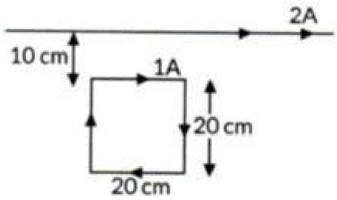
SURE SHOT QUESTIONS 2026

Chapter – 04 (Questions)

Moving Charges and Magnetism

➢ Questions

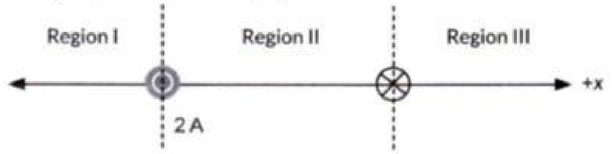
1. A square loop of side 20 cm carrying current of 1 A is kept near an infinite long straight wire carrying a current of 2 A in the same plane as shown in the figure.



Calculate the magnitude and direction of the net force exerted on the loop due to the current carrying conductor. [AI 2015C]

2. An ammeter of resistance 0.8 Ω can measure a current upto 1.0 A. Find the value of shunt resistance required to convert this ammeter to measure a current upto 5.0 A. [2020]

3. Two straight infinitely long wires are fixed in space so that the current in the left wire is 2 A and directed out of the plane of the page and the current in the right wire is 3 A and directed into the plane of the page. In which region(s) is/are there a point on the x-axis, at which the magnetic field is equal to zero due to these currents carrying wires? Justify your answer.



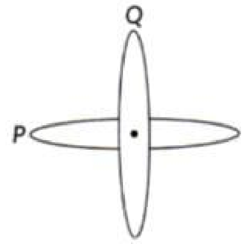
4. A proton, a deuteron and an alpha particle are accelerated through the same potential difference and then subjected to a uniform magnetic field $\vec{B}$, perpendicular to the direction of their motions. [AI 2019]

Compare

(i) Their kinetic energies, and

(ii) If the radius of the circular path described by proton is 5 cm, determine the radii of the path described by deuteron and alpha particle.

5. Two identical loops P and Q each of radius 5 cm are lying in perpendicular planes such that they have a common centre as shown in the figure. Find the magnitude and direction of the net magnetic field at the common centre of the two coils, if they carry currents equal to 3 A and 4 A respectively. [AI 2017]



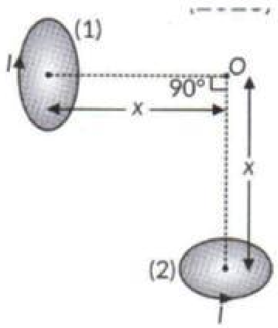
6. Derive an expression for magnetic force $\vec{F}$ acting on a straight conductor of length L carrying current I in an external magnetic field $\vec{B}$. Is it valid when the conductor is in zig-zag form? Justify.

7. Two long, straight, parallel conductors carry steady currents in opposite directions. Explain the nature of the force of interaction between them. Obtain an expression for the magnitude of the force between the two conductors. Hence define one ampere.

8. A straight wire of mass 200 g and length 1.5 m carries a current of 2A. It is suspended in mid air by a uniform magnetic field B. What is the magnitude of the magnetic field?

9. A charged particle q is moving in the presence of a magnetic field B which is inclined to an angle 30° with the direction of the motion of the particle. Draw the trajectory followed by the particle in the presence of the field and explain how the particle describes this path.

10. Two very small identical circular loops, (1) and (2), carrying equal currents I are placed vertically (with respect to the plane of the paper) with their geometrical axes perpendicular to each other as shown in the figure. Find the magnitude and direction of the net magnetic field produced at the point O. [2017C, Foreign 2014]



11. Two infinitely long straight wires A_1 and A_2 carrying currents I and 2I flowing in the same directions are kept 'd' distance apart. Where should a third straight wire A_3 carrying current 1.5 I be placed between A_1 and A_2 so that it experiences no net force due to A_1 and A_2? Does the net force acting on A_3 depend on the current flowing through it? [Delhi 2019]

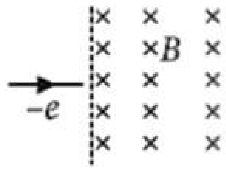
12. (a) Write an expression of magnetic moment associated with a current (I) carrying circular coil of radius r having N turns.
(b) Consider the above mentioned coil placed in YZ plane with its centre at the origin. Derive expression for the value of magnetic field due to it at point (x, 0, 0). [2020]

13. (a) Define current sensitivity of a galvanometer. Write its expression.
(b) A galvanometer has resistance G and shows full scale deflection for current I_g.
(i) How can it be converted into an ammeter to measure current upto $I_0 (I_0 > I_g)$?
(iii) What is the effective resistance of this ammeter? [2020]

14. (a) Briefly explain how a galvanometer is converted into an ammeter.
(b) A galvanometer coil has a resistance of 15 Ω and it shows full scale deflection for a current of 4 mA. Convert it into an ammeter of range 0 to 6A.

15. A circular loop of radius R carries a current I. Obtain an expression for the magnetic field at a point on its axis at a distance x from its centre.
OR
Write, using Biot – Savart law, the expression for the magnetic field $\vec{B}$ due to an element $d\vec{l}$ carrying current I at a distance $\vec{r}$ from it in a vector form. Hence derive the expression for the magnetic field due to a current carrying loop of radius R at a point P distant x from its centre along the axis of the loop. [AI 2015]

16. An electron moving horizontally with a velocity of $4 \times 10^4 m/s$ enters a region of uniform magnetic field of 10^{-5} T acting vertically upward as shown in the figure. Draw its trajectory and find out the time it takes to come out of the region of magnetic field.



