04

Moving Charges and Magnetism

TREND ANALYSIS 3 YEARS

Average No. of Questions Across all Sets

Topic	Types of Questions	2023	2020	2019
TOPIC 01 Magnetic Field, its Laws and Their Applications	1 Mark	1	2	–
	2 Marks	–	–	–
	3 Marks	–	–	–
	5 Marks	–	–	–
TOPIC 02 Lorentz Force	1 Mark	1	2	2
	2 Marks	1	–	2
	3 Marks	[illegible]	–	–
	5 Marks	–	–	–
TOPIC 03 Magnetic Force and Torque	1 Mark	1	1	–
	2 Marks	2	–	1
	3 Marks	2	1	1
	5 Marks	2	–	–

TOPIC 1

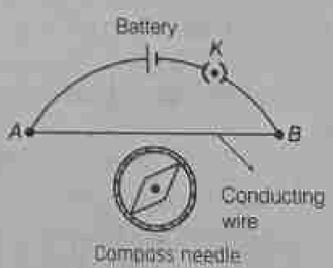
Magnetic Field, its Laws and Their Applications

Magnetic Field

The space around a magnet or a current carrying conductor in which its magnetic influence can be experienced is called **magnetic field**. Its SI unit is **tesla** (T).

Oersted's Experiment

Oersted's experiment demonstrated that the current carrying conductor carrying moving charges produces magnetic field around it.



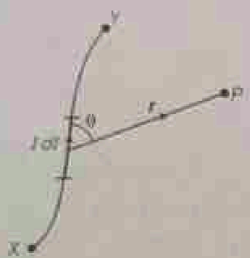
When key *K* is closed, then deflection occurs in the compass needle and *vice-versa*.

Laws of Magnetic Field

There are two laws of magnetic field

Biot-Savart's Law : Magnetic Field due to a Current Element

According to this law, the magnetic field due to small current carrying element dl at any nearby point P is given by



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

or $$d\mathbf{B} = \frac{\mu_0}{4\pi} \cdot \frac{Id\mathbf{l} \times \hat{\mathbf{r}}}{|\mathbf{r}|^3}$$

where, $\mu_0 / 4\pi = 10^{-7}$ T-m/A $= 10^{-7}$ H/m

Here, μ_0 = permeability of free space or vacuum and

r = distance of point P from current carrying element.

Its direction is given by right hand thumb rule.

Permittivity and Permeability

The relation between μ_0, ε_0 and c is

$$\frac{1}{\mu_0 \varepsilon_0} = c^2$$

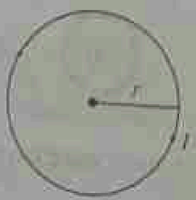
where, c is velocity of light, ε_0 is permittivity of free space and μ_0 is magnetic permeability or permeability of free space or vacuum.

Applications of Biot-Savart's Law

There are following applications of Biot-Savart's law

(i) Magnetic field at the centre of a circular current carrying conductor/coil

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



where, r is the radius of a circular loop.

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

(ii) Magnetic field at the centre of semi-circular current carrying conductor

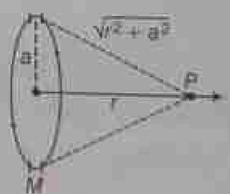
$$B = \frac{\mu_0 I}{4r}$$

(iii) Magnetic field at the centre of an arc of circular current carrying conductor which subtends an angle θ at the centre

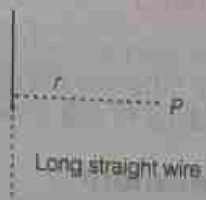
$$B = \frac{\mu_0}{4\pi} \cdot \frac{I\theta}{r}$$

(iv) Magnetic field at any point on the axis of circular current loop

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



(v) Magnetic field due to straight current carrying conductor at any point P at a distance r from the wire is given by



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

Ampere's Circuital Law

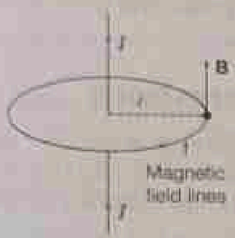
The line integral of the magnetic field **B** around any closed path in vacuum is equal to μ_0 times of the total current I threading through the closed circuitm, i.e. loop

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I$$

Applications of Ampere's Circuital Law

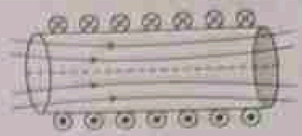
These are some applications of Ampere's circuital law

(i) Magnitude of magnetic field of a straight wire using Ampere's law



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

(ii) Magnetic field due to a straight solenoid



(a) At any point inside the solenoid.

$$B = \mu_0 n I$$

where, n = number of turns per unit length.

(b) At points near the ends of air closed solenoid.

$$B = \frac{1}{2}\mu_0 n I$$

PYQs Previous Years Questions

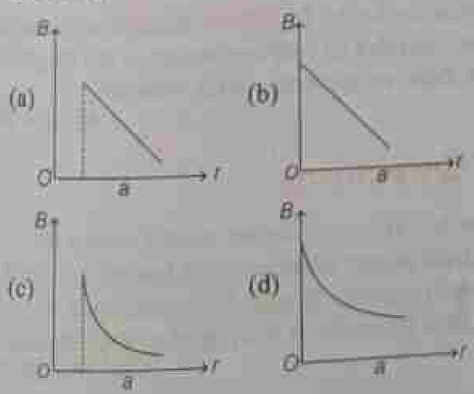
1 Mark Questions

Multiple Choice Questions

1. A long straight wire of radius a carries a steady current I. The current is uniformly distributed across its area of cross-section. The ratio of magnitude of magnetic field $\mathbf{B}_1$ at $\frac{a}{2}$ and $\mathbf{B}_2$ at distance $2a$, is **CBSE 2023**

(a) $\frac{1}{2}$ (b) 1 (c) 2 (d) 4

2. Which of the following graphs correctly represents the variation of the magnitude of the magnetic field outside a straight infinite current carrying wire of radius a, as a funciton of distance r from the centre of the wire? **CBSE 2023**



3. The magnetic field at the centre of a current carrying circular loop of radius R is B_1. The magnetic field at a point on its axis at a distance R from the centre of the loop is B_2. The ratio $\left(\frac{B_1}{B_2}\right)$ is **CBSE 2022 (Term-I)**

(a) $2\sqrt{2}$ (b) $\frac{1}{\sqrt{2}}$

(c) $\sqrt{2}$ (d) 2

4. A constant current is flowing through a solenoid. An iron rod is inserted in the solenoid along its axis. Which of the following quantities will not increase? **CBSE 2022 (Term-I)**

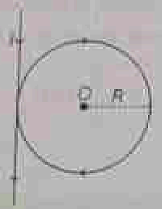
(a) The magnetic field at the centre
(b) The magnetic flux linked with the solenoid
(c) The rate of heating
(d) The self-inductance of the solenoid

5. A current carrying wire kept in a uniform magnetic field will experience a maximum force, when it is **CBSE 2022 (Term-I)**

(a) perpendicular to the magnetic field
(b) parallel to the magnetic field
(c) at an angle of 45° to the magnetic field
(d) at an angle of 60° to the magnetic field

6. A current of 10 A is flowing from east to west in a long straight wire kept on a horizontal table. The magnetic field developed at a distance of 10 cm due north on the table is **All India 2020**
   (a) 2×10^{-5} T, acting downwards
   (b) 2×10^{-5} T, acting upwards
   (c) 4×10^{-5} T, acting downwards
   (d) 4×10^{-5} T, acting upwards

7. A current I flows through a long straight conductor which is bent into a circular loop of radius R in the middle as shown in the figure.



The magnitude of the net magnetic field at point O will be **All India 2020**

(a) zero (b) $\frac{\mu_0 I}{2R}(1+\pi)$
(c) $\frac{\mu_0 I}{4\pi R}$ (d) $\frac{\mu_0 I}{2R}\left(1-\frac{1}{\pi}\right)$

KEY idea

Magnitude of **B** for infinite length of wire is calculated by $B = \frac{\mu_0 I}{2\pi R}$.

Assertion-Reason Questions

Directions (Q. Nos. 8-9) *In the following questions, two statements are given- one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below*

(a) If both Assertion and Reason are correct and Reason is the correct explanation of Assertion.
(b) If both Assertion and Reason are correct but Reason is not the correct explanation of Assertion.
(c) If Assertion is correct but Reason is incorrect.
(d) If both Assertion and Reason are incorrect.

8. **Assertion** When radius of a circular loop carrying a steady current is doubled, its magnetic moment becomes four times.

   Reason The magnetic moment of a circular loop carrying a steady current is proportional to the area of the loop. **CBSE 2023, 2022 (Term-I)**

9. **Assertion** The magnetic field produced by a current carrying solenoid is independent of its length and cross-sectional area.

   Reason The magnetic field inside the solenoid is uniform.

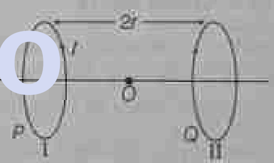
Very Short Answer Question

10. Draw the magnetic field lines due to current carrying loop. **Delhi 2013C**

2 Marks Questions

11. Derive with the help of diagram, the expression for the magnetic field inside a very long solenoid having n turns per unit length carrying a current I. **Delhi 2013C**

12. Two identical circular loops P and Q, each of radius r and carrying equal currents are kept in the parallel planes having a common axis passing through O. The direction of current in P is clockwise and in Q is anti-clockwise as seen from O which is equidistant from the loops P and Q. Find the magnitude of the net magnetic field at O. **Delhi 2012**



13. A long solenoid of length L having N turns carries a current I. Deduce the expression for the magnetic field in the interior of the solenoid. **All India 2011C**

14. A straight wire of length L is bent into a semi-circular loop. Use Biot-Savart's law to deduce an expression for the magnetic field at its centre due to the current I passing through it. **Delhi 2011C**

15. State Ampere's circuital law. Show through an example, how this law enables an easy evaluation of the magnetic field when there is a symmetry in the system? **All India 2010**

3 Marks Questions

16. Using Biot-Savart's law, derive an expression for magnetic field at any point on axial line of a current carrying circular loop. Hence, find magnitude of magnetic field intensity at the centre of circular coil. **CBSE SQP 2019-20**

17. A particle of mass m and charge q is in motion at speed v parallel to a long straight conductor carrying current I as shown below.

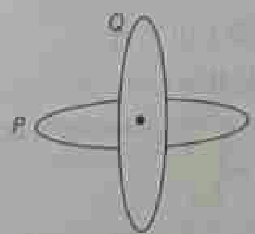
Find magnitude and direction of electric field required so that the particle goes undeflected. **CBSE SQP 2018-19**

18. (i) State Biot-Savart's law and express it in the vector form.
(ii) Using Biot-Savart's law, obtain the expression for the magnetic field due to a circular coil of radius r, carrying a current I at a point on its axis distant x from the centre of the coil. **CBSE 2018C**

19. (i) State Biot-Savart's law and express this law in the vector form.
(ii) Two identical circular coils P and Q each of radius R, carrying currents 1 A and $\sqrt{3}$ A respectively, are placed concentrically and perpendicular to each other lying in the XY and YZ-planes. Find the magnitude and direction of the net magnetic field at the centre of the coils. **All India 2017**

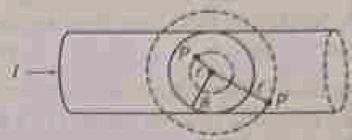
> **KEY idea**
> Magnitude of magnetic field of a circular wire is determined by $B = \frac{\mu_0}{4\pi} \times \frac{2\pi I}{R}$

20. 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. **Delhi 2017**



21. Use Biot-Savart's law to derive the expression for the magnetic field on the axis of a current carrying circular loop of radius R. **Delhi 2016**

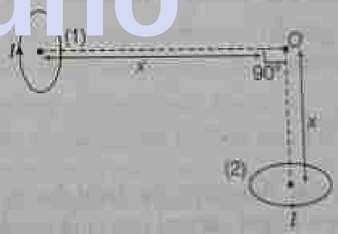
22. Figure shows a long straight wire of a circular cross-section of radius a carrying steady current I. The current I is uniformly distributed across this cross-section. Derive the expressions for the magnetic field in the region (i) $r < a$ and (ii) $r > a$. **All India 2011C**



> **KEY idea**
> In these types of questions, first of all we have to calculate the current per unit area of cross-section, so that we can calculate the current in each loop, then only we can find the magnetic field.

5 Marks Questions

23. Two very small identical circular loops (1) and (2) carrying equal current 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. **Delhi 2014**



24. State Biot-Savart's law expressing it in the vector form. Use it to obtain the expression for the magnetic field at an axial point distance d from the centre of a circular coil of radius a carrying current I. Also, find the ratio of the magnitudes of the magnetic field of this coil at the centre and at an axial point for which $d = a\sqrt{3}$. **Delhi 2013C**

25. State Biot-Savart's law and give the mathematical expression for it.
Use this law to derive the expression for the magnetic field due to a circular coil carrying current at a point along its axis.
How does a circular loop carrying current behave as a magnet? **Delhi 2011**

26. (i) State Ampere's circuital law.

(ii) Use it to derive an expression for magnetic field inside along the axis of an air cored solenoid.

(iii) Sketch the magnetic field lines for a finite solenoid. How are these field lines different from the electric field lines from an electric dipole? **Foreign 2010**

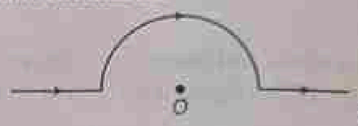
27. (i) Using Biot-Savart's law, deduce an expression for the magnetic field on the axis of a circular current carrying loop.

(ii) Draw the magnetic field lines due to a current carrying loop.

(iii) A straight wire carrying a current of 12 A is bent into a semi-circular arc of radius 2.0 cm as shown in the figure. What is the magnetic field **B** at *O* due to

(a) straight segments and

(b) the semi-circular arc?



Foreign 2011

Explanations

1. (b) For a point inside the solid cylinder,

$$B_{in} = \frac{\mu_0 Ir}{2\pi a^2} \quad \left(\text{at } r = \frac{a}{2}\right)$$

$$B_{in} = \frac{\mu_0 I}{4\pi a}$$

For a point outside the solid cylinder,

$$B_{out} = \frac{\mu_0 I}{2\pi r} \quad (\text{at } r = 2a)$$

$$B_{out} = \frac{\mu_0 I}{4\pi a}$$

$$\Rightarrow \quad \frac{B_{in}}{B_{out}} = 1$$

2. (d) We know that, the magnetic field due to an infinitely long straight current carrying conductor at a distance R is given by

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

For same current, $R = a$ (say)

$$B \propto \frac{1}{a}$$

So, graph (d) is correct.

3. (a) Magnetic field at the centre of a current carrying circular loop of radius R is given by

$$B_1 = \frac{\mu_0 I}{2R} \quad \ldots\text{(i)}$$

Magnetic field at point on its axis at a distance R from the centre loop is

$$B_2 = \frac{\mu_0 IR^2}{2(x^2 + R^2)^{3/2}}$$

Here, $x = R$

$$\Rightarrow \quad B_2 = \frac{\mu_0 IR^2}{2(R^2 + R^2)^{3/2}} = \frac{\mu_0 I}{2(2\sqrt{2}R)} \quad \ldots\text{(ii)}$$

From Eqs. (i) and (ii), we get

$$\frac{B_1}{B_2} = 2\sqrt{2}$$

4. (c) When iron rod is inserted in a current carrying solenoid along its axis, then the magnetic field, magnetic flux and self-inductance of the solenoid increases, but there is no increase in the rate of heating, as it depends on the current flowing in it.

