4 Moving Charges and Magnetism

Fastrack Revision

- **Magnetic field:** Just as static charge produces an electric field, a moving charge or current through conductor produces a magnetic field ($\vec{B}$).
  - It is the space around a conductor carrying current or the space around a magnet in which its magnetic effect can be felt.
  - Magnetic field is also called as magnetic induction or magnetic flux density.
  - SI unit of $\vec{B}$ is Tesla (T) or weber/metre^2 and CGS unit is gauss.

$$1 \text{ Tesla} = 10^4 \text{ gauss}$$

  - The direction of $\vec{B}$ is determined by Fleming's left hand rule.
- **Magnetic Field due to Moving Charges (Oersted's experiment):** Oersted's experiment shows the relation between the magnetic field and electric current.
  As electric current means moving charges, Oersted also concluded that moving charges also produce magnetic field in their surroundings.
- **Magnetic Force:** It is experienced by a single charge particle q moving with velocity v in uniform magnetic field at an angle θ.

$$F = qvB\sin\theta$$

or
$$|\vec{F}| = q|\vec{v}\times\vec{B}|$$

- **Fleming's Left Hand Rule:** It states that if we stretch the first finger (fore finger), the middle finger and thumb of left hand are mutually perpendicular to each other such that the first finger points in the direction of magnetic field and second finger shows the direction of electric current then the thumb represents the direction of force experienced by the charged particle.
- **Lorentz Force:** The force experienced by a charged particle moving in a space where both electric and magnetic fields exist is called Lorentz force.

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

- **Magnetic Force on a Current Carrying Conductor:** The magnetic force experienced by the current carrying conductor placed in uniform magnetic field is

$$\vec{F} = IBl\sin\theta$$

  If $\theta = 0°$ or $180°$, then $F = 0$ and if $\theta = 90°$, then $F = IBl$ *i.e.*, force is maximum.
- **Motion in a Magnetic Field:** The particle will describe a circle if v and B are perpendicular to each other.
  If velocity has a component along B, the particle will produce helical motion.
- **Biot-Savart Law:** According to Biot-Savart's law, the magnitude of the magnetic field is proportional to the current I, the element length and inversely proportional to the square of the distance.

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

  where, μ_0 = permeability of free space
  and $\mu_0 = 4\pi\times10^{-7}$ Wb/Am
- **Magnetic Field on the Axis of a Current Carrying Circular Loop**

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

- **Magnetic Field at the Centre of the Coil**

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

- **Similarities and Dis-similarities between the Biot-Savart's Law and Coulomb's Law**
  - **Similarities**
    (i) Both the laws are for long range, since in both the laws, the field at a point varies inversely as the square of distance from the source to point of observation.
    (ii) Both the fields obey superposition principle.
  - **Dis-similarities**
    (i) The electrostatic field is produced by a scalar source, *i.e.*, 'q' and the magnetic field is produced by a vector source $Id\vec{l}$.
    (ii) The electrostatic field is acting along the displacement vector. The magnetic field is acting perpendicular to the plane *i.e.*, along direction of $Id\vec{l}\times\vec{r}$.
    (iii) Coulomb's law is independent of angle, whereas the Biot-Savart's law is angle dependent.
- **Relation between μ_0, ε_0 and c**

$$\varepsilon_0\mu_0 = 4\pi\varepsilon_0\left(\frac{\mu_0}{4\pi}\right) = \left(\frac{1}{9\times10^9}\right)(10^{-7}) = \frac{1}{(3\times10^8)^2} = \frac{1}{c^2}$$

- **Ampere's Circuital Law:** It states that the line integral of magnetic field around a closed path is equal to μ_0 times the total current I threading the closed path.

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

When there is a system with a symmetry such as for a straight infinite current carrying wire, the Ampere's law enables an easy evaluation of the magnetic field.

The magnetic field at a distance r outside the wire is tangential and given by the following formula:

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

- **Solenoid:** A solenoid consists of an insulated long wire closely wound in the form of a helix. Its length is very large as compared to its diameter.
- **Magnetic Field due to a Straight Solenoid**

$$B = \mu_0 n I$$

- **Force between Two Parallel Current Carrying Conductors :** Magnetic force per unit length between two straight parallel current carrying conductors is

$$F_{ab} = \frac{\mu_0}{2\pi}\frac{I_a I_b}{d}$$

where, d = distance between two conductors.

I_a and I_b = current of conductors a and b respectively.

The above expression is used to define the ampere (A), which is one of the seven SI base units.

The ampere is the value of that steady current which, when maintained in each of the two very long, straight, parallel conductors of negligible cross-section and placed one metre apart in vacuum, would produce on each of these conductors a force equal to 2×10^{-7} newtons per metre of length.

- **Torque on a Current Loop:** The torque experienced by a current carrying loop placed in uniform magnetic field B is

$$\tau = NIBA \sin\theta$$

Further, $\tau = mB \sin\theta$, where m is the magnetic dipole moment of the current loop.

- **Current Loop as a Magnetic Dipole:** A current loop or a solenoid or a coil behaves like a bar magnet. The magnetic dipole moment of current loop is determined by the following formula:

$$M = IA$$

where, M = magnetic dipole moment

I = current

A = area of current loop

The direction of dipole moment can be determined by right hand thumb rule.

The SI unit of dipole moment is A-m^2 and dimension is [AL^2].

- **Moving Coil Galvanometer:** Moving coil galvanometer is an instrument used for detection and measurement of small electric currents.