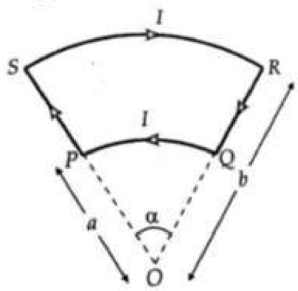
17. Two long straight parallel conductors carry steady current I_1 and I_2 separated by a distance d. if the currents are flowing in the same direction, show how the magnetic fields set up if one produces an attractive force on the other. Obtain the expression for this force. Hence define one ampere.

18. (a) Write the expression for the force $\vec{F}$, acting on a charged particle of charge 'q', moving with a velocity $\vec{v}$ in the presence of both electric field $\vec{E}$ and magnetic field $\vec{B}$. Obtain the condition under which the particle moves undeflected through the fields.
(b) A rectangular loop of size $l \times b$ carrying a steady current I is placed in a uniform magnetic field $\vec{B}$. Prove that the torque $\vec{\tau}$ acting on the loop is given by, $\vec{\tau} = \vec{m} \times \vec{B}$ where $\vec{m}$ is the magnetic moment of the loop.

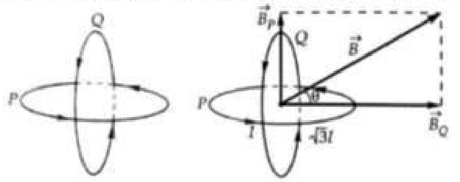
19. A circular coil of N turns and radius R carries a current I. It is unwound and rewound to make another coil of radius R/2, current I remaining the same. Calculate the ratio of the magnetic moments of the new coil and the original coil.

20. State Bio-Savart's law, Write in vector form.

21. Fig., shows a current loop having two circular segments and joined by two radial lines. Find the magnetic field at the centre O.



22. Two identical coils P and Q each of radius R are lying in perpendicular places such that they have a common centre. Find the magnitude and direction of the magnetic fields at the common centre of the two coils, if they carry currents equal to I and $\sqrt{3}I$.

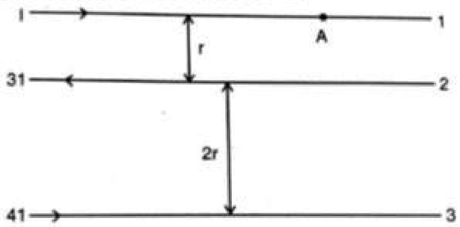


23. What is Lorentz Force? Write the proper expression for it.

24. The figure shows three infinitely long straight parallel current carrying conductors. Find the

i. Magnitude and direction of the net magnetic field at point A lying on conductor 1,

ii. Magnetic force on conductor 2.



25. An electron of mass m_e revolves around a nucleus of charge $+Z_e$. Show that it behaves like a tiny magnetic dipole. Hence, prove that the magnetic moment associated with it is expressed as $\vec{\mu} = -\frac{e}{2m_e}\vec{L}$, where $\vec{L}$ is the orbital angular momentum of the electron. Give the significance of negative sign.

26. Draw a labelled diagram of a moving coil galvanometer. Describe briefly its principle & working. How will you convert galvanometer into (i) ammeter (ii) Voltmeter.

27. Explain Current & Voltage sensitivity of galvanometer

28. A rectangular coil having each turn of length 5 cm and breadth 2 cm is suspended freely in a radial magnetic field of induction 2.5×10^{-2} Wb m^{-2}, torsional constant of the suspension fibre is 1.5×10^{-8} Nm rad^{-1}. The coil deflects through an angle of 0.2 radian when a current of 2 μA is passed through it. Find the number of turns of the coil.

29. An ammeter of resistance 0.80Ω can measure currents upto 1.0 A. (i) What must be the shunt resistance to enable the ammeter to measure current upto 5.0 A? (ii) What is the combined resistance of the ammeter and the shunt?

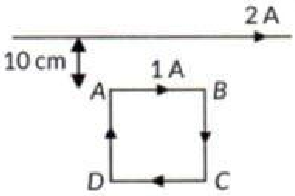
SURE SHOT QUESTIONS 2026

Chapter – 04 (Solutions)

Moving Charges and Magnetism

➢ Solutions

1. Ans. Force between two parallel current carrying wires,



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

Force on arm AB,

$$F_{AB} = \frac{\mu_0 \times 2 \times 1 \times 20 \times 10^{-2}}{2\pi \times 10 \times 10^{-2}}$$

$= \frac{2\mu_0}{\pi} N$ (Attractive, towards the wire)

Force on arm CD,

$$F_{CD} = \frac{\mu_0 \times 2 \times 1 \times 20 \times 10^{-2}}{2\pi \times 30 \times 10^{-2}}$$

$= \frac{2\mu_0}{3\pi} N$ (Repulsive, away from the wire)

Force on arms BC and DA are equal and opposite. So, they cancel out each other.

Net force on the loop is $F = F_{AB} - F_{CD}$

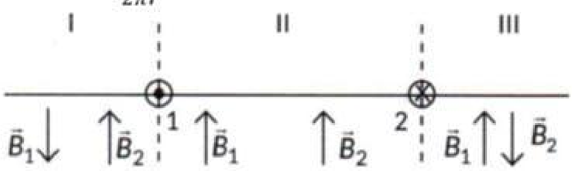
$$= \frac{\mu_0}{\pi}\left[2 - \frac{2}{3}\right] = \frac{4\mu_0}{3\pi} = \frac{4 \times 4\pi \times 10^{-7}}{3\pi}$$

$= 5.33 \times 10^{-7} N$ (Attractive, towards the wire)

2. Ans. Let the resistance is R. So, V = IR

$1 \times 0.8 = 5 \times \frac{0.8R}{R+0.8}; R = 0.2\Omega$

3. Ans. For a straight current carrying wire magnetic field is $B = \frac{\mu_0 I}{2\pi r}$



From the figure, we see magnetic field can be zero in region I or III. But for region $I, r_2 > r_1$ and for region III, $r_1 > r_2$. As $I_2 > I_1$, so we can conclude that magnetic field will vanish in region I only.