5. (a) The force experienced by a current carrying wire in a uniform magnetic field is given by

$$F = IlB \sin\theta$$

So, it will be maximum, when $\sin\theta$ is maximum i.e. at $\theta = 90°$ or the wire is perpendicular to the magnetic field.

6. (a) Given, current, $I = 10$ A (east to west)

Distance, $r = 10$ cm

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

Magnetic field, $|\mathbf{B}| = ?$

The magnitude of magnetic field $|\mathbf{B}|$ for infinite length of wire $= \dfrac{\mu_0 I}{2\pi r}$

$$\Rightarrow \quad |\mathbf{B}| = \frac{4\pi \times 10^{-7} \times 10}{2 \times \pi \times 10 \times 10^{-2}}$$

$$= 2 \times 10^{-5}\,\text{T}$$

Hence, magnetic field (**B**) acting downward.

7. (d) The magnetic field due to the long straight conductor at O is given by

$$B_1 = \frac{\mu_0 I}{2\pi R}$$

and that due to circular loop of radius R is

$$B_2 = \frac{\mu_0 I}{2R}$$

As, $\quad B_2 > B_1$

$\therefore$ The magnitude of net magnetic field at point O is

$$B_{\text{net}} = B_2 - B_1 = \frac{\mu_0 I}{2R} - \frac{\mu_0 I}{2\pi R}$$

$$= \frac{\mu_0 I}{2R}\left(1 - \frac{1}{\pi}\right)$$

8. (b) Magnetic dipole moment of the current loop

$$= AN \times I$$

Initially magnetic moment, $M = I\pi r^2$

New magnetic moment, $M = I\pi(2r)^2$

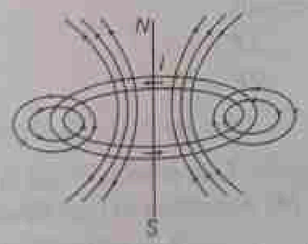
$$= 4I(\pi r^2) = 4M$$

So, magnetic moment becomes four times when radius is doubled.

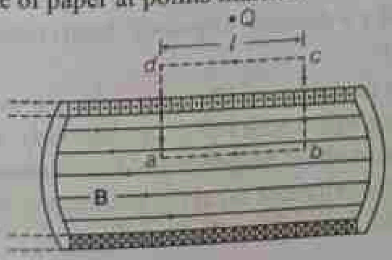
9. (b) The magnetic field due to solenoid having n number of turns/metre and carrying current I is $B = \mu_0 nI$.

It is obvious that, magnetic field is independent of length and cross-sectional area. Also, magnetic field is uniform inside the solenoid.

10. Magnetic field lines due to a current carrying loop are given by



11. Figure shows the longitudinal sectional view of long current carrying solenoid. The current comes out of the plane of paper at points marked.



Let **B** be the magnetic field at any point inside the solenoid.

Considering the rectangular closed path $abcda$. Applying Ampere's circuital law over loop $abcda$.

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 \times (\text{Total current passing through loop } abcda)$$

$$\int_a^b \mathbf{B} \cdot d\mathbf{l} + \int_b^c \mathbf{B} \cdot d\mathbf{l} + \int_c^d \mathbf{B} \cdot d\mathbf{l} + \int_d^a \mathbf{B} \cdot d\mathbf{l} = \mu_0 \left(\frac{N}{L} lI\right)$$

where, $\frac{N}{L}$ = number of turns per unit length and $ab = cd = l$ = length of rectangle.

$$\int_a^b Bdl \cos 0^\circ + \int_b^c Bdl \cos 90^\circ + 0 + \int_d^a Bdl \cos 90^\circ = \mu_0 \left(\frac{N}{L}\right) lI$$

$$B \int_a^b dl = \mu_0 \left(\frac{N}{L}\right) lI$$

$$\Rightarrow \quad Bl = \mu_0 \left(\frac{N}{L}\right) lI$$

$$\Rightarrow \quad B = \mu_0 (N/L) I$$

or $\quad B = \mu_0 nI$

where, n = number of turns per unit length.

This is the required expression for magnetic field inside the long current carrying solenoid.

12. To calculate net magnetic field at point O, first of all, calculate the magnetic field at point O due to both coils separately, with direction. By vector addition of these two magnetic fields, net magnetic field can be obtained.

Magnetic field at O due to two rings will be in same direction ($Q \to P$, along the axis) and of equal magnitude.

$$B = B_1 + B_2 \text{ but } B_2 = B_1$$

$$\Rightarrow \quad B = 2B_1 = 2\left[\frac{\mu_0 Ir^2}{2(r^2 + r^2)^{3/2}}\right]$$

$$B = \frac{\mu_0 Ir^2}{(2r^2)^{3/2}} = \frac{\mu_0 Ir^2}{2^{3/2} r^3}$$

$$B = \frac{\mu_0 I}{2^{3/2} r}$$

13. Refer to Sol. 11 on page 121.

14. When a straight wire is bent into semi-circular loop, then there are two parts which can produce the magnetic field at the centre, one is circular part and

other is straight part due to which magnetic field is zero i.e. net magnetic field at C is only due to semi-circular loop.

$\because$ Length L is bent into semi-circular loop

Length of wire = Circumference of semi-circular wire

$$\Rightarrow \quad L = \pi r \Rightarrow r = \frac{L}{\pi} \qquad \text{...(i)}$$

Considering a small element dl on current loop. The magnetic field dB due to small current element Idl at centre C. Using Biot-Savart's law, we have

$$dB = \frac{\mu_0}{4\pi} \frac{Idl \sin 90^\circ}{r^2} \qquad [\because Idl \perp r, \therefore \theta = 90^\circ]$$

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

Net magnetic field at C due to semi-circular loop,

$$B = \int_{\text{semi-circle}} \frac{\mu_0}{4\pi} \frac{Idl}{r^2}$$

$$\Rightarrow \quad B = \frac{\mu_0}{4\pi} \frac{I}{r^2} \int_{\text{semi-circle}} dl$$

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

But, $\quad r = L/\pi$

$$B = \frac{\mu_0}{4\pi} \frac{IL}{(L/\pi)^2}$$

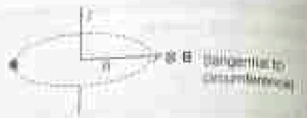
$$= \frac{\mu_0}{4\pi} \times \frac{IL}{L^2} \times \pi^2 \Rightarrow B = \frac{\mu_0 I\pi}{4L}$$

This is the required expression.

15. **Ampere's circuital law** It states that the line integral of magnetic field **B** around any closed loop is equal to μ_0 times the total current threading through the loop.

i.e. $$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I$$

Derivation To explain the Ampere's circuital law consider an infinitely long conductor wire carrying a steady current I as shown in the figure.



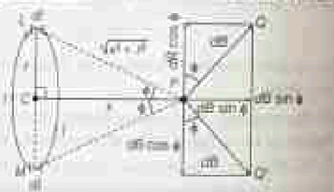
In order to determine the magnetic field at point P which is situated at a distance R from the centre of the circular loop around the conductor wire, **B** (magnetic field) is tangential to circumference of the loop.

Now, $\oint \mathbf{B} \cdot d\mathbf{l} = \oint B\, dl = B \cdot 2\pi R = \mu_0 I$

$\Rightarrow \quad B = \mu_0 I / 2\pi R$ [from Ampere's circuital law]

The direction of magnetic field will be determined by right hand rule.

16. Let us consider a circular loop of radius r with centre C. Let the plane of the coil be perpendicular to the plane of the paper and current I be flowing in the direction as shown in the figure. Suppose P is any point on the axis at a distance x from the centre.



Now, consider a current element Idl on top (L) where current comes out of paper normally, whereas at bottom (M) enters into the plane of paper normally.

$\because \quad LP \perp Idl$

Also, $\quad MP \perp Idl$

$\because \quad LP = MP = \sqrt{x^2 + r^2}$

The magnetic field at point P due to current element Idl. According to Biot-Savart's law,

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

where, r = radius of circular loop

and x = distance of point P from centre along the axis.

The direction of dB is perpendicular to LP and along PQ, where $PQ \perp LP$. Similarly, the same magnitude of magnetic field is obtained due to current element Idl at the bottom and direction is along PQ', where $PQ' \perp MP$.

Now, resolving dB due to current element at L and M, $dB \cos\phi$ components balance each other and net magnetic field is given by

$$B = \oint dB \sin\phi = \oint \frac{\mu_0}{4\pi}\left(\frac{Idl}{x^2 + r^2}\right)\frac{r}{\sqrt{x^2 + r^2}}$$

$$\left[\because \text{In } \triangle PCL,\ \sin\phi = \frac{r}{\sqrt{x^2 + r^2}}\right]$$

$$= \frac{\mu_0}{4\pi} \frac{Ir}{(x^2 + r^2)^{3/2}} \oint dl$$

$$= \frac{\mu_0}{4\pi} \frac{Ir}{(x^2 + r^2)^{3/2}} (2\pi r)$$

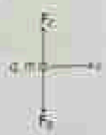
or $$B = \frac{\mu_0 I r^2}{2(x^2 + r^2)^{3/2}}$$

For N turns, $B = \dfrac{\mu_0 N I r^2}{2(x^2 + r^2)^{3/2}}$ T

At the centre of circular coil, $x = 0$

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

17. The charge particles will move undeflected.



As, $\quad \mathbf{F}_E = -\mathbf{F}_B$

$|\mathbf{F}_E| = |\mathbf{F}_B|$

$qE = qvB \sin\theta$

Then, electric field, $E = vB \sin 90^\circ$

and $\quad B = \dfrac{\mu_0 I}{2\pi r}$

and $\quad E = \dfrac{\mu_0 I v}{2\pi r}$

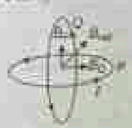
Thus, magnetic force acts towards the conductor.

18. (i) Refer to text on page 116 (Biot-Savart's law).

(ii) Refer to Sol. 16 on pages 122 and 123.

19. (i) Refer to text on page 116. (Biot-Savart's law).

(ii)



Magnitude of magnetic field due to circular wire P,

$$B_P = \frac{\mu_0}{4\pi} \times \frac{2\pi I_1}{R} \text{ (along vertically upwards)}$$

$$= \mu_0 I_1 / 2R$$

Magnitude of magnetic field due to circular wire Q,

$$B_Q = \mu_0 / 4\pi \times 2\pi I_2 / R$$

(along horizontal towards left)

$$= \mu_0 I_2 / 2R$$

Net magnitude of magnetic field at the common centre of the two coils,

$$B = \sqrt{B_P^2 + B_Q^2}$$

$$\Rightarrow \quad B = \sqrt{\left(\frac{\mu_0 I_1}{2R}\right)^2 + \left(\frac{\mu_0 I_2}{2R}\right)^2}$$

$$B = \sqrt{\left(\frac{\mu_0}{2R}\right)^2 (I_1^2 + I_2^2)}$$

$$\Rightarrow \quad B = \frac{\mu_0}{2R}\sqrt{I_1^2 + I_2^2}$$

$$B = \frac{4\pi \times 10^{-7}}{2 \times R}\sqrt{(1)^2 + (\sqrt{3})^2}$$

$$B = 4\pi \times 10^{-7}/R \text{ T}$$

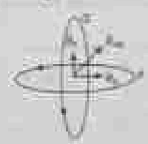
Resultant magnetic field makes an angle θ with direction of B_Q, which is given by

$$\tan\theta = B_P / B_Q = 1/\sqrt{3}$$

$$\Rightarrow \quad \theta = 30^\circ$$

20. Magnetic field due to circular loop P,

$$B_P = \frac{\mu_0 I_P}{2r}$$



Magnetic field due to circular loop Q,

$$B_Q = \mu_0 I_Q / 2r$$

So, net magnetic field at the common centre of the loop is,

$$B_{net} = \sqrt{B_P^2 + B_Q^2}$$

$$= \sqrt{(\mu_0 I_P/2r)^2 + (\mu_0 I_Q/2r)^2}$$

$$= \frac{\mu_0}{2r}\sqrt{I_P^2 + I_Q^2} = \frac{4\pi \times 10^{-7}}{2 \times 5 \times 10^{-2}} \times \sqrt{3^2 + 4^2}$$

$$= 2\pi \times 10^{-5} \text{ T}$$

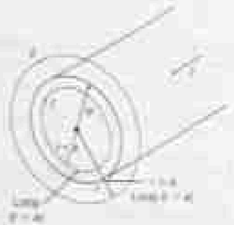
Resultant magnetic field makes an angle θ with direction of B_Q which is given by

$$\tan\theta = \frac{B_P}{B_Q} = \frac{I_P}{I_Q} = \frac{3}{4} \Rightarrow \theta = \tan^{-1}\left(\frac{3}{4}\right)$$

Concept Enhancer Magnetic field due to a circular loop is always inversely proportional to r.

21. Refer to Sol. 16 on pages 122 and 123.

22. The current is distributed uniformly across the cross-section of radius a.



∴ Current passes per unit cross-section $= I/\pi a^2$

∴ Current passes through the cross-section of radius r,

$$I' = \left(\frac{I}{\pi a^2} \times \pi r^2\right) = \frac{I r^2}{a^2} \quad ...(i)$$

(i) Consider a loop of radius r whose centre lies at the axis of wire, where $r < a$ as shown in figure inside the wire.

Applying Ampere's circuital law,

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I'$$

$$\oint B dl \cos 0° = \mu_0 (I r^2/a^2) \quad \text{[From Eq. (i)]}$$

$$B \oint dl = \mu_0 \frac{I r^2}{a^2} \Rightarrow B \times 2\pi r = \frac{\mu_0 I r^2}{a^2}$$

$$\Rightarrow B = \frac{\mu_0 I r}{2\pi a^2} \Rightarrow B \propto r$$

(ii) Considering a loop of radius r whose centre lies at the axis of wire and $(r > a)$ as shown in outer dotted line.

∴ Current I threads the loops.

Applying Ampere's circuital law,

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I$$

$$\oint B dl \cos 0° = \mu_0 I \Rightarrow B \oint dl = \mu_0 I$$

$$B \times 2\pi r = \mu_0 I \Rightarrow B = \mu_0 I / 2\pi r \Rightarrow B \propto 1/r$$

Thus, the field **B** is proportional to r as we move from the axis of cylinder towards its surface and then decreases as $1/r$.

23. The magnetic field at a point due to a circular loop is given by

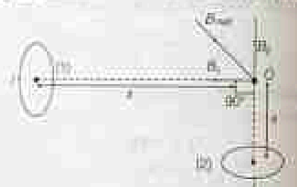
$$B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi I a^2}{(a^2 + r^2)^{3/2}}$$

where, I = current through the loop,
a = radius of the loop
and r = distance of O from the centre of the loop.

