unchanged (*i*) kinetic energy (*ii*) momentum?

17. A charge particle with charge q enters a region of constant E and B with velocity V perpendicular to both E and B, and comes out without any charge in magnitude or direction of V, then establish a relation between V, E and B.

18. A long straight wire of radius 'a' carries a steady current I. The current is uniformly distributed across its cross-section. Find the ratio of magnetic field at $a/2$ and $2a$.

19. A solenoid of length 75 cm, has a radius of 1 cm and has a total of 750 turns wound on it. It carries a current of 4A. Calculate the magnitude of the axial magnetic field inside the solenoid. If a proton were to move with a speed of 10^3 ms^{-1} along the axis of this current carrying solenoid, what would be the force experienced by this proton?

20. What is direction of force acting on a charged particle q, moving with a velocity υ in a uniform magnetic field B?

21. How does the value of maximum safe current through a galvanometer changed, when its coil is shunted by a low resistance?

22. Two small identical coils marked 1, 2 carry equal currents and are placed with their geometric axes perpendicular to each other as shown. Derive an expression for the resultant magnetic field at O.

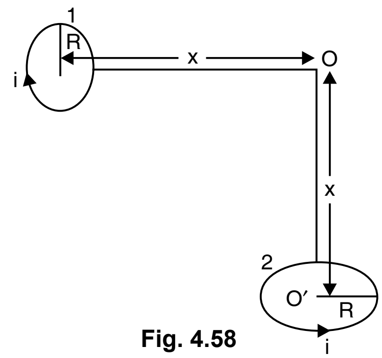

Fig. 4.58

23. Why should the spring/suspension wire in a moving coil galvanometer have low torsional constant?

24. Using Ampere's circuital law, derive an expression for the magnetic field along the axis of current carrying torodial solenoid of N number of turns having radius r.

25. Magnetic field lines can be entirely confined within the core of a toroid, but not within a straight solenoid. Why?

26. A charge 'q' moving along the X-axis with a velocity υ is subjected to a uniform magnetic field B acting along z-axis as it crosses the origin.

(*i*) Trace it trajectory.

(*ii*) Does the charge gain kinetic energy as it enters the magnetic field? Justify your answer.

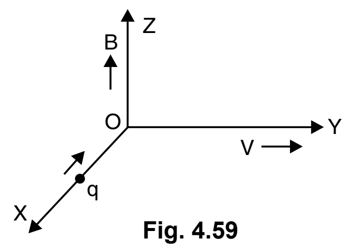

Fig. 4.59

27. Increasing the current sensitivity may not necessarily increase the voltage sensitivity of a galvanometer. Justify.

28. A rectangular current carrying loop EFGH is kept in a uniform magnetic field as shown in the figure 4.60.

(*i*) What is the direction of the magnetic moment of current loop?

(*ii*) When is the torque acting on the loop (*a*) maximum (*b*) zero?

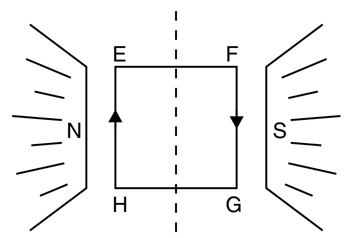

Fig. 4.60

29. An electron does not suffer any deflection while passing through a region of uniform magnetic field. What is the direction of magnetic field?

30. A current coil of 200 turns and radius 10 cm is placed in a uniform magnetic field of 0.5 T, normal to the plane of the coil. If the current in the coil is 3.0 A, Calculate the (*i*) 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. Assuming that the area of cross-section of the wire to be 10^{-5} m^2 and the free electron density is $10^{29}/m^3$.

31. A given rectangular coil *OLMN* of area A carrying a given current I, is placed in a uniform magnetic field $B = B_{K}$, in two different orientation (*a*) and (*b*) as shown in figure 4.61. What is the magnitude of torque experienced by the coil in two cases?

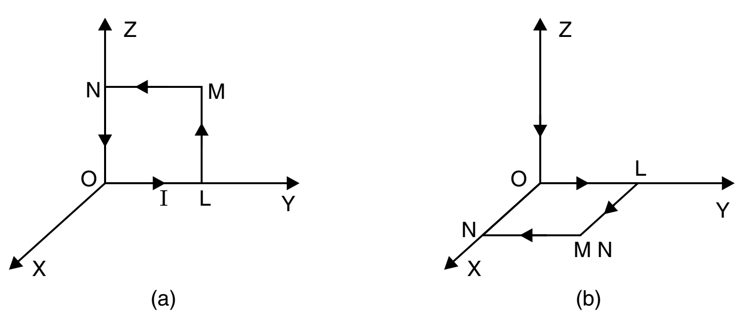

Fig. 4.61

32. Using the relation for potential energy of a current carrying planer loop, in a uniform magnetic field, obtain the expression for the work done in moving the planer loop from its unstable equilibrium position to its stable equilibrium position.

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