4. Ans. When a proton, a deuteron and an alpha particle are accelerated through potential difference V, then their energies are

$E_p = eV, E_d = eV, E_\alpha = 2eV$

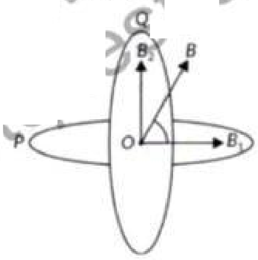
(i) $KE_p : KE_d : KE_\alpha = 1:1:2$

(ii) $r = \frac{mv}{qB} = \frac{\sqrt{2mKE}}{qB}$

$r_p : r_d : r_\alpha \frac{\sqrt{m_p}}{e} : \frac{\sqrt{2m_p}}{e} : \frac{\sqrt{4m_p}}{2e} = 1 : \sqrt{2} : 1$

$As\, r_p = 5cm \therefore r_d = 5\sqrt{2}cm, r_\alpha = 5cm$

5. Ans. Magnetic field induction due to vertical loop at the centre O is,



$B_1 = \frac{\mu_0 I_1}{2R} = \frac{4\mu_0}{10^{-1}}$

$(\because R = 5\, cm)$

Magnetic field induction due to horizontal loop at the centre O is,

$B_2 = \frac{\mu_0 I_2}{2R} = \frac{4\mu_0}{10^{-1}}$

$\because$ B_1 and B_2 are perpendicular to each other, therefore the resultant magnetic field induction at the centre O is,

$$B_{net} = \sqrt{B_1^2 + B_2^2} = \sqrt{\left(\frac{4\mu_0}{10^{-1}}\right)^2 + \left(\frac{3\mu_0}{10^{-1}}\right)^2} =$$

$$\frac{\mu_0}{10^{-1}}\sqrt{9+16} = \frac{5\mu_0}{10^{-1}}$$

$= 50 \times 4\pi \times 10^{-7} = 62.8 \times 10^{-6} T = 62.8 \mu T$

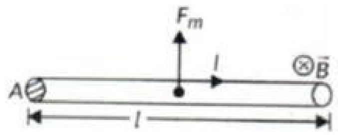
Direction of resultant magnetic field,

$tan\, \theta = \frac{B_2}{B_1} = \frac{3\mu_0 \times 10^{-1}}{4\mu_0 \times 10^{-1}}$

$tan\, \theta = \frac{3}{4} or \theta \simeq 37^0$

Resultant magnetic field B making an angle 37^0 with B_1.

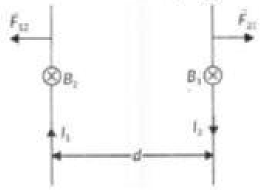
6. Ans. Magnetic force on a current carrying conductor:



Net mobile charge carrier in a conductor, $q = nAle$

Average drift velocity of electron = v_d
Magnetic force on charge
$\vec{F}_m = (nAl)e(\vec{v}_d \times \vec{B}) = [(ne\vec{v}_d)Al] \times \vec{B} = I(\vec{l} \times \vec{B})$
This law is also valid for zig-zag shape of conductor.
For an arbitrary shape of wire $\vec{F} = \sum_k I(d\vec{l}_k \times \vec{B})$
This force acts through the centre of the rod of length (l).

7. Ans. When two parallel infinite straight wires carrying currents I_1 and I_2 are placed at distance d from each other, then current I_1 produces magnetic field, which at any point on the second current carrying wire is



$B_1 = \frac{\mu_0 I_1}{2\pi d}$ directed inwards perpendicular to plane of wires.
So, this current (I_2) carrying wire then experiences a force due to this magnetic field which on its length l is given by

$$\vec{F}_{21} = I_2(\vec{l} \times \vec{B}_1)$$

$$F_{21} = F_{12} = I_2 l B_1 \sin 90° = I_2 l \times \frac{\mu_0 I_1}{2\pi d}$$

or $$F_{21} = F_{12} = \frac{\mu_0 I_1 I_2}{2\pi d} l$$

The vector product $(\vec{l} \times \vec{B}_1)$ has a direction away from the wire carrying current I_1. Hence, both the wires repel each other.
So, force per unit length that each wire exerts on the other is

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

If $I_1 = I_2 = 1$ A and $d = 1$ m and $l = 1$ m

then $F = \frac{\mu_0}{2\pi} = 2 \times 10^{-7}$ N m^{-1}

Thus, electric current through each of two parallel long wires placed at distance of 1 m from each other is said to be 1 ampere, if they exert a force of 2×10^{-7} N m^{-1} on each other.

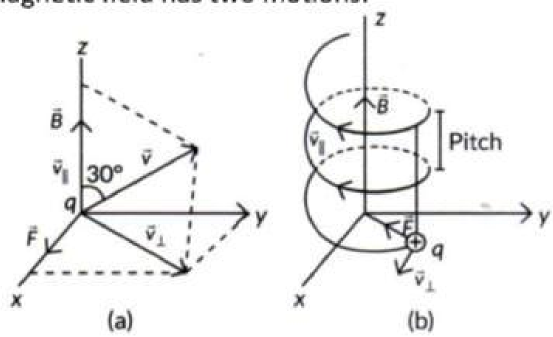
8. Ans. Mass of wire, m = 200 g = 0.2 kg, length of wire, ℓ = 1.5 m, current in the wire, ℓ = 2A

In the equilibrium position, the net force on the wire will be zero.

Thus, $mg = Bl\ell$

$$\Rightarrow B = \frac{mg}{l\ell} \Rightarrow B = \frac{0.2 \times 9.8}{2 \times 1.5} \Rightarrow B = 0.65T$$

9. Ans. A charged particle moving in a uniform magnetic field has two motions.



A linear motion in the direction of $\vec{B}$ (along z-axis) as shown in figure (a) and a circular motion in a plane perpendicular to $\vec{B}$ (in xy-plane). Hence, the resultant path of the charged particle will be a helix, with its axis along the direction of $\vec{B}$, as shown in figure (b).