Since I, a and $r = x$ are the same for both the loops, 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 of the magnetic field due to loop (2) will be towards O as shown. The direction of the net magnetic field will be as shown below



The magnitude of the net magnetic field is given by

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

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

24. Refer to text on page 116 (For the statement of Biot-Savart's law).

Refer to Sol. 16 on pages 122 and 123.
(For field at axial point of a circular coil).

Magnetic field induction at the centre of the circular coil carrying current,

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

and magnetic field induction at an axial point,

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

$$\frac{B_2}{B_1} = \frac{a^2 \times a}{(a^2 + d^2)^{3/2}} = \frac{a^3}{(a^2 + d^2)^{3/2}}$$

$$\frac{B_2}{B_1} = \frac{a^3}{(a^2 + 3a^2)^{3/2}} \quad [\because d = a\sqrt{3}]$$

$$= \frac{a^3}{(4a^2)^{3/2}} = \frac{a^3}{8a^3} \Rightarrow \frac{B_2}{B_1} = \frac{1}{8}$$

25. Refer to text on page 116 (For Biot-Savart's law).

Refer to Sol. 16 on pages 122 and 123 (For the magnetic field due to a circular coil carrying current at a point along its axis).

As current carrying loop has the magnetic field lines around it which exerts a force on a moving charge. Thus, it behaves as a magnet with two mutually opposite poles.

The anti-clockwise flow of current behaves like a north pole, whereas clockwise flow as south pole. Hence, loop behaves as a magnet.

26. (i) Refer to Sol. 15 on page 122.
(ii) Refer to Sol. 11 on page 121.
(iii) Magnetic field lines for a finite solenoid has been shown below

All the magnetic field lines are necessarily closed loops, whereas electric lines of force are not closed.

27. (i) Refer to Sol. 16 on page 122.
(ii) Refer to Sol. 10 on page 121.
(iii) (a) Magnetic field due to straight part:

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

For point O, $d\mathbf{l}$ and $\mathbf{r}$ for each element of the straight segments AB and DE are parallel. Therefore, $d\mathbf{l} \times \mathbf{r} = 0$. Hence, magnetic field due to straight segments is zero.

(b) Magnetic field at the centre due to circular point

$$= \frac{\text{Magnetic field at the centre of circular coil}}{2} \quad [\because \text{Here, coil is half}]$$

$$= \frac{1}{2}\left(\frac{\mu_0 I}{2r}\right) = \frac{\mu_0 I}{4r}$$

$$B = \frac{\mu_0 I}{4r} = \frac{(4\pi \times 10^{-7}) \times 12}{4 \times 2 \times 10^{-2}} = 6\pi \times 10^{-5}\ \text{T}$$

TOPIC 2

Lorentz Force

Force on Moving Charge in a Uniform Magnetic Field

Force experienced by a single charged particle q moving with speed v in a uniform magnetic field at an angle θ with it is given as

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B}) \quad \text{[in vector form]}$$

Magnitude of $F = qvB \sin\theta$ and direction of force is given by right hand palm rule or Fleming's left hand rule.

- Work done by this magnetic force on charge particle is zero as $\mathbf{F} \perp \mathbf{v}$, hence $\mathbf{F}$ is perpendicular to displacement.
- Magnetic force cannot increase the kinetic energy of charged particle.

SI Unit of Magnetic Field

Magnetic force, $F = qvB \sin\theta$

$$\Rightarrow B = F/qv \sin\theta$$

If $F = 1\ \text{N}, q = 1\ \text{C}, v = 1\ \text{ms}^{-1}$

$\sin\theta = 1 = \sin 90°$

$$\Rightarrow \theta = 90°$$

$$\therefore \text{SI unit of } B = \frac{1\text{N}}{(1\text{C})(1\ \text{ms}^{-1})} = 1\text{NA}^{-1}\text{m}^{-1} = 1\text{T}$$

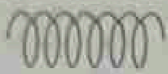
SI unit of magnetic field, B = 1 tesla (T).

Right Hand Palm Rule

If all four fingers of right hand together points in the direction of magnetic field and thumb points in the direction of motion of positive charge, then the palm of right hand faces in the direction of force.

Motion of a Charged Particle in a Uniform Magnetic Field

- The trajectory path followed by the charged particle in a uniform magnetic field is a
  - (i) straight line when angle between **v** and **B** is 0° or 180°
  - (ii) circle when angle between **v** and **B** is 90°.
  - (iii) helix when angle between **v** and **B** is an acute angle.


Helix

- When charged particle enter a magnetic field perpendicularly, then
  - (i) $mv^2/r = qvB$
  - (ii) radius, $r = mv/qB$
  - (iii) $T = \frac{2\pi m}{qB}$
  - (iv) $f = \frac{qB}{2\pi m}$
  - (v) $KE = \frac{q^2B^2r^2}{2m}$
- When angle between **v** and **B** is θ, then
  - (i) Radius of helical path,

$$r = \frac{mv\sin\theta}{qB} = \frac{mv_\perp}{qB}$$

where, $v_\perp = v\sin\theta$ = perpendicular component of velocity.

  - (ii) Time period,

$$T = \frac{2\pi}{v_\perp}\cdot r = \frac{2\pi}{v\sin\theta}\cdot\frac{mv\sin\theta}{qB} = \frac{2\pi m}{qB}$$

  - (iii) Frequency, $f = \frac{qB}{2\pi m}$
  - (iv) Pitch, $p = \frac{2\pi m\, v\cos\theta}{qB} = \frac{2\pi m v_\parallel}{qB}$

where, $v_\parallel = v\cos\theta$ = parallel component of velocity.

Charge Moving in Combined Electric Field and Magnetic Field

The net force exerted on a charged particle moving in the presence of both electric and magnetic fields is known as **Lorentz force.** It is given as

$$\mathbf{F}_{\text{Lorentz}} = \mathbf{F}_{\text{electric}} + \mathbf{F}_{\text{magnetic}}$$
$$= q\mathbf{E} + q(\mathbf{v}\times\mathbf{B}) \Rightarrow \mathbf{F}_{\text{Lorentz}} = q[\mathbf{E} + (\mathbf{v}\times\mathbf{B})]$$

The condition for the charge to move in the fields undeflected is $qE = qvB$.

$$\boxed{v = E/B}$$

PYQs Previous Years Questions

1 Mark Questions

Multiple Choice Questions

1. An electron enters a uniform magnetic field with speed v. It describes a semi-circular path and comes out of the field. The final speed of the electron is **CBSE 2023**

(a) zero (b) v
(c) $\frac{v}{2}$ (d) $2v$

2. Beams of electrons and protons move parallel to each other in the same direction. They **CBSE 2023**

(a) attract each other
(b) repel each other
(c) neither attract nor repel
(d) force of attraction or repulsion depends upon speed of beams

3. A particle of mass m and charge q moving with a uniform velocity $\mathbf{v} = v_{0x}\hat{\mathbf{i}} + v_{0y}\hat{\mathbf{j}}$ enters a region with a magnetic field $\mathbf{B} = B_0\hat{\mathbf{j}}$. After sometime, an electric field $\mathbf{E} = E_0\hat{\mathbf{j}}$ is also switched on in the region. The resulting path described by the particle will be **CBSE 2023**

(a) a circle in XZ-plane
(b) a parabola in XY-plane
(c) a helix with constant pitch
(d) a helix with increasing pitch

4. A free electron and a free proton are placed between two oppositely charged parallel plates both are close to the positive plate than the negative plate.

Which of the following statement(s) is/are true? **CBSE SQP 2021-22**

I. The force on the proton is greater than the force on the electron.

II. The potential energy of the proton is greater than that of the electron.

III. The potential energy of the proton and the electron is the same.

(a) I only (b) II only

(c) III and I (d) II and I

5. A proton and an alpha particle move in circular orbits in a uniform magnetic field. Their speeds are in the ratio of 9 : 4. The ratio of radii of their circular orbits $\left(\frac{r_p}{r_\alpha}\right)$ is **CBSE 2022 (Term-I)**

(a) $\frac{3}{4}$ (b) $\frac{4}{3}$ (c) $\frac{8}{9}$ (d) $\frac{9}{8}$

6. Time period of a charged particle undergoing a circular motion in a uniform magnetic field is independent of **CBSE SQP 2019-20**

(a) speed of the particle (b) mass of the particle

(c) charge of the particle (d) magnetic field

7. A charge particle after being accelerated through a potential difference V enters in a uniform magnetic field and moves in a circle of radius r. If V is [illegible], the radius of the circle will be[illegible] **[illegible] Delhi [illegible]**

(a) $2r$ (b) $\sqrt{2}\,r$ (c) $4r$ (d) $\frac{r}{\sqrt{2}}$

Assertion-Reason Questions

Directions (Q. Nos. 8-9) *In the following questions, two statements are given- one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below*

(a) If both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) If both Assertion and Reason are correct but Reason is not the correct explanation of Assertion.

(c) If Assertion is correct but Reason is incorrect.

(d) If both Assertion and Reason are incorrect.

8. **Assertion** An electron has a high potential energy when it is at a location associated with a more reactive value of potential and low potential energy when at a location associated with a more positive potential.

Reason Electrons move from a region of higher potential to region of lower potential. **CBSE SQP 2021-22**

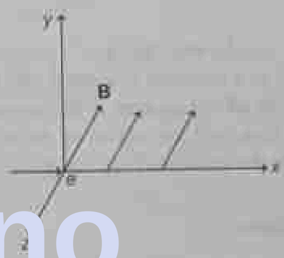
9. **Assertion** A proton and an electron with same momenta, enter in a magnetic field in a direction at right angles to the lines of the force. The radius of the paths followed by them will be same.

Reason Electron has less mass than the proton. **CBSE SQP 2021-22**

Very Short Answer Questions

10. An electron with charge $-e$ and mass m travels at a speed v in a plane perpendicular to a magnetic field of magnitude B. The electron follows a circular path of radius R. In a time t, the electron travels half-way around the circle. What is the amount of work done by the magnetic field? **CBSE SQP 2020-21**

11. An electron moves along $+x$-direction. It enters into a region of uniform magnetic field **B** directed along $-z$ direction as shown in figure. Draw the shape of trajectory followed by the electron after entering the field. **Delhi 2020**



12. Write the relation for the force acting on a charged particle q moving with velocity **v** in the presence of a magnetic field **B**. **All India 2019**

13. When a charge q is moving in the presence of electric field (E) and magnetic field (B) which are perpendicular to each other and also perpendicular to the velocity v of the particle, write the relation expressing v in terms of E and B. **All India 2019**

14. A proton and an electron travelling along parallel paths enter a region of uniform magnetic field, acting perpendicular to their paths. Which of them will move in a circular path with higher frequency? **CBSE 2018C**

15. A narrow beam of protons and deuterons, each having the same momentum, enters a region of uniform magnetic field directed perpendicular to their direction of momentum. What would be the ratio of the radii of the circular path described by them? **Foreign 2011**

16. Two particles A and B of masses m and $2m$ have charges q and $2q$ respectively. They are moving with velocities v_1 and v_2 respectively in the same direction, enters the same magnetic field B acting normally to

their direction of motion. If the two forces F_A and F_B acting on them are in the ratio of 1 : 2, find the ratio of their velocities. **Delhi 2011C**

17. A beam of α-particles projected along $+X$-axis, experiences a force due to a magnetic field along the $+Y$-axis. What is the direction of the magnetic field? **All India 2010**

18. Use the expression $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$ to define the SI unit of magnetic field. **All India 2010C**

2 Marks Questions

19. Write the expression for the Lorentz force on a particle of charge q moving with a velocity $\mathbf{v}$ in a magnetic field $\mathbf{B}$. When is the magnitude of this force maximum? Show that no work is done by this force on the particle during its motion from a point $\mathbf{r}_1$ to point $\mathbf{r}_2$. **CBSE 2023**

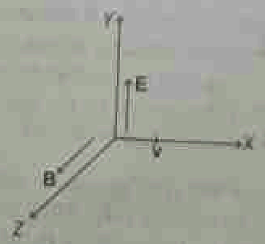
20. A proton is accelerated through a potential difference V, subjected to a uniform magnetic field acting normal to the velocity of the proton. If the potential difference is doubled, how will the radius of the circular path described by the proton in the magnetic field change? **All India 2017**

KEY idea

Radius of circular path is given by $r = \frac{\sqrt{2meV}}{qB}$.

21. 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. **Delhi 2019**

22. A particle of charge q is moving with velocity v in the presence of crossed electric field E and magnetic field B as shown in figure. Write the condition under which the particle will continue moving along X-axis. How would the trajectory of the particle be affected, if the electric field is switched OFF? **CBSE SQP 2017-18**



23. Find the condition under which the charged particles moving with different speeds in the presence of electric and magnetic field vectors can be used to select charged particles of a particular speed. **All India 2011**

24. Define one tesla using the expression for the magnetic force acting on a particle of charge q moving with velocity v in a magnetic field $\mathbf{B}$. **Foreign 2014**

25. A particle of charge q and mass m is moving with velocity $\mathbf{v}$. It is subjected to a uniform magnetic field $\mathbf{B}$ directed perpendicular to its velocity. Show that it describes a circular path. Write the expression for its radius. **Foreign 2011**

26. Write the expression for Lorentz magnetic force on a particle of charge q moving with velocity $\mathbf{v}$ in a magnetic field $\mathbf{B}$. Show that no work is done by this force on the charged particle. **All India 2011**

27. An electron and a proton moving with the same speed enter the same magnetic field region at right angles to the direction of the field.

Show the trajectory followed by the two particles in the magnetic field. Find the ratio of the radii of the circular paths which the particles may describe. **Foreign 2010**

28. A deuteron and a proton moving with the same speed enter the same magnetic field region at right angles to the direction of the field. Show the trajectories followed by the two particles in the magnetic field. Find the ratio of the radii of the circular paths which the two particles may describe. **Foreign 2010**

3 Marks Questions

29. Derive an expression for the velocity v_c of a positive ions passing undeflected through a region where crossed and uniform electric field E and magnetic field B are simultaneously present.

Draw and justify the trajectory of identical positive ions whose velocity has a magnitude less than $|v_c|$. **CBSE SQP 2018-19**

30. (i) Write the expression for the force $\mathbf{F}$ acting on a particle of mass m and charge q moving with velocity $\mathbf{v}$ in a magnetic field $\mathbf{B}$.

Under what conditions, will it move in
(a) a circular path and
(b) a helical path?

(ii) Show that the kinetic energy of the particle moving in magnetic field remains constant. **Delhi 2017**

5 Marks Question

31. Write the expression for the force $\mathbf{F}$, acting on a charged particle of charge q moving with a velocity $\mathbf{v}$ in the presence of both electric field $\mathbf{E}$ and magnetic field $\mathbf{B}$. Obtain the condition under which the particle moves undeflected through the fields. **All India 2012C**

Explanations

1. (b) By using, magnetic force, $F = qvB$ ...(i)

and centripetal force required to keep the electron moving,

$$F_c = \frac{mv^2}{r} \quad \text{...(ii)}$$

From Eqs. (i) and (ii), $r = \dfrac{mv}{qB}$

Time taken, $t = \dfrac{\pi r}{v}$

Thus, $t = \dfrac{\pi m}{qB}$

Magnetic force does not affect the magnitude of the velocity, so velocity remains same.