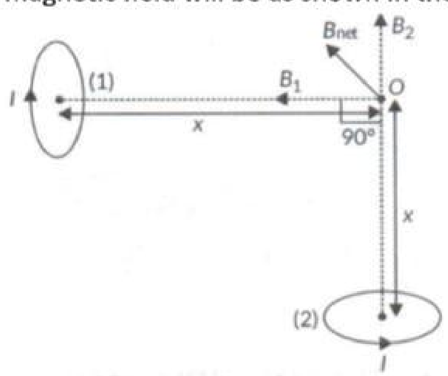
10. Ans. The magnetic field at an axial point due to circular loop is given by

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi I a^2}{(a^2 + r^2)^{3/2}}$$

Where, I = current through the loop
a = radius of the loop
r = distance of O from the centre of the loop.
Since I, a and r = x are the same for both the loops, the magnitude of B will be the same and is given by

$$B_1 = B_2 = \frac{\mu_0}{4\pi} \cdot \frac{2\pi I a^2}{(a^2 + x^2)^{3/2}}$$

The direction of magnetic field due to loop (1) will be away from O and that due to loop (2) will be towards O as shown. The direction of the net magnetic field will be as shown in the figure.

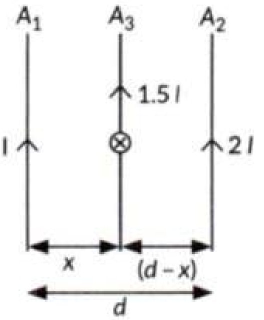


The magnitude of the net magnetic field is given by

$$B_{net} = \sqrt{B_1^2 + B_2^2}$$

$$B_{net} = \frac{\mu_0}{4\pi} \frac{2\sqrt{2}\pi l a^2}{4\pi(a^2+x^2)^{3/2}}$$

11. Ans. Force on A_3 due to A_1



$$f_1 = \frac{4\pi \times 10^{-7} \times l \times 1.5l}{2\pi x}$$

Force on A_3 due to A_2

$$f_2 = \frac{4\pi \times 10^{-7} \times 2l \times 1.5l}{2\pi(d-x)}$$

When there is no net force on A_3 $f_1 = f_2$

$$\frac{4\pi \times 10^{-7} \times l \times 1.5l}{2\pi x} = \frac{4\pi \times 10^{-7} \times 2l \times 1.5l}{2\pi(d-x)}$$

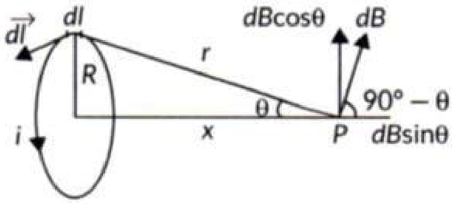
$$d - x = 2x \Rightarrow x = \frac{d}{3}$$

Hence, from $A_1 at \frac{d}{3}$there is no net force on A_3.

Also from the above result we can say that net force is independent of current flowing on A_3.

12. Ans. (a) The magnetic moment associated with a current (I) carrying circular coil of radius r having N turns, is given by, $M = NIA = NI\pi r^2$.

(b) Magnetic field at a distance x from the centre of the ring due to element



$dl, dB = \frac{\mu_0}{4\pi}\frac{idl\, sin\, 90^0}{r^2}$

Since, angle between $d\vec{l}\, and \vec{r}$is 90°. The component $dB\, cos\, \theta$will get cancelled due to symmetry

$B = \int dB\, sin\, \theta = \int \left(\frac{\mu_0}{4\pi}\frac{idl}{r^2}\right)(sin\, \theta)$

Here, r and $\theta$are constants and $\sin\theta = \frac{R}{r}$

$B = \int \frac{\mu_0}{4\pi}\frac{idl}{r^2}\left(\frac{R}{r}\right) = \int \frac{\mu_0}{4\pi}\frac{idl}{r^3}$

$= \frac{\mu_0}{4\pi}\frac{iR}{r^3}\int dl = \frac{\mu_0 iR}{4\pi r^3}(2\pi R) = \frac{\mu_0 iR^2}{2r^3}$

Putting $r = (R^2+x^2)^{1/2}$, we get $B = \frac{\mu_0 iR^2}{2(R^2+x^2)^{3/2}}$

For N turns, $B = \frac{\mu_0 NiR^2}{2(R^2+x^2)^{3/2}}$

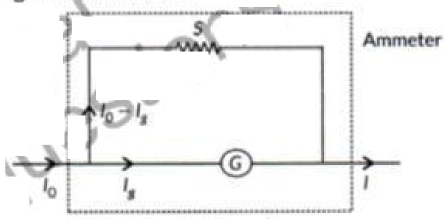
13. Ans. (a) Current sensitivity is defined as the deflection of coil per unit current flowing in it, i.e.,

$$I_S = \frac{\theta}{l} = \frac{NAB}{k}$$

(b) A galvanometer can be converted into an ammeter of given range by connecting a suitable low resistance S called shunt in parallel to the given galvanometer, whose value is given by

$$S = \left(\frac{l_g}{l_0 - l_g}\right)G$$

Where l_g is the current for full scale deflection of galvanometer, $l_0$is the current to be measured by the galvanometer and G is the resistance of galvanometer.

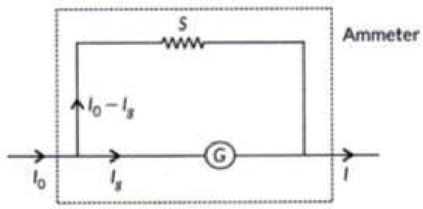


In order to increase the range of an ammeter n times, the value of shunt resistance to be connected in parallel is S = G/(n – 1).

14. Ans. (a) A galvanometer can be converted into an ammeter of given range by connecting a suitable low resistance S called shunt in parallel to the given galvanometer, whose value is given by

$S = \left(\frac{l_g}{l_o - l_g}\right)G$

Where l_g is the current for full scale deflection of galvanometer, $l_0$is the current to be measured by the galvanometer and G is the resistance of galvanometer.