2. (b) The flow of positive charge is taken as the direction of current. So, here the current are in opposite direction, so they will repel each other.

3. (c) Mass of the particle $= m$

Charge $= q$

Uniform velocity, $\mathbf{v} = v_{0x}\hat{\mathbf{i}} + v_{0y}\hat{\mathbf{j}}$

Magnetic field, $\mathbf{B} = B_0\hat{\mathbf{j}}$

Electric field, $\mathbf{E} = E_0\hat{\mathbf{j}}$

When the electric field is switched ON, the particle will experience an additional force in the x-direction and it is given by $F = qE$. This force will cause the particle to move in a helical path with constant pitch.

$$\text{pitch} = \frac{2\pi m v\cos\theta}{qB} = \frac{2\pi m v_{\parallel}}{qB}$$

4. (b) When both plates have equal charge, the forces are the same and the potential energy of the charge is equal in magnitude but positive for the proton and negative for the electron.

5. (d) The radius of circular path traversed by a moving charged particle in a magnetic field is

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

$$\Rightarrow \quad r \propto \frac{mv}{q}$$

$$\therefore \quad \frac{r_p}{r_\alpha} = \frac{m_p v_p}{q_p} \times \frac{q_\alpha}{m_\alpha v_\alpha}$$

$$= \frac{m_p}{q_p} \times \frac{2q_p}{4m_p} \times \frac{9}{4} \qquad \left(\because \frac{v_p}{v_\alpha} = \frac{9}{4}\right)$$

$$= \frac{9}{8}$$

6. (a) As we know,

Time period of a charge particle is given by

$$T = \frac{2\pi m}{Bq}$$

Thus, time period is independent of speed of the particle.

7. (b) For the given charged particle, the radius of the circular path is

$$r = \frac{mv}{Bq} = \frac{\sqrt{2qVm}}{Bq} \quad \text{... (i)}$$

Keeping q, B and m fixed, if V is doubled, then

$$r' = \frac{\sqrt{2q(2V)m}}{Bq}$$

$$= \frac{\sqrt{2}\sqrt{2qVm}}{Bq}$$

$$= \sqrt{2}\, r \qquad [\because \text{from Eq. (i)}]$$

8. (c) Electrons move from a region of low potential region to high potential region.

9. (b) We know that, centripetal force = magnetic Lorentz force

$$\frac{mv^2}{r} = Bqv \sin\theta$$

$\sin\theta = \sin 90° = 1$

$$\frac{mv^2}{r} = Bqv \Rightarrow \frac{mv}{r} = Bq$$

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

Also q for proton and electron is same. So, radius of the paths followed by proton and electron will be same.

10. When an electron with charge e and mass m travel at speed v in plane perpendicular to **B**, then electron follows circular path.

Amount of work done,

$W = Fs \cos\theta$

Let, $\theta = 90°$

$W = Fs \cos 90°$

$\Rightarrow W = 0$

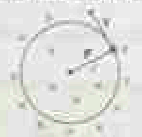
11. The magnetic force acting on the electron is given as

$\mathbf{F} = e(\mathbf{v} \times \mathbf{B}) = evB \sin\theta$

If the electron moves along +x-direction and **B** is directed along +y-direction, then $\theta = 90°$

$\Rightarrow F = evB$

So, the trajectory followed by the electron after entering the field will be circular as shown below



12. When a charged particle q moves with velocity **v** in a uniform magnetic field **B**, then the force acting on it is given by

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

13. $F_{Lorentz} = F_{electric} + F_{magnetic}$

$= q\mathbf{E} + q(\mathbf{v} \times \mathbf{B}) = q[\mathbf{E} + (\mathbf{v} \times \mathbf{B})]$

14. As we know that in a circular path, frequency of a charged particle is given by

$$\nu = \frac{qB}{2\pi m} \quad \text{or} \quad \nu \propto \frac{1}{m}$$

Since, $m_p > m_e$, therefore electron will move in circular path with higher frequency.

15. For the given momentum of charge particle, radius of circular paths depends on charge and magnetic field,

$r = mv/qB$ $\quad [\because qvB = mv^2/r]$

For constant momentum, $r \propto (1/qB)$

$\therefore r_{proton} : r_{deuteron} = q_{deuteron} : q_{proton} = 1:1$

16. Ratio of forces acting on the two particles,

$$\frac{F_1}{F_2} = \frac{qv_1 B \sin 90°}{(2q)v_2 B \sin 90°} = \frac{1}{2}$$

[Given, $B_1 = B_2 = B$]

$\Rightarrow v_1/v_2 = 1 \Rightarrow v_1 : v_2 = 1:1$

17. Velocity of α-particles

$\mathbf{v} = v\hat{\mathbf{i}}$ [Projected along X-axis]

Magnetic force on α-particles,

$\mathbf{F}_m = q(\mathbf{v} \times \mathbf{B}) = q(v\hat{\mathbf{i}} \times \mathbf{B})$

As, $\mathbf{F}_m = F_m\hat{\mathbf{j}}$ [Oriented along Y-axis]

$\Rightarrow F_m\hat{\mathbf{j}} = q(v\hat{\mathbf{i}} \times \mathbf{B}) \Rightarrow \mathbf{B} = -B\hat{\mathbf{k}} = B(-\hat{\mathbf{k}})$

The direction of magnetic field must be along −Z-axis.

18. Given, $\mathbf{F} = q(\mathbf{v} \times \mathbf{B}) \Rightarrow F = qvB \sin\theta$

where, θ is the angle between **v** and **B**.

$\Rightarrow B = F/qv \sin\theta$

If $q = 1$ C, $v = 1$ ms^{-1}, $\theta = 90°$, the magnetic field at any point can be given by

$$B = \frac{1\text{ N}}{[(1\text{ C})(1\text{ ms}^{-1})\sin 90°]} = 1\text{ N/A-m} = 1\text{ T}$$

∴ SI unit of magnetic field = 1 T

Thus, the magnetic field induction at a point is said to be one tesla, if a charge of one coulomb while moving at right angle to a magnetic field with a velocity of 1 ms^{-1} experiences a force of 1 N at that point.

19. Suppose a particle is moving in the presence of magnetic field. Consider q be the charge on the particle, v be the velocity of the particle, **B** be the magnitude of magnetic field.

Then, the magnitude of force is given by

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

This force is acting perpendicular to the plane containing **v** and **B** and is directed as given by right hand rule. Since, work done,

$W = \mathbf{F} \cdot \mathbf{s} = F \cdot s\cos\theta$

Displacement of the charged particle,

$s = (r_2 - r_1)$

and angle, $\theta = 90°$

So, work done by this force on the particle during its motion

$W = F \cdot (r_2 - r_1)\cos 90°$

$W = 0$

20. The kinetic energy of proton due to potential V is given by

$K = eV$

where, e = charge on a proton.

The radius of circular path of a proton in a magnetic field is

$$r = \frac{\sqrt{2mK}}{qB} = \frac{\sqrt{2meV}}{qB}$$

If potential is doubled, i.e. $V' = 2V$, then

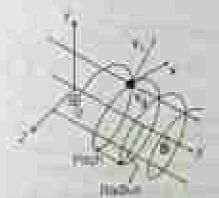
$$r' = \frac{\sqrt{2me \times 2V}}{qB} = \sqrt{2}\,r$$

Thus, radius becomes $\sqrt{2}$ times of previous value.

21. When an charged particle q enters a uniform magnetic field at an angle of 30°, then its path becomes helix of radius

$$r = \frac{mv \sin 30°}{eB} = \frac{mv}{2eB}$$

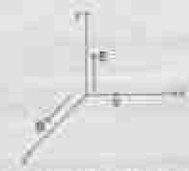
For diagram and discription If a charged particle has a velocity not perpendicular to **B**, then component of velocity along **B** remains unchanged as the motion along the magnetic field will not be affected by the magnetic field. Then, the motion of the particle in a plane perpendicular to **B** is as before a circular one, thereby producing a helical motion.



22. Condition for a particle continue moving along X-axis

$qE = qvB$

$$v = \frac{E}{B}$$



The trajectory becomes helical about the direction of the magnetic field.

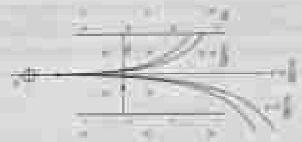
23. If we adjust the value of electric field (E) and magnetic field (B), such that the magnitude of two forces are equal, then the total force on the charge is zero. Also, the charge will move in the fields undeflected. This happens, when

Electric force (F_e) = Magnetic force (F_m)

$\Rightarrow qE = qvB$ or $v = E/B$

The above condition can be used to select a charged particle of a particular velocity from the charges moving with different speeds.

A diagram in which particle has being deflected in the presence of magnetic and electric field is shown below.

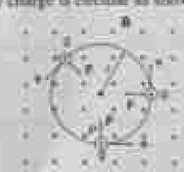


24. One tesla is defined as the field which produces a force of 1 newton when a charge of 1 coulomb moves perpendicularly in the region of the magnetic field at a velocity of 1 ms^{-1}.

As, $F = qvB \Rightarrow B = F/qv$

$\Rightarrow 1\text{ T} = 1\text{ N}/(1\text{C})(1\text{ ms}^{-1})$

25. A charge q projected perpendicular to the uniform magnetic field **B** with velocity **v**, the perpendicular force $F = qvB$, acts like a centripetal force perpendicular to the magnetic field, then the path followed by charge is circular as shown in the figure.



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

where, r = radius of the circular path followed by charge projected perpendicular to a uniform magnetic field.

Concept Enhancer A charged particle is moving perpendicular to the magnetic field then it will experience maximum force.

26. Lorentz force always acts along the direction perpendicular to the direction of velocity of the particle.

Magnetic Lorentz force,

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

$\Rightarrow$ Force is perpendicular to displacement made by charged particle.

$\therefore \quad W = Fd \cos 90° = 0$

$\Rightarrow \quad W = 0$

Hence, no work is done by magnetic Lorentz force on the charged particle.

27. When a charged particle enters in the magnetic field at right angle, then the particle follows a circular path. The trajectory of the two particles in the magnetic field is shown below.

Radius of the circular path, $r = \frac{mv}{qB}$

For same speed v, magnitude of charge q and magnetic field B

$$r \propto m \Rightarrow \frac{r_e}{r_p} = \frac{m_e}{m_p}$$

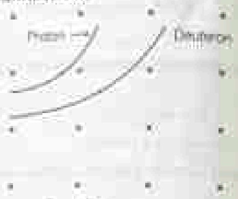
where, m_e and m_p are masses of electron and proton, respectively.

$$m_e < m_p$$
(Proton is much heavier than electron)

$\Rightarrow \quad r_e < r_p$

The radius of curvature of path of proton is much more than radius of curvature of path of electron. Hence, curvature of path of electron is more than curvature of path of electron.

28. The trajectory of the two particles in the magnetic field is shown below.



$\because \quad \frac{r_d}{r_p} = \frac{m_d}{m_p}$

$\because \quad m_d = 2m_p \Rightarrow r_d = 2r_p$

or $\quad r_d : r_p = 2 : 1$

29. Electric and magnetic field,

$$\mathbf{E} = E\hat{\mathbf{j}} \text{ and } \mathbf{B} = B\hat{\mathbf{k}}$$

Force on positive ion due to electric field,

$$\mathbf{F}_E = qE\hat{\mathbf{j}}$$

Force due to magnetic field, $\mathbf{F}_B = q(\mathbf{v}_i \times \mathbf{B})$

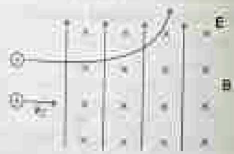
for passing undeflected, $\mathbf{F}_E = -\mathbf{F}_B$

$$qE\hat{\mathbf{j}} = -q(v_x \times B\hat{\mathbf{k}})$$

Only possible, when

$$qv_x \times B\hat{\mathbf{k}} = qv_x B\hat{\mathbf{j}}$$

or $\quad \mathbf{v}_x = \left(\frac{E}{B}\right)\hat{\mathbf{i}}$



For positive ions with speed $v < v_x$

Force due to electric field, $F_E' = qE$

Due to magnetic field, $F_B' = qvB < F_B$

Since, $v < v_x$

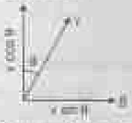
Now, forces are unbalanced thus, ion will experience an acceleration along it. Hence, initial velocity is perpendicular to **E**, the trajectory would be parabolic.

30. (i) Force acting on the particle, $F = Bqv$

In vector form, $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$

where, **B** is uniform magnetic field and **v** is velocity with which particle is moving.

(a) From this equation, it is clear that direction of force is perpendicular to the plane containing both **v** and **B**. In other words, force acts perpendicular to both **v** and **B**. When velocity becomes perpendicular to force, the path of the object becomes circular.



(b) In this case, **B** is assumed to act perpendicular to **v**.

In case, **B** is not perpendicular to **v**, a component of **v** remains perpendicular to **B** creates circular path. The component of **v** parallel to **B** will create linear path.

Here, the particle will have circular path due to $v \cos \theta$ and linear path due to $v \sin \theta$. Both when combined gives helical path.

(ii) Since, force always adjusts itself in a direction which becomes perpendicular to velocity, so only direction of velocity is changed not the magnitude. Hence, the kinetic energy of the particle always remains constant.

31. Force experienced by the charged particle in the presence of electric and magnetic field is the sum of electric force and magnetic force acting on it.

As, electric force, $\mathbf{F}_e = q\mathbf{E}$

Magnetic force, $\mathbf{F}_m = q(\mathbf{v} \times \mathbf{B})$

Thus, Lorentz force, $\mathbf{F} = \mathbf{F}_e + \mathbf{F}_m = q\mathbf{E} + q(\mathbf{v} \times \mathbf{B})$

$$= q[\mathbf{E} + (\mathbf{v} \times \mathbf{B})]$$

For a charged particle moves undeflected through these field, $\quad \mathbf{F} = 0$

$$q[\mathbf{E} + (\mathbf{v} \times \mathbf{B})] = 0 \text{ or } \mathbf{E} + (\mathbf{v} \times \mathbf{B}) = 0$$
$$\mathbf{E} = -(\mathbf{v} \times \mathbf{B}) = (\mathbf{B} \times \mathbf{v})$$

$\Rightarrow \quad |\mathbf{E}| = |\mathbf{B}||\mathbf{v}| \sin \theta$

It is maximum, when $\theta = 90°$

$\Rightarrow \quad |\mathbf{v}| = |\mathbf{B}|/|\mathbf{E}|$

The above condition can be used to select a charged particle of a particular velocity from charges moving with different speed for a condition of the particle undeflected through the field.

TOPIC 3

Magnetic Force and Torque

Force on a Current Carrying Conductor in a Uniform Magnetic [illegible]ld

The **magnetic force** experienced by a current carrying conductor placed in a uniform magnetic field is given by

$$\mathbf{F} = I(\mathbf{l} \times \mathbf{B}) \quad \text{[vector form]}$$

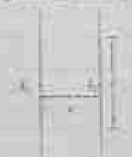
where, **l** = a vector whose magnitude is equal to length of the conductor and has identical direction in the flow of electric current I and **B** = magnetic field.