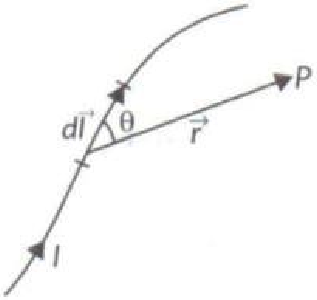


In order to increase the range of an ammeter n times, the value of shunt resistance to be connected in parallel is S = G/(n – 1).

(b) For $l = 6A$

$$S = \left(\frac{I_g}{I - I_g}\right) G = \frac{4\times10^{-3}}{6-0.004} \times 15\Omega$$
$$\approx \frac{2}{3} \times 15 \times 10^{-3}\Omega \simeq 0.01\Omega$$

15. Ans. A current carrying wire produces a magnetic field around it. Biot – Savart law states that magnitude of intensity of small magnetic field $d\vec{B}$ due to current I carrying element $d\vec{l}$ at any point P at distance r from it is given by



$$|d\vec{B}| = \frac{\mu_0}{4\pi} \frac{I d\vec{l} \sin\theta}{r^2}$$

Where θ is the angle between $\vec{r}$ and $d\vec{l}$ and $\mu_0 = 4\pi \times 10^{-7} TmA^{-1}$ is called permittivity of free space.

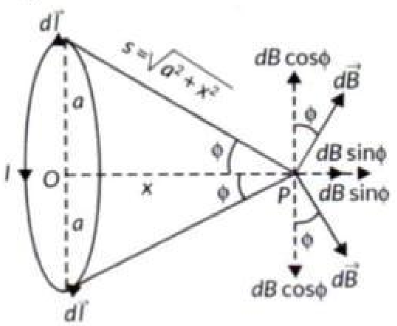
In vector form,

$$d\vec{B} = \frac{\mu_0 I}{4\pi} \frac{d\vec{l} \times \vec{r}}{r^3}$$

So, the direction of $d\vec{B}$ is perpendicular to the plane containing $\vec{r}$ and $d\vec{l}$.

S.I. unit of magnetic field strength is tesla denoted by 'T' and cgs unit is gauss denoted by 'G', where 1 T = 10^4 G

Magnetic field on the axis of a circular coil



Small magnetic field due to a current element of circular coil of radius r at point P at distance x from its centre is

$$dB = \frac{\mu_0}{4\pi} \frac{I d\vec{l} \sin 90^0}{s^2} = \frac{\mu_0}{4\pi} \frac{I d\vec{l}}{(a^2 + x^2)}$$

Component $dB\cos\phi$ due to current element at point P is cancelled by equal and opposite component $dB\cos\phi$ of another diametrically opposite current element, whereas the since components $dB\sin\phi$ add up to give net magnetic field along the axis. So, net magnetic field at point P due to entire loop is

$$B = \oint dB\sin\phi = \int_0^{2\pi r} \frac{\mu_0}{4\pi} \frac{I d\vec{l}}{(a^2+x^2)} \cdot \frac{r}{(a^2+x^2)^{1/2}}$$

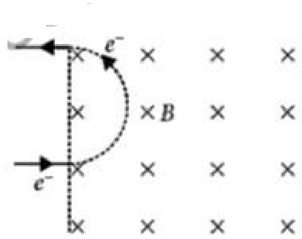
$$B = \frac{\mu_0 I r}{4\pi(a^2+x^2)^{3/2}} \int_0^{2\pi r} dl \quad \text{or} \quad B = \frac{\mu_0 I r}{4\pi(a^2+x^2)^{3/2}} 2\pi r$$

Or $B = \dfrac{\mu_0 I r^2}{2(a^2 + x^2)^{3/2}}$ directed along the axis,

(a) Towards the coil if current in it is in clockwise direction

(b) Away from the coil if current in it is in anticlockwise direction.

16. Soln.



Trajectory of electron

Let the time taken by the electron to come out of the region of magnetic field be t.

Velocity of the electron, $v = 4 \times 10^4 m/s$

Magnetic field, $B = 10^{-5}T$

Mass of the electron, $m = 9 \times 10^{-31} kg$

We know

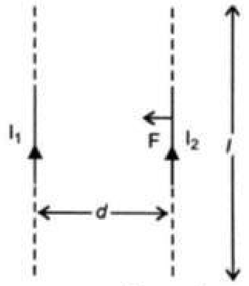
$t = \frac{\pi r}{v}$ where $r = \frac{mv}{qB}$

Now, $t = \frac{\pi m}{Bq} = \frac{3.14\times9\times10^{-31}}{10^{-5}\times1.6\times10^{-19}}$

$\Rightarrow t = 17.66 \times 10^{-7}s = 1.77\mu s$

Thus, the time taken by the electron to come out of the region of magnetic field is 1.77 μs.

17. Soln. Magnetic field produced on the wire (carrying current I_2) due to I_1 will be



Force acting at l length is

$$F = I_2 / B$$

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

If $l = 1m, d = 1m, I_1 = I_2 = I$ and $F = 2 \times 10^{-7} N$

$\Rightarrow \quad I = 1A$

So one ampere is defined as the current, which when maintained in two parallel infinite length conductors, held at a separation of one metre will produce a force of 2×10^{-7} N per metre on each conductor.

18. Soln. (a) Force acting on a charge 'q' moving with velocity $\vec{v}$ in the presence of both electric field $\vec{E}$ and magnetic field $\vec{B}$ is given by,

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

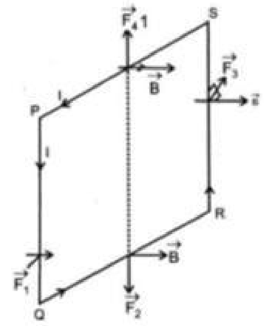
Consider a region in which magnetic field, electric field and velocity of charge particle are perpendicular to each other.

To move charge particle undeflected, the net force acting on the particle must be zero i.e., the electric force must be equal and opposite to the magnetic force.

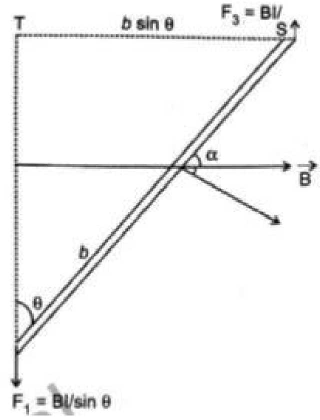
$$q\vec{E} = -q(\vec{v} \times \vec{B})$$
$$\vec{E} = -(\vec{v} \times \vec{B})$$
$$\vec{E} = \vec{B} \times \vec{v}$$
$$\vec{E} = Bv \sin\theta = Bv (\because \theta = 90^0)$$
$$v = \frac{E}{B}$$

The direction of electric and magnetic forces are in opposite direction. Their magnitudes are in such a way that they cancel out each other to give net force zero and so the charge particle does not deflect.

(b) When an electric current flows in closed loop of wire, placed in a uniform magnetic field, the magnetic forces produce a torque which tends to rotate the loop so that area of the loop is perpendicular to the direction of the magnetic field.



Consider a rectangular coil PQRS placed in an external magnetic field as shown in fig.



Let 'I' be the current flowing through the coil. Each part of the coil experiences a Lorentz force. Forces of each part is $\vec{F_1}, \vec{F_2}, \vec{F_3}$ and $\vec{F_4}$ as shown. The $\vec{F_4}$ and $\vec{F_2}$ are equal in magnitude but act in opposite directions along the same straight line. Hence, they cancel out each other.

The force $\vec{F_1} = I(\vec{PQ} \times \vec{B})$

$F_1 = I/B (\because \theta = 90^0)$

($\vec{F_1}$ acts in direction perpendicular to the plane of paper)

Similarly, $\vec{F_3} = I(\vec{RS} \times \vec{B})$

$F_3 = I/B$

These two forces constitute a couple and so rotates the coil in the anticlockwise direction.

The torque

τ = force x arm of couple

$\tau = Fb \cos\theta$

$\tau = I/Bb \cos\theta$

$\tau = IAB \cos\theta \ (\because l \times b = A)$

If the coil has N turns then

$$\tau = NIAB \cos\theta$$

The area vector A makes an angle α with $\vec{B}$ so

$\theta + \alpha = 90^0$

$\cos\theta = \cos(90 - \alpha) = \sin\alpha$

$\therefore \tau = NIAB \sin \alpha$
$\tau = mB \sin \alpha$
$or \vec{\tau} = \vec{m} \times \vec{B}$
Where m = NIA is called the magnetic dipole moment of the loop.

19. Soln. We have:

$$N_1.2\pi R = N_2.2\pi(R/2)$$
$$\therefore N_2 = 2N_1$$

Magnetic moment of a coil, M = NAI
For the coil of radius 'R',

$$M_1 = N_1 I A_1 = N_1 I \pi R^2$$

For the coil of radius R/2,

$$M_2 = N_2 I A_2 = 2N_1 I \pi R^2/4 = N_1 I \pi R^2/2$$
$$\Rightarrow M_2 : M_1 = 1:2$$

20. Soln. According to Biot-Savart law, the magnitude of the field $\vec{dB}$ is

1. Directly proportional to the current I through the conductor,
   $dB \propto l$
2. Directly proportional to the length dl of the current element,
   $dB \propto dl$
3. Directly proportional to $\sin\theta$,
   $dB \propto \sin\theta$
4. Inversely proportional to the square of the distance r of the point P from the current element,

$$dB \propto \frac{1}{r^2}$$

Combining all these four factors, we get

$$dB \propto \frac{Idl \sin\theta}{r^2}$$

Or $$dB = K.\frac{Idl \sin\theta}{r^2}$$

The proportionality constant K depends on the medium between the observation point P and the current element and the system of units chosen. For free space and in SI units,

$$K = \frac{\mu_0}{4\pi} = 10^{-7}\, T\, mA^{-1} (\text{or}\, \text{Wbm}^{-1}\, \text{A}^{-1})$$

Here μ_0 is a constant called *permeability* of free space. So the Biot – Savart law in SI units may be expressed as

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

We can write the above equation as

$$dB = \frac{\mu_0 I}{4\pi}\frac{dlr \sin\theta}{r^3}$$

As the direction of $\overrightarrow{dB}$ is perpendicular to the plane of $\overrightarrow{dl}$ and $\overrightarrow{r}$, so from the above equation, we get the vector form of the Biot – Savart law as

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

21. Soln. Since the point O lies on lines SP and QR, so the magnetic field at O due to these straight portions is zero.

The magnetic field at O due to the circular segment PQ is

$$B_1 = \frac{\mu_0}{4\pi}\frac{I}{a^2}l$$

Here, l =length of arc PQ = $\alpha\, a$

$\therefore B_1 = \frac{\mu_0}{4\pi}\frac{I\alpha}{a}$, directed normally upward

Similarly, the magnetic field at O due to the circular segment SR is

$B_2 = \frac{\mu_0}{4\pi}.\frac{I\alpha}{b}$, directed normally downward.