Magnitude of magnetic force, $F = IBl \sin \theta$

where, θ is the angle between current and magnetic field. The direction of force is given by Fleming's left hand rule.

Magnetic Force between Two Parallel Current Carrying Conductors

Magnetic force per unit length between two straight parallel current carrying conductors is given by



$$\frac{F}{l} = \frac{\mu_0}{4\pi} \cdot \frac{2I_1 I_2}{r}$$

Force will be of attractive nature, if direction of flow of currents in the two conductors are in the same direction i.e. parallel. The force of repulsion will act when direction of flow of currents are in opposite directions i.e. anti-parallel.

If both wires are of length l_1 and l_2 (if $l_1 > l_2$), then magnetic force between two straight current carrying wires/conductors is given by

$$F = \frac{\mu_0}{4\pi} \frac{2I_1 I_2}{r} l_2$$

where, l_2 = smaller length.

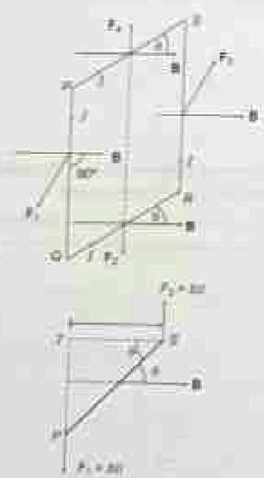
Torque on Current Carrying Loop (Magnetic Dipole)

Torque is experienced by a current carrying loop placed in a uniform magnetic field B as shown in the figure given below. It is given by $\tau = NIAB \sin\theta$, where θ is the angle between the direction of magnetic field B and that of vector **A** drawn normal to the plane of the coil.

or $\tau = \mathbf{M} \times \mathbf{B}$

where, $\mathbf{M} = NI\mathbf{A}$

and **M** is known as **magnetic dipole moment** of coil. Its SI unit is A-m².



Circular Current Loop as a Magnetic Dipole

A current loop behaves as a magnetic dipole. If we look at the upper face, current is anti-clockwise, so it has north polarity. If we look at lower face, then current is clockwise, so it has south polarity.

Magnetic dipole moment of the loop, $M = IA$

$\Rightarrow \quad |\mathbf{M}| = I\pi r^2$

The magnitude of magnetic field on axis of a circular loop of radius r carrying steady current I is given by

$$B = \frac{\mu_0 I r^2}{2(x^2 + r^2)^{3/2}} \quad (\text{for } x >> r)$$

$$B = \frac{\mu_0 I r^2}{2x^3} \Rightarrow \mathbf{B} = \frac{\mu_0 \mathbf{M}}{2\pi x^3}$$

If loop has N turns, $\mathbf{M} = NI\mathbf{A}$

Moving Coil Galvanometer

It is a device used to detect the current in electrical circuits. It is based on the principle that a current carrying loop placed in a uniform magnetic field experiences torque, magnitude of which depends on the strength of current.

In equilibrium position of the coil of MCG,

Restoring torque = Deflecting torque

$$k\theta = NIBA$$

[Torque, τ = Force × perpendicular distance $= NIbB \times a \sin 90^\circ = NIBA$]

$\Rightarrow \quad I = G\theta$

Current sensitivity, $I_s = \frac{\theta}{I} = \frac{NBA}{k}$

where, $G = \frac{k}{NBA}$

Its SI unit is rad/A or div/A.

Voltage sensitivity, $V_s = \frac{\theta}{V} = \frac{\theta}{IR} = \frac{I_s}{R} = \frac{NBA}{kR}$

Its SI unit is rad/V or div/V.

Clearly, $V_s = \frac{I_s}{R}$

The current sensitivity and voltage sensitivity of galvanometer depends on number of turns of coil, magnetic field B, area A of the coil and torsion constant k of the spring or suspension wire.

Conversion of Galvanometer into an Ammeter

A galvanometer can be converted into an ammeter by connecting a very low resistance (shunt S) in parallel with galvanometer whose value is given by

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

where, G = resistance of galvanometer,
I_g = current through galvanometer,
I = total current in circuit,
and S = resistance of the shunt (low resistance).

Ammeter

Conversion of a Galvanometer to Voltmeter

A galvanometer can be converted into voltmeter by connecting a very high resistance R in series with galvanometer which is given by

$$R = \frac{V}{I_g} - G$$

where, I_g = current through the galvanometer,
G = resistance of galvanometer
and V = potentials difference across the terminal A and B.

Voltmeter

NOTE The resistance of an ideal ammeter is zero and an ideal voltmeter is infinite. Ammeter is always connected in series with electrical circuit, whereas voltmeter is connected in parallel with the circuit.

PYQs Previous Years Questions

1 Mark Questions

Multiple Choice Questions

1. A long straight wire of circular cross-section of radius a carries a steady current I. The current is uniformly distributed across its cross-section. The ratio of the magnitudes of magnetic field at a point distant $a/2$ above the surface of wire to that at a point distant $a/2$ below its surface is **CBSE SQP 2022-23**
(a) 4 : 1 (b) 1 : 1 (c) 4 : 3 (d) 3 : 4

KEY Idea
The magnetic field is determined at the point by using $B = \frac{\mu_0}{4\pi} \times \frac{2I}{r}$

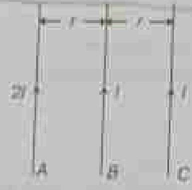
2. The coil of a moving coil galvanometer is wound over a metal frame in order to **CBSE SQP 2021-22**
(a) reduce hysteresis
(b) increase sensitivity
(c) increase moment of inertia
(d) provide electromagnetic damping

3. The current sensitivity of a galvanometer increases by 20%. If its resistance also increases by 25%, the voltage sensitivity will **CBSE SQP 2021-22**
(a) decrease by 1% (b) increased by 5%
(c) increased by 10% (d) decrease by 4%

4. Two wires of the same length are shaped into a square of side a and a circle with radius r. If they carry same current, the ratio of their magnetic moment is **CBSE SQP 2021-22**
(a) 2 : π (b) π : 2
(c) π : 4 (d) 4 : π

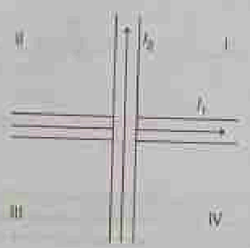
5. Three infinitely long parallel straight current carrying wires A, B and C are kept at equal distance from each other as shown in the figure. The wire C experiences

net force F. The net force on the wire C, when the current in wire A is reversed will be **CBSE SQP 2021-22**



(a) zero

above the other, in a horizontal plane as shown in figure. The region of vertically upward strongest magnetic field is **CBSE 2022 (Term-I)**



(a) I (b) II (c) III (d) IV

7. Two parallel conductors carrying current of 4.0 A and 10.0 A are placed 2.5 cm apart in vacuum. The force per unit length between them is **CBSE 2022 (Term-I)**

(a) 6.4×10^{-5} N/m (b) 6.4×10^{-2} N/m
(c) 4.6×10^{-4} N/m (d) 3.2×10^{-4} N/m

8. If an ammeter is to be used in place of a voltmeter, then we must connect with the ammeter a **CBSE 2022 (Term-I)**

(a) low resistance in parallel
(b) low resistance in series
(c) high resistance in parallel
(d) high resistance in series

9. A straight conducting rod of length l and mass m is suspended in a horizontal plane by a pair of flexible strings in a magnetic field of magnitude B. To remove the tension in the supporting strings, the magnitude of the current in the wire is **CBSE 2022 (Term-I)**

(a) $\frac{mgB}{l}$ (b) $\frac{mgl}{B}$
(c) $\frac{mg}{lB}$ (d) $\frac{lB}{mg}$

Assertion-Reason Questions

Directions (Q. Nos. 10-13) *In the following questions, two statements are given- one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below*

(a) If both Assertion and Reason are correct and Reason is the correct explanation of Assertion.
(b) If both Assertion and Reason are correct but Reason

10. Assertion The deflecting torque acting on a current carring loop is zero when its plane is perpendicular to the direction of magnetic field.

Reason The deflecting torque acting on a loop of magnetic moment **m** in a magnetic field **B** is a given by the dot product of **m** and **B**. **CBSE 2023**

11. Assertion On increasing the current sensitivity of a galvanometer by increasing the number of turns, may not necessarily increase its voltage sensitivity.

Reason The resistance of the coil of the galvanometer increases on increasing the number of turns. **CBSE SQP 2021-22**

12. Assertion To increase the range of an ammeter, we must connect a suitable high resistance in series to it.

Reason The ammeter with increased range should have high resistance. **CBSE SQP 2021-22**

13. Assertion Higher the range, lower is the resistance of an ammeter.

Reason To increase the range of an ammeter, additional shunt is added in series to it. **CBSE 2022 (Term-I)**

Very Short Answer Questions

14. Define the term current sensitivity of a moving coil galvanometer. **Delhi 2020**

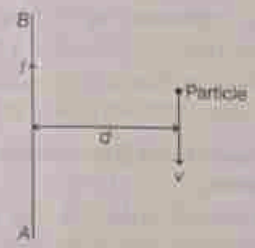
15. Write the underlying principle of a moving coil galvanometer. **CBSE Delhi 2018**

16. Using the concept of force between two infinitely long parallel current carrying conductors, define one ampere of current. **All India 2014**

17. Is the steady electric current the only source of magnetic field? Justify your answer. **Delhi 2013C**

2 Marks Questions

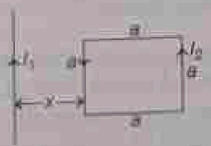
18. A long straight wire AB carries a current I. A particle (mass m and charge q) move with a velocity $\mathbf{v}$ parallel to the wire, at a distance d from it as shown in the figure. Obtain the expression for the force experienced by the particle and mention its directions. **CBSE 2023**



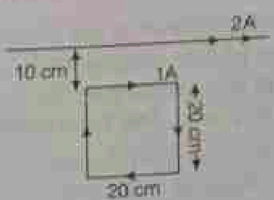
19. Briefly explain why and how a galvanometer is converted into an ammeter. **CBSE 2023**

20. 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. **CBSE QP 20[illegible]**

21. A square loop of side a carrying a current I_2 is kept at distance x from an infinitely long straight wire carying a current I_1 as shown in the figure. Obtain the expression for the resultant force acting on the loop. **Delhi 2019**



22. A square loop of side 20 cm carrying current of 1 A 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. **All India 2015C**

23. A rectangular coil of sides l and b carrying a current I is subjected to a uniform magnetic field $\mathbf{B}$ acting perpendicular to its plane. Obtain the expression for the torque acting on it. **Delhi 2014C**

24. (i) Two long straight parallel conductors a and b carrying steady currents I_a and I_b respectively are separated by a distance d. Write the magnitude and direction, what is the nature and magnitude of the force between the two conductors?
    (ii) Show with the help of a diagram, how the force between the two conductors would change when the currents in them flow in the opposite directions. **Foreign 2014**

25. A coil of N turns and radius R carries a current I. It is unwound and rewound to make a square coil of side a having same number of turns N. Keeping the current I same, find the ratio of the magnetic moments of the square coil and the circular coil. **Delhi 2013C**

26. A circular coil of closely wound N turns and radius r carries a current I. Write the expressions for the following
    (i) The magnetic field at its centre.
    (ii) The magnetic moment of this coil. **All India 2012**

27. 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. **All India 2012**

28. A circular coil of N turns and diameter d carries a current I. It is unwound and rewound to make another coil of diameter $2d$, current I remaining the same. Calculate the ratio of the magnetic moments of the new coil and the original coil. **All India 2012**

> **KEY Idea**
> Magnetic moment of length of wire will be given by
> $M = NIA$
> where, N is number of turns.

29. A steady current I_1 flows through a long straight wire. Another wire carrying steady current I_2 in the same direction is kept close and parallel to the first wire. Show with the help of a diagram, how the magnetic field due to the current I_1 exert a magnetic force on the second wire. Deduce the expression for this force. **All India 2011**

30. How is a moving coil galvanometer converted into a voltmeter? Explain giving the necessary circuit diagram and the required mathematical relation used. **All India 2011C**

31. A square coil of side 10 cm has 20 turns and carries a current of 12 A. The coil is suspended vertically and normal to the plane of the coil, makes an angle θ with the direction of a uniform horizontal magnetic field of 0.8 T. If the torque experienced by the coil equals 0.96 N-m, find the value of θ. **Delhi 2010C**

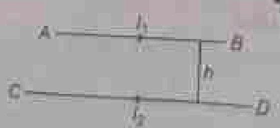
3 Marks Questions

32. (i) Briefly describe how the current sensitivity of a moving coil galvanometer can be increased.
(ii) A galvanometer shows full scale deflection for current I. A resistance R_1 is required to convert it into a voltmeter of range (0-V) and a resistance R_2, to convert it into a voltmeter of range (0-2V). Find the resistance of the galvanometer. **CBSE 2023**

33. Two circular loops A and B, each of radius 3 m, are placed co-axially at a distance of 4 m. They carry currents of 3 A and 2 A in opposite directions, respectively. Find the net magnetic field at the centre of loop A. **CBSE 2022**

34. Two long straight parallel conductors carrying current I_1 and I_2 are separated by a distance d. If the currents are flowing in the same direction, show how the magnetic field produced by one exerts an attractive force on the other. Obtain the expression for this force and hence define 1 ampere. **CBSE SQP 2022-23**

35. A horizontal wire AB of length l and mass m carries a steady current I_1, free to move in vertical plane is in equilibrium at a height of h over another parallel long wire CD carrying a steady current I_2, which is fixed in a horizontal plane as shown. Derive the expression for the force acting per unit length on the wire AB and write the condition for which wire AB is in equilibrium. **CBSE SQP 2022-23**



36. Derive the expression for the force acting between two long parallel current carrying conductors. Hence, define 1 A current. **All India 2020**

37. 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**

38. (i) Derive the expression for the torque acting on a current carrying loop placed in a magnetic field.
(ii) Explain the significance of a radial magnetic field when a current carrying coil is kept in it. **Delhi 2019**

39. (i) State the underlying principle of a moving coil galvanometer.
(ii) Give two reasons to explain why a galvanometer cannot as such be used to measure the value of the current in a given circuit.
(iii) Define the terms (a) voltage sensitivity and (b) current sensitivity of a galvanometer. **Delhi 2019**

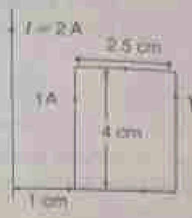
40. (i) Define SI unit of current in terms of the force between two parallel current carrying conductors.
(ii) Two long straight parallel conductors carrying steady currents I_a and I_b along the same direction are separated by a distance d. How does one explain the force of attraction between them? If a third conductor carrying a current I_c in the opposite direction is placed just in the middle of these conductors, find the resultant force acting on the third conductor. **CBSE 2018C**

41. Two long straight parallel conductors carry steady currents I_1 and I_2 are separated by a distance d. If the currents are flowing in the same direction, show how the magnetic field set-up in one produces an attractive force on the other. Obtain the expression for this force. Hence, define one ampere. **Delhi 2014**

42. A wire AB is carrying a steady current of 12A and is lying on the table. Another wire CD carrying 5A is held directly above AB at a height of 1 mm. Find the mass per unit length of the wire CD, so that it remains suspended at its position when left free. Give the direction of the current flowing in CD with respect to that in AB. [Take, the value of g = 10 ms^{-2}] **All India 2013**

43. A rectangular loop of wire of size 2.5 cm × 4 cm carries steady current of 1 A. A straight wire carrying 2 A current is kept near the loop as shown. If the loop and the wire are co-planar, find the (i) torque acting on the

loop and (ii) the magnitude and direction of the force on the loop due to the current carrying wire.
Delhi 2012

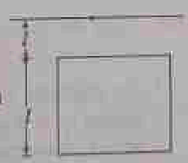


44. Depict the magnetic field lines due to two straight, long, parallel conductors carrying currents I_1 and I_2 in the same direction. Hence, deduce an expression for the force per unit length acting on one of the conductors due to the other. Is this force attractive or repulsive?
Delhi 2011C

45. State the underlying principle of working of a moving coil galvanometer. Write two reasons why a galvanometer cannot be used as such to measure the current in a given circuit. Name any two factors on which the current sensitivity of a galvanometer depends.
Delhi 2010

46. A moving coil galvanometer of re[illegible] full scale deflection when a current I [illegible] ws th[illegible]ugh its c[illegible]. It can be converted into a ammete[illegible] ange (0 to [illegible]) ($I > I_g$) when a shunt of resistance S is connected, find the expression for the shunt required in terms of I_g and G.
Delhi 2010C

47. Write the expression for the magnetic moment (**M**) due to a planar square loop of side l carrying a steady current I in a vector form. In the given figure, this loop is placed in a horizontal plane near a long straight conductor carrying a steady current I_1 at a distance l as shown.



Give reasons to explain that the loop will experience a net force but no torque. Write the expression for this force acting on the loop.
Delhi 2010

5 Marks Questions

48. (i) Write the principle and explain the working of a moving coil galvanometer. A galvanometer as such cannot be used to measure the current in a circuit. Why?

(ii) Why is the magnetic field made radial in a moving coil galvanometer? How is it achieved? **CBSE 2023**

49. Explain, using a labelled diagram, the principle and working of a moving coil galvanometer. What is the function of (i) uniform radial magnetic field (ii) soft iron core? Define the terms (i) current sensitivity and (ii) voltage sensitivity of a galvanometer.

Why does increasing the current sensitivity not necessarily increase voltage sensitivity?
Delhi 2015, Foreign 2016

50. (i) Draw a labelled diagram of a moving coil galvanometer. Describe briefly its principle and working.

(ii) Answers the following questions
(a) Why is it necessary to introduce a cylindrical soft iron core inside the coil of a galvanometer?
(b) Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity. Explain with giving reasons.
All India 2014

51. (i) State using a suitable diagram, the working principle of a moving coil galvanometer. What is the function of a radial magnetic field and the soft iron core used in it?

(ii) For converting a galvanometer into an ammeter, a shunt resistance of small value is used in parallel. Whe[illegible] of a voltmeter a resistance of [illegible] value [illegible] ed [illegible] series. Explain, why?
Delhi 2014C

52. (i) Explain giving reasons, the basic difference in converting a galvanometer into (a) a voltmeter and (b) an ammeter.

(ii) Two long straight parallel conductors carrying steady currents I_1 and I_2 are separated by a distance d.
Explain briefly with the help of a suitable diagram, how the magnetic field due to one conductor acts on the other? Hence, deduce the expression for the force acting between the two conductors. Mention the nature of this force.
All India 2012

53. A rectangular loop of size $l \times b$ carrying a steady current I is placed in a uniform magnetic field **B**. Prove that the torque τ acting on the loop is given by $\tau = \mathbf{M} \times \mathbf{B}$, where **M** is the magnetic moment of the loop.
All India 2012

54. (i) Show that a planer loop carrying a current I, having N closely wound turns and area of cross-section A, possesses a magnetic moment $\mathbf{M} = NI\mathbf{A}$.

(ii) When this loop is placed in a magnetic field **B**, find out the expression for the torque acting on it.

(iii) A galvanometer coil of 50 Ω resistance shows full scale deflection for a current of 5 mA. How will you convert this galvanometer into a voltmeter of range 0 to 15 V? **Foreign 2011**

55. (i) With the help of a diagram, explain the principle and working of a moving coil galvanometer.

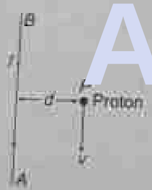
(ii) What is the importance of radial magnetic field and how is it produced?

(iii) Why is it that while using a moving coil galvanometer as a voltmeter, a high resistance in series is required whereas in an ammeter a shunt is used? **All India 2010**

56. (i) Derive an expression for the force between two long parallel current carrying conductors.

(ii) Use this expression to define SI unit of current.

(iii) A long straight wire AB carries a current I. A proton P travels with a speed v, parallel to the wire at a distance d from it in a direction opposite to the current as shown in the figure. What is the force experienced by the proton and what is its direction? **All India 20[illegible]**

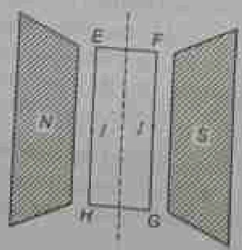


57. (i) Two straight long parallel conductors carry currents I_1 and I_2 in the same direction. Deduce the expression for the force per unit length between them. Depict the pattern of magnetic field lines around them.

(ii) A rectangular current carrying loop $EFGH$ is kept in a uniform magnetic field as shown in the figure.

(a) What is the direction of the magnetic moment of the current loop?

(b) When is the torque acting on the loop maximum and zero? **Foreign 2010**



Case Based Questions (4 Marks) (For Complete Chapter)

Directions (Q.Nos. 58-59) *These questions are Case Study based questions. Read the following paragraph and answer the questions.*

58. A beam of electrons moving horizontally with velocity of 3×10^7 m/s enters a region between two plates as shown in the figure. A suitable potential difference is applied across the plates, such that the electron beam just strikes the edge of the lower plate.

Answer the following questions based on the above.

(i) How long does an electron take to strike the edge? (1)

(ii) What is the shape of the path followed by the electron and why? (1)

(iii) Find the potential difference applied. (2)

Or

(iii) Find the magnitude and direction of the magnetic field which should be created in the space between the plates, so that the electron beam goes straight undeviated. **CBSE 2023** (2)

KEY Idea
The time period is inversely proportional to the magnetic field and charge.

59. *Read the following paragraph and answer any four questions.*

An electron with a speed $v_0 << c$ moves in a circle of radius r_0 in a uniform magnetic field. This electron is able to traverse a circular path as magnetic field is perpendicular to the velocity of the electron. The time required for one revolution of the electron is T_0. The speed of the electron is now inversely to $4v_0$.

(i) The radius of the circle will change to (1)

(a) $4r_0$ (b) $2r_0$ (c) $\frac{r_0}{4}$ (d) $r_0/2$

(ii) The time required for one revolution of the electron will change to (1)

(a) $4T_0$ (b) $2T_0$ (c) T_0 (d) $T_0/2$

Or

(iii) A charged particle is projected in a magnetic field $\mathbf{B} = (2\hat{\mathbf{i}} + 4\hat{\mathbf{j}}) \times 10^2$ T. The acceleration of the particle is found to be $\mathbf{a} = (x\hat{\mathbf{i}} + 4\hat{\mathbf{j}})\text{ms}^{-2}$. Find the value of x. (1)

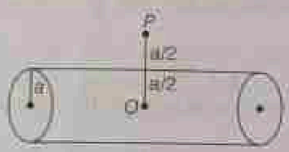
(a) 8 ms^{-2} (b) -8 ms^{-2}
(c) -4 ms^{-2} (d) 4 ms^{-2}

(iv) If the given electron has a velocity not perpendicular to **B**, then the trajectory of the electron is **(1)**
(a) straight line (b) circular
(c) helical (d) Both (a) and (c)

(v) If electron of charge (e) is moving parallel to uniform magnetic field (B) with constant velocity v, the force acting on the electron is **(1)**
(a) Bev
(b) $2Bev$
(c) $\frac{Bev}{2}$
(d) zero

Explanations

1. (c) Assume the point P lies at distance $a/2$ above the surface of the wire



$$= a + \frac{a}{2} = \frac{3a}{2}$$

Magnetic field at point P,

$$B_1 = \frac{\mu_0}{4\pi} \times \frac{2I}{r} = \frac{\mu_0}{4\pi} \times \frac{2I}{\left(\frac{3a}{2}\right)} = \frac{\mu_0 I}{3\pi a} \quad \dots(i)$$

The distance of point O,

$$r' = a - \frac{a}{2} = \frac{a}{2}$$

Magnetic field at point O,

$$B_2 = \frac{\mu_0 I r}{2\pi a^2} = \frac{\mu_0}{2\pi} \cdot \frac{I}{a^2} \times \frac{a}{2} = \frac{\mu_0}{4\pi} \frac{I}{a} \quad \dots(ii)$$

From Eqs. (i) and (ii), we get

$$\frac{B_1}{B_2} = \frac{\mu_0 I}{3\pi a} \times \frac{4\pi a}{\mu_0 I}$$

$$\frac{B_1}{B_2} = \frac{4}{3}$$

Thus, ratio will be 4 : 3.

2. (d) It will provide electromagnetic damping because aluminium is a diamagnetic substance and it does not interact with external magnetic field.

3. (d) Given that,

$$I_g' = I_g + \frac{20}{100} \times I_g$$

$$= \frac{120}{100} I_g = 1.2 I_g$$

$$R' = R + \frac{25}{100} R = \frac{125}{100} R$$

$$R' = 1.25R$$

$$V_g' = ?$$

$$V_g' = \frac{I_g'}{R'} = \frac{1.2 I_g}{1.25 R} = \frac{120}{125} V_g = \frac{24}{25} V_g$$

$$\% \text{ change} = \frac{V_g' - V_g}{V_g} \times 100$$

$$= \frac{\left(\frac{24}{25} - 1\right) V_g}{V_g} \times 100$$

$$= \frac{(24 - 25)}{25} \times 100$$

$$= -\frac{1}{25} \times 100 = 4\%$$

4. (c) As given,

Area of a square $= a^2$

Also, $1 = 4a$ and $a = \frac{1}{4}$

$$\text{Area } (A_1) = \frac{1}{16} \quad \dots(i)$$

Area of a circle $= \pi r^2$

Also, $2\pi r = 1$

$$r = \frac{1}{2\pi}$$

Now area of a circle $= \pi \left(\frac{1}{2\pi}\right)^2$

$$A_2 = \frac{1}{4\pi} \quad \dots(ii)$$

From Eqs. (i) and (ii),

$$\frac{1}{16}=\frac{4\pi}{1}\Rightarrow\frac{\pi}{4}\Rightarrow M_1M_2=\pi:4$$

5. (a) Let F_1 is force per unit length between A and C,

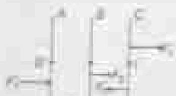
then $F_1=\frac{\mu_0}{4\pi}\frac{2I\times I}{2r}$ ...(i)

and $F_2=\frac{\mu_0}{4\pi}\frac{I\times I}{r}$ ...(ii)

Now net force on C is per unit length,

$$F_{net}=F_1+F_2=\frac{\mu_0}{4\pi}\frac{I^2}{r}(1+1)$$

$$\Rightarrow\quad\frac{2\mu_0}{4\pi}\frac{I^2}{r}=F$$



Now, F_1' = Repulsive force between A and C

$$=\frac{\mu_0}{4\pi}\frac{2I^2}{2r}$$

$F_2'=F_2=$ Attractive force between B and C

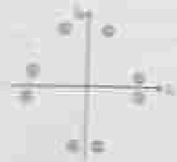
$\therefore$ Net force on C, $F_1'-F_2'=0$

$$F_1'=F_2=\frac{\mu_0}{4\pi}\frac{2I^2}{2r}$$

$\therefore$ Net force on C is zero.

Concept Enhancer If the wire is of infinite length, the field due to it at a non-zero distance is not infinite.

6. (b) The region II has vertically upward strongest magnetic field produced by both the wires carrying currents. The direction of field in other region is as shown.



7. (d) Given, $I_1=4$ A, $I_2=10$ A,

$r=2.5$ cm $=2.5\times10^{-2}$ m

Force per unit length, $\frac{F}{l}=\frac{\mu_0}{2\pi}\frac{I_1I_2}{r}$

$$=\frac{2\times10^{-7}\times4\times10}{2.5\times10^{-2}}=32\times10^{-5}\text{ N/m}$$

8. (a) If an ammeter is to be used in place of a voltmeter, then a low resistance must be connected in parallel to it. So, that the current flow through it and the voltage across it is measured accurately by ammeter that becomes a high resistance voltmeter.

9. (a) The magnetic force due to field on a current carrying wire is

$$F_m=IlB$$

When rod is suspended, the gravitational force acts on it is

$$F_g=mg$$

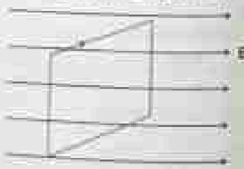
To remove tension in strings, these two forces must be balanced i.e.

$$F_m=F_g$$
$$IlB=mg$$
$$\Rightarrow\quad I=\frac{mg}{lB}$$

10. (c) The deflecting torque acting on a current carrying loop placed in magnetic field is given by

$$\tau=MB\sin\theta$$

When plane of current loop is perpendicular to the direction of magnetic field, then $\theta=0°$



$$\tau=MB\sin0=0$$

Thus, Assertion (A) is true and Reason (R) is false.

11. (a) When the number of turns in a coil is increased, the resistance of the coil increase and higher current sensitivity does not always equal to increased voltage sensitivity.

$$V_s=\frac{I_s}{R}$$

Moreover resistance of the coil of galvanometer directly proportional to number of turns. Thus, resistance increase on increase turns.

12. (d) To increase the range of ammeter suitable resistance (R) (low) should be connected in parallel to ammeter.

An ammeter with increased range always have low resistance.

13. (i) The higher the range, lower is the resistance of an ammeter. This can be achieved by adding a shunt parallel to it.

14. Current sensitivity of the galvanometer is the deflection per unit current flowing through it.

It is given as $I_s=\frac{\theta}{I}=\frac{NAB}{k}$

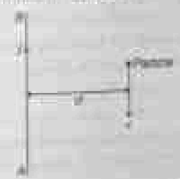
where, k is the restoring torque per unit twist of phosphor-bronze strip.

15. The principle of moving coil galvanometer is based on the fact that when a current carrying coil is placed in a magnetic field, it experiences a torque.

16. One ampere is the current which flows through each of two parallel uniform long linear conductors, which are placed in free space at a distance of 1 m from each other and which attract or repel each other with a force of 2×10^{-7} N/m of length.

17. No, steady current is not the only source of magnetic field. As, magnetic field can be produced by other sources also, e.g. alternating current, moving charged particle, permanent magnets, etc.