The resultant field at O is

$$B = B_1 - B_2 = \frac{\mu_0 I\alpha}{4\pi}\left[\frac{1}{a} - \frac{1}{b}\right]$$

Or $$B = \frac{\mu_0 I\alpha(b-a)}{4\pi ab}$$

22. Soln. $\vec{B}_P = \frac{\mu_0 I}{2R}$, vertically upwards,

$\vec{B}_Q = \frac{\mu_0 \sqrt{3} I}{2R}$, along horizontal

Resultant field at the centre is

$$B = \sqrt{B_P^2 + B_Q^2} = \left[\left(\frac{\mu_0 I}{2R}\right)^2 + \left(\frac{\mu_0\sqrt{3}I}{2R}\right)^2\right]^{1/2}$$
$$= \frac{\mu_0 I}{2R}(1+3)^{1/2} = \left(\frac{\mu_0 I}{R}\right)$$
$$\tan\theta = \frac{BP}{BQ} = \frac{1}{\sqrt{3}} \Rightarrow \theta = 30^0$$

23. Soln. Lorentz force. *The total force experienced by a charged particle moving in a region where both electric and magnetic fields are present, is called Lorentz force.*

A charge q in an electric field $\vec{E}$ experiences the electric force,

$$\vec{F}_e = q\vec{E}$$

This force acts in the direction of field $\vec{E}$ and is independent of the velocity of the charge.
The magnetic force experienced by the charge q moving with velocity $\vec{v}$ in the magnetic field $\vec{B}$ is given by

$$\vec{F}_m = q(\vec{v} \times \vec{B})$$

This force acts perpendicular to the plane of $\vec{v}$ and $\vec{B}$ and depends on the velocity $\vec{v}$ of the charge.

The total force, or the *Lorentz force,* experienced by the charge q due to both electric and magnetic field is given by

$$\vec{F} = \vec{F_e} + \vec{F_m}$$

Or $$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

24. Soln. (i) Magnitude of magnetic field at A

Direction of magnetic field at A

(ii) Magnitude of magnetic force on conductor 2

Direction of magnitude force on conductor 2

(i) $B_2 = \frac{\mu_0}{4\pi}\frac{2(3I)}{r} = \frac{\mu_0}{4\pi}\left(\frac{6I}{r}\right)$ into the plane of the paper/ (⊗)

$B_3 = \frac{\mu_0}{4\pi}\left(\frac{2(4I)}{3r}\right) = \frac{\mu_0}{4\pi}\left(\frac{8I}{3r}\right)$ out of the plane of the paper/ (*)

$B_A = B_2 - B_3$ into the paper

$= \frac{\mu_0}{4\pi}\left(\frac{10I}{3r}\right)$ into the paper/ (⊗)

(ii) $F_{21} = \frac{\mu_0}{4\pi}\frac{2I(3I)}{r}$ away from wire 1 (/towards 3)

$F_{23} = \frac{\mu_0}{4\pi}\frac{2I(3I)}{r}$ away from 3 (towards 1)

$F_{net} = F_{23} - F_{21}$ towards wire 1

$= \frac{\mu_0}{4\pi}\frac{6(I)^2}{r}$ towards wire 1

25. Soln. (i) Behaviour of revolving electron as a tiny magnetic dipole.

(ii) Proof of the relation $\vec{\mu} = -\frac{e}{2m_e}\vec{L}$

(iii) Significance of negative sign

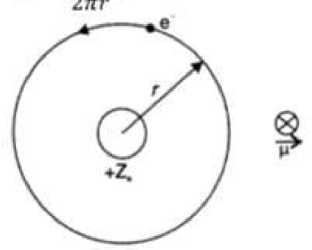
Electron, in circular motion around the nucleus constitutes a current loop which behaves like a magnetic dipole.

Current associated with the revolving electron.

$$I = \frac{e}{T}$$

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

$\therefore I = \frac{e}{2\pi r}v$



Magnetic moment of the loop, $\mu = IA$

$$\mu = IA = \frac{ev}{2\pi r}\pi r^2$$
$$= \frac{evr}{2} = \frac{e.m_e vr}{2m_e}$$

Orbital angular momentum of the electron,

$L = m_e vr$

$\vec{\mu} = \frac{-e}{2m_e}\vec{L}$

-ve sign signifies that the angular momentum of the revolving electron is opposite in direction to the magnetic moment associated with it.

26. Soln.

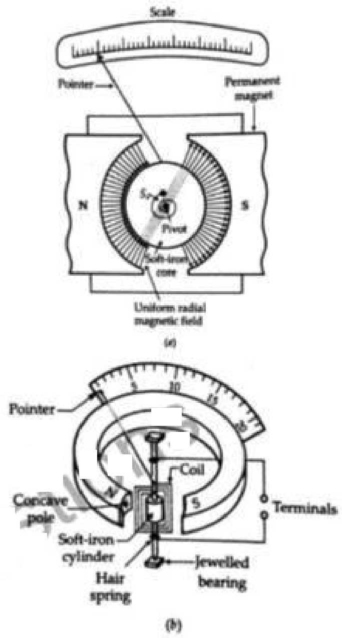


Fig. 4.94 (a) Top view (b) Front view of a pivoted-type galvanometer.

I = current flowing through the coil PQRS

a,b = sides of the rectangular coil PQRS

A = ab = area of the coil

N = number of turns in the coil.

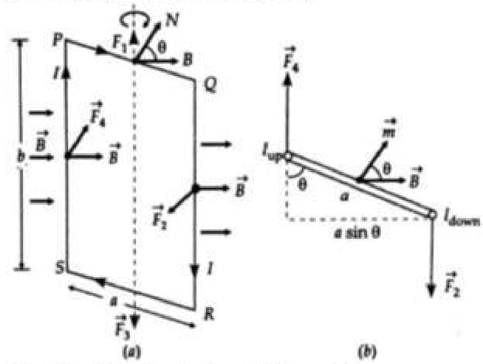


Fig. 4.95 (a) Rectangular loop PQRS in a uniform magnetic field. (b) Top view of the loop.

Since the field is radial, the plane of the coil always remains parallel to the field $\vec{B}$. The magnetic forces on sides PQ and SR are equal, opposite and collinear, so their resultant is zero. According to Fleming's left rule, the side PS experiences a normal inward force equal to NIbB while the side QR experiences an equal normal outward force. The two forces on sides PS and QR are equal and opposite. They form a couple and exert a torque given by

$\tau =$ Force x Perpendicular distance

$= NIbB \times a\sin 90^0 = NIB(\text{ab}) = \text{NIBA}$

Here $\theta = 90^0$, because the normal to the plane of coil remains perpendicular to the field $\vec{B}$ in all positions.