18.



Magnetic field due to current carrying wire is perpendicular to plane of paper downward.

i.e. $\mathbf{B}=-\frac{\mu_0 I}{2\pi d}\hat{\mathbf{k}}$

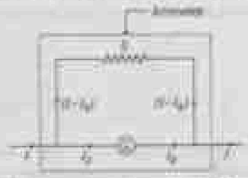
Force on a current carrying wire,

$$\mathbf{F}=q\mathbf{v}\times\mathbf{B}=(e)(-v\hat{\mathbf{j}})\times\left(\frac{-\mu_0 I}{2\pi d}\hat{\mathbf{k}}\right)$$

$$\mathbf{F}=\frac{\mu_0 evI}{2\pi d}\hat{\mathbf{i}}$$

The direction along positive X-axis, i.e. in the plane of paper perpendicular to direction of v and to the right.

19. To convert a galvanometer into ammeter, its resistance needs to be lowered, so that maximum current can pass through it and it can give exact reading.



A shunt (low resistance) is connected in parallel with the galvanometer

$$S=\left(\frac{I_g}{I-I_g}\right)G$$

where, I = total current in circuit,

G = resistance of the galvanometer,

S = resistance of the shunt (low resistance)

I_g = current through galvanometer

Common Mistake When galvanometer is converted into ammeter, students think that the lower resistance will pass lower current and does not give exact reading.

20. **For region I** Magnetic field due to 2A and 3A current wire is in opposite direction.

For region II Magnetic field due to 2A and 3A current wire is in opposite direction. But we can have neutral point

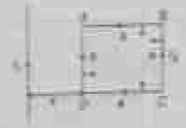
$$B_1=\frac{2\mu_0}{2\pi R_1}$$

$$B_2=\frac{3\mu_0}{2\pi R_2}$$

Thus, $R_2>R_1$ and I_2 (3A) > I_1 (2A) and B_1 and B_2 are in opposite directions, so net magnetic field intensity will becomes zero at existing null or neutral point.

21. According to right-hand screw rule, force on AD is

$$F_1=\frac{\mu_0 I_1 I_2 l}{2\pi x}\text{ (towards right)}$$



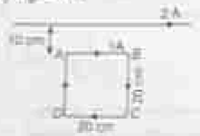
Force on BC is $F_2 = \frac{\mu_0 I_1 I_2 a}{2\pi(x+a)}$ (towards left)

The forces on AB and DC are equal and opposite, so they will cancel each other. Thus, net force on loop is

$$F_R = \frac{\mu_0 I_1 I_2 a}{2\pi}\left(\frac{1}{x} - \frac{1}{x+a}\right)$$

$$= \frac{\mu_0 I_1 I_2 a^2}{2\pi x(x+a)} \text{ (towards right)}$$

22. According to the question, as the loop is square, its sides are parallel. So, 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)

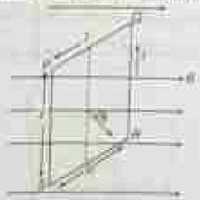
Force on arms BC and DA are equal and opposite, so they cancel out each other.

Net force on the loop, $F = F_{AB} - F_{CD} = \frac{\mu_0}{\pi}\left[2 - \frac{2}{3}\right]$

$$= \frac{4\mu_0}{3\pi} = \frac{4 \times 4\pi \times 10^{-7}}{3\pi} = 5.33 \times 10^{-7} \text{ N}$$

(attractive, towards the wire)

23. A rectangular coil $PQRS$ is placed in a uniform magnetic field as shown in the figure below.



Forces on arm PQ and RS are equal and opposite and they cancel each other as they are collinear.

Force on SP is F_1 and force on QR is F_2

and $F_1 = F_2 = IlB$

Thus, magnitude of torque due to these forces on the coil will be given as

$$\tau = IbB \sin\theta = IAB \sin\theta$$

where, $A = lb$ (area of coil)

or in vector form, $\tau = MB \sin\theta\ \hat{n} = \mathbf{M} \times \mathbf{B}$

where, $\mathbf{M} = NI\mathbf{A}$, is the magnetic moment of [illegible]

Since, according to the question,

$\theta = 0°$ (as plane of coil is perpendicular to the field)

Thus, torque acting on the coil will be zero.

Concept Enhancer In a current carrying loop, the net magnetic force in a uniform magnetic field is zero but torque will depend upon angle between magnetic field and area v[illegible]

24. (i) Let a and b be two long straight parallel conductors, I_a and I_b are the current flowing through them and separated by a distance d. Magnetic field induced at a point P on a conductor b due to current I_a passing through a is

$$B_1 = \frac{\mu_0 2I_a}{4\pi d}$$

Now, unit length of b will experience [illegible] as

$$F_2 = B_1 I_b \times 1 = B_1 I_b$$

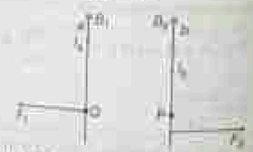
$$\therefore \quad F_2 = \frac{\mu_0}{4\pi}\frac{2I_a I_b}{d}$$

Conductor a also experiences the same amount of force directed towards b, hence a and b attract each other.

∴ The force between two current carrying parallel conductors per unit length is

$$F = \frac{\mu_0}{4\pi}\frac{2I_a I_b}{d}$$

(ii)



Now, let the direction of current in conductor b be reversed. The magnetic field B_2 at point P due

to current I_a flowing through a will be downwards. Similarly, the magnetic field B_1 at point Q due to current I_b passing through b will also be downward as shown. The force on a will be, therefore towards the left. Also, the force on b will be towards the right. Hence, the two conductors will repel each other by equal amount of force as shown above.

Common Mistake Usually in such kind of problem, direction of current and force always gives confusion. To find the direction of current, use should we right thumb rule and other to.

25. According to the question,

$$2\pi r = 4a \Rightarrow a = \frac{\pi r}{2} \quad \text{...(i)}$$

Thus, the ratio of magnetic moment of square coil and circular coil is given as

$$\frac{M_s}{M_c} = \frac{NIA_s}{NIA_C} = \frac{NI(a)^2}{NI\pi r^2} = \frac{NI(\pi r/2)^2}{NI\pi r^2} \quad [\because \text{from Eq. (i)}]$$

$$= \pi : 4$$

$\Rightarrow \quad M_s : M_c = \pi : 4$

26. (i) Magnetic field at centre due to circular current carrying coil, $B = \mu_0 NI/2r$

(ii) Magnetic moment, $M = NIA = NI(\pi r^2)$

$$M = \pi NIr^2$$

where, r is the radius of circular coil, μ_0 is permeability of free space and N is number of turns.

27. The length of wire will be same in two cases as the same coil is unwound and rewound.

Length of the wire is same

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

[N_1 and N_2 = number of turns in two coils]

$N_2 = 2N_1$

Now, the ratio of magnetic moments is given by

$$\frac{M_1}{M_2} = \frac{N_1 I A_1}{N_2 I A_2} = \frac{N_1 \times \pi R_1^2}{N_2 \times \pi R_2^2}$$

$$\frac{M_1}{M_2} = \left(\frac{N_1}{2N_1}\right) \times \left(\frac{R}{R/2}\right)^2 = \frac{1}{2} \times 4 = 2$$

$$M_1 : M_2 = 2 : 1$$

28. The length of wire will be same in two cases as the same coil in unwound and rewound.

Length of wire of coil 1 = Length of wire of coil 2

$$N_1 \times \pi d_1 = N_2 \times \pi d_2$$

$$N_1 \times \pi d = N_2 \times \pi \times 2d$$

$$N_2 = \frac{N_1}{2} \quad [\text{where, } N_1 = N]$$

$\Rightarrow \quad N_2 : N_1 = 1 : 2$

$\Rightarrow \quad N_1 : N_2 = 2 : 1$

Magnetic moment, $M = NIA$

$$\therefore \quad \frac{M_1}{M_2} = \frac{N_1 I A_1}{N_2 I A_2} = \frac{N_1 \pi d^2}{N_2 \pi (2d)^2}$$

$$\frac{M_1}{M_2} = \left(\frac{N_1}{N_2}\right) \times \frac{1}{4} = 2 \times \frac{1}{4} = \frac{1}{2}$$

$$\frac{M_1}{M_2} = \frac{1}{2} \Rightarrow M_1 : M_2 = 1 : 2$$

29. Let two infinitely long straight current carrying conductors carry currents I_1 and I_2 in the same direction.

Magnetic field due to first wire on second

$$B_1 = \frac{\mu_0}{4\pi}\frac{2I_1}{r} = \frac{\mu_0 I_1}{2\pi r} \quad \text{...(i)}$$

The magnetic field is perpendicular to the plane of paper and directed inwards.

Now, magnetic force on length L of second wire is given by $F_2 = I_2 B_1 L \sin 90°$

$$\Rightarrow \quad F_2 = I_2\left(\frac{\mu_0}{4\pi}\frac{2I_1}{r}\right)L$$

$$\Rightarrow \quad \frac{F_2}{L} = \frac{\mu_0}{4\pi}\frac{2I_1 I_2}{r} = \frac{\mu_0 I_1 I_2}{2\pi r} \quad \text{...(ii)}$$

By Fleming's left hand rule, the direction of force F_2 is perpendicular to the second wire in the plane of paper towards the first wire.

Similarly, magnetic force on first wire is given by

$$\frac{F_1}{L} = \frac{\mu_0}{4\pi}\frac{2I_1 I_2}{r} \quad \text{...(iii)}$$

$$\mathbf{F}_1 = -\mathbf{F}_2$$

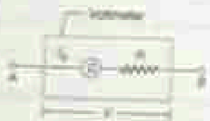
The force F_1 is directed towards the second wire.

Thus, two straight parallel current carrying conductors have the same direction of flow of current attracting each other.

30. The resistance of an ideal voltmeter is infinity or very high in practical condition. So, to convert a galvanometer into voltmeter, its resistance needs to be increased, which can be done by connecting a high resistance in series with it.

A galvanometer can be converted into a voltmeter by connecting a very high resistance R in series with it. This is done, so that there is no potential drop across it.

Let R is so chosen that current I_g gives full deflection in the galvanometer where I_g is the range of galvanometer.



Let galvanometer of resistance G, range I_g is to be converted into voltmeter of range V (volt). Now,

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

$$\Rightarrow \quad R + G = \frac{V}{I_g}$$

$$\Rightarrow \quad R = \frac{V}{I_g} - G$$

The appropriate scale need to be graduated to measure potential difference.

31. Given, area of a coil, $A = 10 \times 10 = 100\ cm^2 = 10^{-2}\ m^2$

Number of turns, $N = 20$ turns

Current, $I = 12$ A

Coil makes an angle with magnetic field, $\theta = ?$

Magnetic field, $B = 0.8$ T

Torque, $\tau = 0.96$ N-m

Torque (τ) experienced by current carrying coil in the magnetic field,

$$\tau = NIAB \sin\theta$$

$$0.96 = 20 \times 12 \times 10^{-2} \times 0.8 \times \sin\theta$$

$$\Rightarrow \quad \sin\theta = \frac{0.96}{1.92} = \frac{1}{2} \Rightarrow \theta = \frac{\pi}{6} \text{ rad}$$

32. (i) Sensitivity of a moving coil galvanometer can be increased by increasing the number of turns in the coil, the area of coil and magnetic field, whereas decreasing the couple per unit twist of the suspension.

(ii) A galvanometer full deflection for current I_g

Range (0-V), required resistance R_1

Range (0-$2V$), required resistance R_2

Resistance of galvanometer = ?

For voltmeter (range 0-V),

$$V = (G + R_1)$$

where, I_g is the current in galvanometer

for voltmeter (range 0-$2V$),

$$2V = (G + R_2) I_g$$

From Eqs. (i) and (ii), we get

$$\frac{1}{2} = \frac{(G + R_1)}{(G + R_2)}$$

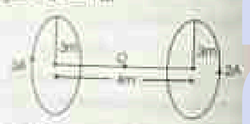
$$G + R_2 = 2(R + R_1)$$

$$G + R_2 = 2R + 2R_1$$

Thus, $\quad G = R_2 - 2R_1$

33. $R_1 = R_2 = 3$ m

$I_1 = 3$ A, $I_2 = 2$ A, $x = 4$ m



As magnetic field,

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

$$B_1 = \frac{\mu_0 I_1 R_1^2}{2(R_1^2 + x^2)^{3/2}}$$

$$= \frac{4\pi \times 10^{-7} \times 3 \times (3)^2}{2[(3)^2 + (4)^2]^{3/2}}$$

$$B_1 = 1.36 \times 10^{-7}\ T$$

$$B_2 = \frac{\mu_0 I_2 R_2^2}{2(R_2^2 + x^2)^{3/2}}$$

$$= \frac{4\pi \times 10^{-7} \times 2(3)^2}{2[(3)^2 + (4)^2]^{3/2}}$$

$$= 0.90 \times 10^{-7}\ T$$

Net magnetic field, $B_{net} = \sqrt{B_1^2 + B_2^2}$

$$= \sqrt{(1.36 \times 10^{-7})^2 + (0.90 \times 10^{-7})^2}$$

$$= \sqrt{2.65 \times 10^{-14}}$$

$$B_{net} = 1.63 \times 10^{-7}\ T$$

34. Refer to Sol. 29 on pages 145 and 146.

Refer to Sol. 16 on page 143 (For definition of one ampere)

35. Expression for magnetic force acting per unit length of the wire,

$$\frac{F_m}{l} = \frac{\mu_0 I_1 I_2}{2\pi h} \quad \text{(upward on AB)} \quad \text{...(i)}$$

But at equilibrium position,

Magnetic force per unit length is given by

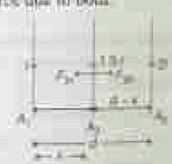
magnetic force = mass per unit length × g

From Eq. (i), $\frac{\mu_0 I_1 I_2}{2\pi h} = \frac{m}{l} \times g$

36. Refer to Sol. 29 on pages 145 and 146.

Refer to Sol. 16 on page 143 (For 1 A current)

37. Let the current in the third wire A_3 be in same direction as that of A_1 and A_2, so it will experience attractive force due to both.



The force on A_3 due to A_1 is $F_{31} = \frac{\mu_0}{2\pi} \frac{I \times 15 I \times l}{x}$

where, l = unit length of conductor wire A_3

and $\quad x$ = distance between A_1 and A_3

Similarly, force on A_3 due to A_2 is

$$F_{32} = \frac{\mu_0}{2\pi} \frac{15I \times 2I \times l}{(d - x)}$$

According to question, $F_{31} = F_{32}$

$$\Rightarrow \quad \frac{\mu_0}{2\pi} \frac{15 I^2 l}{x} = \frac{\mu_0}{2\pi} \frac{30 I^2}{(d - x)} l$$

$$\Rightarrow \quad \frac{15}{x} = \frac{30}{d - x}$$

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

Yes, the net force acting on A_3 depends on the current flowing through it.

38. (i) Refer to Sol. 23 on page 144.

(ii) In a radial magnetic field, the magnetic torque remains maximum for all positions of the coils.

39. (i) Refer to Sol. 15 on page 143.