The torque τ deflects the coil through an angle α. A restoring torque is set up in the coil due to elasticity of the springs such that

$$\tau_{restoring} \propto \alpha \;\; or \;\; \tau_{restoring} = k\alpha$$

Where k is the *torsion constant* of the springs i.e., torque required to produce unit angular twist. In equilibrium position.

Restoring torque = Deflecting torque

$$k\alpha = NIBA$$

Or $$\alpha = \frac{NBA}{k}.I$$

Or $$\alpha \propto I$$

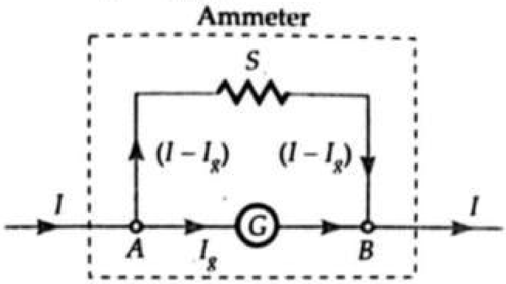
Thus the deflection produced in the galvanometer coil is proportional to the current flowing through it. Consequently, the instrument can be provided with a scale with equal divisions along a circular scale to indicate equal steps in current. Such a scale is called *linear scale.*

Also, $$I = \frac{k}{NBA}.\alpha = G\alpha$$

The factor $G = k / \text{NBA}$ is constant for a galvanometer and is called *galvanometer constant* or *current reduction factor* of the galvanometer.

Fig. of merit of a galvanometer. *It is defend as the current which produces a deflection of one scale division in the galvanometer and is given by*

$$G = \frac{I}{\alpha} = \frac{k}{NBA}$$



Let G = resistance of the galvanometer

I_g = the current with which galvanometer gives full scale deflection

$0 - I$ = the required current range of the ammeter

S = shunt resistance

$I - I_g$ = current through the shunt.

As galvanometer and shunt are connected in parallel, so

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

$$I_g G = (\text{I} - \text{I}_g)\text{S}$$

Or $$S = \frac{I_g}{I - I_g} \times G$$

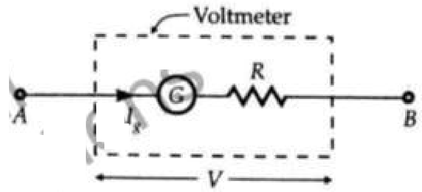
So by connecting a shunt of resistance S across the given galvanometer, we get an ammeter of desired range. Moreover,

$$I_g = \frac{S}{G+S} \times I$$

The deflection in the galvanometer is proportional to I_g and hence to I. So the scale can be graduated to read the value of current I directly.

Hence *an ammeter is a shunted or low resistance galvanometer.* Its effective resistance is

$$R_A = \frac{GS}{G+S} < S$$



A galvanometer can be converted into a voltmeter by connecting a high resistance in series with it. The value of this resistance is so adjusted that only current I_g which produces full scale deflection in the galvanometer, passes through the galvanometer.

Let

G = resistance of the galvanometer

I_g = the current with which galvanometer gives full scale deflection

$0 - V$ = required range of the voltmeter, and

R = the high series resistance which restricts the current to safe limit I_g.

$\therefore$ Total resistance in the circuit = R + G

By Ohm's law,

$$I_g = \frac{\text{Potential difference}}{\text{Total resistance}} = \frac{V}{R+G}$$

So by connecting a high resistance R in series with the galvanometer, we get a voltmeter of desired range. Moreover, the deflection in the galvanometer is proportional to current I_g and hence to V. The scale can be graduated to read the value of potential difference directly.

Hence a *voltmeter is a high resistance galvanometer.* Its effective resistance is

$$R_V = R + G >> G.$$

27. Soln. Current sensitivity. It is defined as the deflection produced in the galvanometer when a unit current flows through it.

Current sensitivity, $I_S = \frac{\alpha}{I} = \frac{NBA}{k}$

Voltage sensitivity. *It is defined as the deflection produced in the galvanometer when a unit potential difference is applied across its ends.*

Voltage sensitivity, $V_S = \frac{\alpha}{V} = \frac{\alpha}{IR} = \frac{NBA}{k\,R}$

Clearly, Voltage sensitivity = $\frac{\text{Current sensitivity}}{R}$

28. Soln. $A = 5cm \times 2cm = 10 \times 10^{-4} m^2 = 10^{-3} m^2$

$B = 2.5 \times 10^{-2} Wbm^{-2}, k = 1.5 \times 10^{-8} Nmrad^{-1}$

$\theta = 0.2rad, I = 2\mu A = 2 \times 10^{-6} A$

As $I = \frac{k}{NBA}.\alpha$

$\therefore N = \frac{k}{IBA}.\alpha$

$= \frac{1.5 \times 10^{-8} \times 0.2}{2 \times 10^{-6} \times 2.5 \times 10^{-2} \times 10^{-3}} = 60.$

29. Soln. The given ammeter can be regarded as the galvanometer.

$\therefore I_g = 1.0A, R_g = 0.80\Omega$

(i) Total current in the circuit, $I = 5.0A$

The required shunt resistance,

$R_s = \frac{I_g}{I - I_g} \times R_g = \frac{1.0}{5.0 - 1.0} \times 0.80 = 0.20\Omega.$

(ii) The combined resistance R_A of the ammeter and the shunt is given by

$\frac{1}{R_A} = \frac{1}{R_g} + \frac{1}{R_s} = \frac{1}{0.8} + \frac{1}{0.2} = \frac{1+4}{0.8} = \frac{25}{4}$

Or $R_A = 4/25 = 0.16\Omega.$