(ii) The galvanometer cannot be used to measure the current because

(a) all the currents to be measured passes through coil and it gets damaged easily.

(b) its coil has considerable resistance because of length and it may affect original current.

(iii) (a) **Voltage sensitivity** is the deflection per unit voltage.

It is given by

$$V_s = \frac{\theta}{V} = \left(\frac{NAB}{k}\right)\frac{I}{V}$$

$$\text{or} \quad V_s = \frac{NAB}{k} \times \frac{I}{IR} = \frac{NAB}{kR}$$

[∵ According to Ohm's law, $V = IR$]

Its unit is rad/V or div/V.

(b) **Current sensitivity** of the galvanometer is the deflection per unit current flowing through it.

It is given by $I_s = \frac{\theta}{I} = \frac{NAB}{k}$

Its unit is rad/A or div/A.

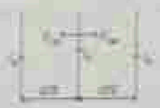
40. (i) Refer to Sol. 16 on page 143.

(ii) Refer to Sol. 29 on pages 145 and 146.

When a third conductor of current I_c is placed in between them having current in opposite direction, then the forces will be

Force on C due to current I_a is

$$F_{ca} = \frac{\mu_0}{4\pi} \frac{2 I_a I_c}{d/2} \quad \text{(toward right)}$$



Force on C due to current I_b is

$$F_{cb} = \frac{\mu_0}{4\pi} \frac{2 I_b I_c}{d/2} \quad \text{(toward left)}$$

Then, net force,

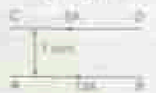
$$F = F_{ca} - F_{cb} = \frac{\mu_0}{4\pi} \frac{4 I_c}{d} (I_a - I_b) \text{ (towards right)}$$

41. Refer to Sol. 29 on pages 145 and 146 (For the expression of force)

Refer to Sol. 16 on page 143 (For the definition of one ampere).

42. Force per unit length between two parallel current carrying wires separated by a distance r is given as

$$\frac{F}{l} = \frac{\mu_0}{4\pi}\frac{2I_1 I_2}{r}$$



It is repulsive, if the current in the wires is in opposite direction. (otherwise attractive)

The magnetic force of repulsion on the upper wire (CD) should be balancing its own weight in order to remain suspended.

Thus, to remain suspended at its position in equilibrium, magnetic force on CD due to

AB = weight of CD

$$\Rightarrow \frac{\mu_0 I_1 I_2}{2\pi r} l = mg \qquad (g = 10\ m/s^2)$$

$$m/l = 2\times 10^{-7}\frac{I_1 I_2}{rg}$$

$$m/l = \frac{2\times 10^{-7}\times 12\times 5}{10^{-2}\times 10} = 1.2\times 10^{-4}\ kg\ m^{-1}$$

∴ Mass per unit length of wire CD is $1.2\times 10^{-4}\ kg\ m^{-1}$.

Current in CD should be in opposite direction to that in AB.

43. There will be force of attraction between the straight wire and 4 cm long arm of loop nearer to the straight conductor. Thus,

$$F_1 = \frac{\mu_0}{4\pi}\frac{2\times 2\times 1}{(1\times 10^{-2})}\times(4\times 10^{-2})$$

$$F_1 = 16\times 10^{-7}\ N$$

[towards straight wire] ...(i)

Similarly, force on other 4 cm arm of loop, away from the straight conductor,

$$F_2 = \frac{\mu_0}{4\pi}\times\frac{2\times 2\times 1}{(3.5\times 10^{-2})}\times(4\times 10^{-2})$$

$$F_2 = 4.57\times 10^{-7}\ N \text{ [away from straight wire]} \quad ...(ii)$$

(i) Since, F_1 and F_2 are of different magnitudes, therefore they do not form couple and torque will be zero.

(ii) The magnitude of net force on loop,

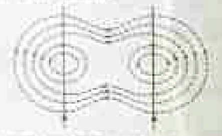
$$F = F_1 - F_2$$

$$F = 16\times 10^{-7} - 4.57\times 10^{-7}$$

$$\Rightarrow F = 11.43\times 10^{-7}\ N$$

The direction of the force would be towards the straight wire.

44. Magnetic field lines due to straight long parallel conductors carrying currents I_1 and I_2 in the same direction is shown below.



Magnetic field lines due to both conductors

Refer to Sol. 29 on pages 145 and 146 (For deduction of the force acting between two long parallel conductors).

As, the current carrying conductors has same direction of flow of current, so the force between them will be attractive.

45. Principle The current carrying coil placed in uniform magnetic field experiences a torque which is given by

$$\tau = NIAB$$

where, N = number of turns,

I = current, A = area of a coil

and B = magnetic field.

The galvanometer cannot be used to measure the current because

(i) all the currents to be measured has to be, then passes through coil which would gets damaged as it is a hair line spring.

(ii) its coil has considerable resistance because of length and it may affect original current.

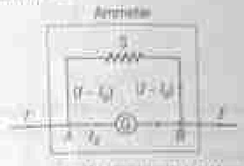
Current sensitivity of galvanometer can be increased by

(i) increasing the magnetic field and

(ii) decreasing the value of torsional constant.

46. The resistance of an ideal ammeter is zero or very low in practical condition, so to convert a galvanometer into ammeter its resistance needs to be decreased which can be done by connecting a low resistance in its parallel order.

A moving coil galvanometer of range I_g and resistance G can be converted into ammeter by connecting a very low shunt resistance (S) in parallel with galvanometer.



This is done, so that the potential difference across the combination is same.

∴ PD across galvanometer = PD across shunt S

$$I_g G = I_s S$$

But $\quad I_s + I_g = I$

$$\Rightarrow I_s = I - I_g \Rightarrow I_g G = (I - I_g) S$$

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

47. The magnetic moment of a current carrying loop

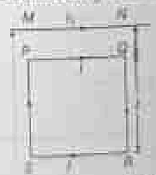
$$\mathbf{M} = I\mathbf{A}$$

where, $\mathbf{A}$ = area of the loop (square)

$$\therefore \mathbf{A} = l^2\,\hat{\mathbf{n}}$$

Here, $\hat{\mathbf{n}}$ is a unit vector normal to the direction of area vector.

The forces acting on the arms QR and SP of given loop are equal, mutually opposite and collinear. Hence, they are balanced by one another.



Force on arm PQ, $F_1 = B_1 \cdot Il = \frac{\mu_0 I_1}{2\pi l}\cdot Il = \frac{\mu_0 I_1 I}{2\pi}$

Since, the direction of the current in the arm PQ and the wire is same; so F_1 is of the attractive nature and directed towards MN.

Again, force on arm RS,

$$F_2 = B_2 Il = \frac{\mu_0 I_1 Il}{2\pi(2l)} = \frac{\mu_0 I_1 I}{4\pi}$$

F_2 is perpendicular to wire RS and directed away from the conductor MN.

Net force on loop $PQRS$,

$$\mathbf{F}_{net} = \mathbf{F}_1 - \mathbf{F}_2 = \frac{\mu_0 I_1 I}{2\pi} - \frac{\mu_0 I_1 I}{4\pi}$$

or $\quad F_{net} = \frac{\mu_0 I_1 I}{4\pi}$ [attractive]

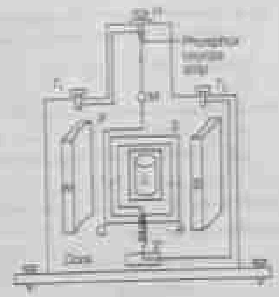
As, $\mathbf{F}_1$ and $\mathbf{F}_2$ are collinear. Hence, they do not produce torque on the loop $PQRS$.

48. (i) Refer to Sol. 15 on page 143.

Refer to Sol. 45 on page 148.

(ii) The uniform radial magnetic field keeps the plane of the coil always parallel to the direction of the magnetic field i.e., the angle between the plane of the coil and the magnetic field is zero for all the orientations of the coil.

49. For Principle of galvanometer Refer to Sol. 15 on page 143.



(i) By making uniform radial magnetic field, magnetic field lines are perpendicular to the magnetic moment of a galvanometer.

(ii) Soft iron core makes the electromechanical field as radial which also increase the magnetic field.

Refer to Sol. 39 (iii) on page 147 (For current and voltage sensitivity).

Current sensitivity, $\quad I_s = \frac{NAB}{k}$

and voltage sensitivity, $V_s = \frac{NAB}{kR}$

Since, the resistance of the coil may vary, it implies an increase in current sensitivity may not necessarily increase voltage sensitivity.

50. (i) Refer to Sol. 49 on page 149.

(ii) (a) It is necessary to introduce a cylindrical soft iron core inside the coil of a galvanometer because it increases its magnetic field. Thus, its sensitivity increases and magnetic field becomes radial. So, angle between the plane of coil and magnetic line of force is zero in all orientations of coil.

(b) Refer to Sol. 49 (iii) on page 149.

51. (i) Refer to Sol. 49 on page 149.

(ii) Refer to Sol. 19 on page 143 (For converting galvanometer into ammeter).

In the case, when galvanometer is converted into voltmeter, its resistance needs to be increased, so that there is no potential drop across it because of high resistance no current passes through it. Hence, a high resistance is connected in series with the galvanometer.

52. (i) A galvanometer of range I_g and resistance G can be converted into

(a) a voltmeter of range V by connecting a high resistance R in series with it whose value is given by $R = \frac{V}{I_g} - G$

(b) an ammeter of range I by connecting a very low resistance (shunt) in parallel with galvanometer whose value is given by

$S = I_g G / (I - I_g)$

(ii) Refer to Sol. 29 on pages 145 and 146.

53. Refer to Sol. 23 on page 144.

54. (i) Torque on rectangular loop,

$$\tau = NIAB \sin\theta \quad \ldots(i)$$

Also, torque on the loop can be expressed in terms of magnetic moment of the coil and the magnetic field as

$$\tau = MB \sin\theta \quad \ldots(ii)$$

Comparing Eqs. (i) and (ii), we get

The magnetic dipole moment, $M = NIA$

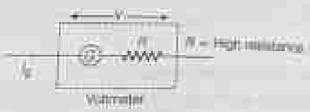
Also, **M** is along **A**.

$\Rightarrow \quad \mathbf{M} = NI\mathbf{A}$

(ii) Refer to Sol. 23 on page 144.

(iii) Given, $G = 50\,\Omega$,

$I_g = 5 \times 10^{-3}$ A, $V = 15$ V



$\because \quad V = I_g (G + R)$

$\Rightarrow \quad R = \frac{V}{I_g} - G$

$\Rightarrow \quad = \frac{15}{5 \times 10^{-3}} - 50$

$\Rightarrow \quad R = 2950\,\Omega$

A resistance $R = 2950\,\Omega$ is to be connected in series with galvanometer to convert it into a desired voltmeter.

55. (i) Refer to Sol. 49 on page 149.

(ii) Refer to Sol. 48 (ii) on page 149.

(iii) Refer to Sol. 51 (ii) on page 150.

56. (i) Refer to Sol. 29 on pages 145 and 146.

(ii) As, $\frac{F}{L} = \frac{\mu_0}{4\pi} \frac{2 I_1 I_2}{r}$

$\Rightarrow \quad I_1 = I_2 = 1$ A, $r = 1$ m

$\frac{F}{L} = 2 \times 10^{-7}$ Nm^{-1}

Refer to Sol. 16 on page 143 (For definition).

(iii) Here, magnetic field due to the current carrying conductor at a distance d from it is given as

$$B = \frac{\mu_0}{4\pi} \frac{2I}{d}$$

$\therefore$ Force on proton,

$F = (e)(v) B \sin 90°$

$\Rightarrow \quad F = evB$

$F = ev\left(\frac{\mu_0}{4\pi} \frac{2I}{d}\right)$

$F = \frac{\mu_0}{4\pi} \cdot \frac{2Iev}{d}$

The proton is directed perpendicular to straight conductor and away from it.

57. (i) Refer to Sol. 29 on pages 145 and 146.

Refer to Sol. 44 on page 148.

(ii) (a) The direction of the magnetic moment of the current loop is perpendicular to the plane of the paper and directed inward.

(b) When angle between area vector of coil and magnetic field is 90°, then maximum torque experienced by the coil.

When $\theta = 0°$ or $180°$, then torque will be minimum, i.e. zero.

58. (i) Mass of electron, $m_e = 9 \times 10^{-31}$ kg

Velocity, $v = 3 \times 10^7$ m/s

$u_x = 3 \times 10^7$ m/s

$v_x = 0$

$\therefore \quad x = u_x t + \frac{1}{2} at^2$

$3 \times 10^{-2} = 3 \times 10^7 t + \frac{1}{2} \times 0 \times t^2$

$\Rightarrow \quad t = \frac{3 \times 10^{-2}}{3 \times 10^7}$

$\Rightarrow \quad t = 10^{-9}$ s

(ii) The shape of the electron is circular because when a charged particle enter in magnetic field, it always project perpendicularly.

(iii) Potential difference,

$\frac{1}{2} mv^2 = q \cdot \Delta V$

$\Delta V = \frac{1}{2} \frac{mv^2}{q} = \frac{1}{2} \times \frac{9 \times 10^{-31} \times (3 \times 10^7)^2}{1.6 \times 10^{-19}}$

$\Delta V = 2531.25$ V

Or

(iii) Magnitude of the magnetic field.

by using Lorentz force,

$F_m = q(\mathbf{v} \times \mathbf{B})$

$\hat{\mathbf{j}} = -(\hat{\mathbf{i}} \times \hat{\mathbf{k}}) = -(-\hat{\mathbf{j}}) = \hat{\mathbf{j}}$

Magnitude will be $\hat{\mathbf{j}}$ and direction in Z-axis.

59. (i) (a) As, $r_0 = \frac{mv}{Bq}$

$\Rightarrow \quad r = \frac{m(4v_0)}{Bq}$

$= 4\frac{mv_0}{Bq} = 4r_0$

(ii) (c) As, time period, $T = \frac{2\pi m}{Bq}$

So, time period (T) does not depend upon velocity. Thus, it remains same.

(iii) (b) $\mathbf{B} = (2\hat{\mathbf{i}} + 4\hat{\mathbf{j}}) \times 10^2$ T

$\mathbf{a} = (x\hat{\mathbf{i}} + 4\hat{\mathbf{j}})$ m / s^2

Since, $F \perp B$

$a \perp B \quad [\because F = ma]$

$\therefore \quad \mathbf{a} \cdot \mathbf{B} = 0$

$(x\hat{\mathbf{i}} + 4\hat{\mathbf{j}}) \cdot (2\hat{\mathbf{i}} - 4\hat{\mathbf{j}}) \times 10^2 = 0$

$(x\hat{\mathbf{i}} + 4\hat{\mathbf{j}}) \cdot (2\hat{\mathbf{i}} - 4\hat{\mathbf{j}}) = 0$

$2x + 16 = 0$

$x = -8$ m s^{-2}

(iv) (d) When electron enters into magnetic field not perpendicular to B, then for $\theta = 0°$ or $180°$, it move in a straight line and for other value of θ, it will move on helical path.

(v) (d) Here, $\theta = 0°$

$\therefore \quad F = Bev \sin 0° = 0$