Principle: It is based on the principle that when a current carrying coil is placed in a magnetic field, it experiences a torque.

$$I \propto \phi$$

$$\phi = \left(\frac{NAB}{K}\right) I$$

where, ϕ = angle of deflection and K = torsional constant of the spring.

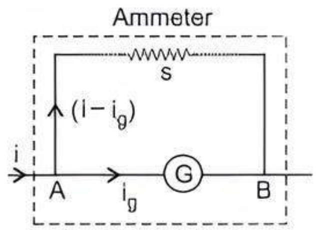
- **Current Sensitivity:** It is defined as the deflection produced in the galvanometer when a unit current flows through it.

$$\frac{\phi}{I} = \frac{nAB}{K}$$

- **Voltage Sensitivity**

$$\frac{\phi}{V} = \left(\frac{nAB}{K}\right)\frac{1}{R}$$

> A galvanometer can be converted into an ammeter by using a low resistance wire in parallel with the galvanometer ($R \cong 0$).

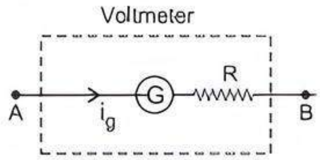


Now, effective resistance of ammeter will be

$$\frac{1}{R_A} = \frac{1}{G} + \frac{1}{S}$$

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

> A galvanometer can be converted into a voltmeter by connecting a high resistance wire in series with the galvanometer ($R = \infty$).



Effective resistance of voltmeter will be $R_V = G + R$.

Practice Exercise

Multiple Choice Questions

Q 1. An electron is moving along positive X-axis in a magnetic field which is parallel to the positive Y-axis. In what direction will the magnetic force be acting on the electron? *(CBSE SQP 2023-24)*

a. Along – X-axis

b. Along – Z-axis

c. Along + Z-axis

d. Along – Y-axis

Q 2. Which one of the following is not correct about Lorentz force?

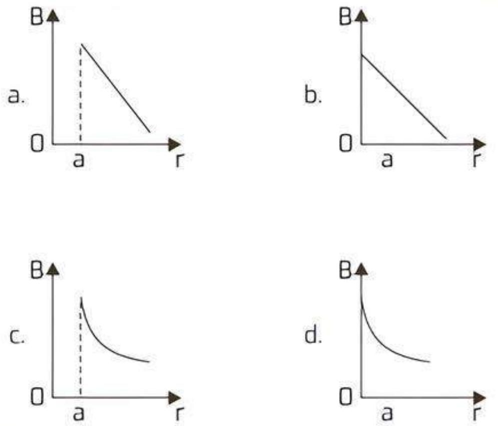
a. In presence of electric field $\vec{E}(r)$ and magnetic field $\vec{B}(r)$ the force on a moving electric charge is $\vec{F} = q[\vec{E}(r) + \vec{v} \times \vec{B}(r)]$.

b. The force due to magnetic field on a negative charge is opposite to that on a positive charge.

c. The force due to magnetic field becomes zero if velocity and magnetic field are parallel or anti-parallel.

d. For a static charge, the magnetic force is maximum.

Q 3. 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 function of distance '*r*' from the centre of the wire? *(CBSE 2023)*



Q 4. Two horizontal thin long parallel wires separated by a distance *r* carry current *I* each in the opposite directions. The net magnetic field at a point midway between them will be: *(CBSE 2023)*

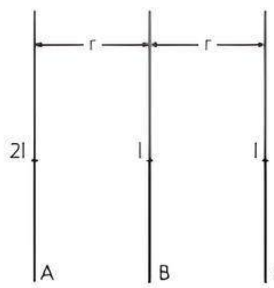
a. zero

b. $\left(\frac{\mu_0 I}{2\pi r}\right)$ vertically downward

c. $\left(\frac{2\mu_0 I}{r}\right)$ vertically upward

d. $\left(\frac{\mu_0 I}{\pi r}\right)$ vertically downward

Q 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*. What will be the net force on wire *C*, when the current in wire *A* is reversed: *(CBSE SQP 2021 Term-1)*



a. Zero b. *F*/2 c. *F* d. 2*F*

Q 6. Biot-Savart's law indicates that the moving electrons (velocity $\vec{v}$) produce a magnetic field $\vec{B}$ such that: *(NCERT EXEMPLAR)*

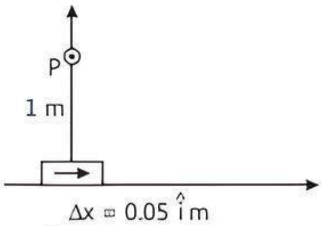
a. $\vec{B} \perp \vec{v}$

b. $\vec{B} \parallel \vec{v}$

c. it obeys inverse cube law

d. it is along the line joining the electron and point of observation

Q 7. An element of $0.05\hat{i}$ m is placed at the origin as shown in figure which carries a large current of 10 A. The magnetic field at a distance of 1 m in perpendicular direction is:



a. 4.5×10^{-8} T b. 5.5×10^{-8} T

c. 5.0×10^{-8} T d. 7.5×10^{-8} T

Q 8. The magnitude of the magnetic field of a long straight wire carrying a current of 1 A at a distance of 2 cm is:

a. 10^{-5} T b. 10^{-7} T c. 2×10^{-7} T d. 2×10^{-5} T

Q 9. A current loop in a magnetic field:

a. experiences a torque whether the field is uniform or non-uniform in all orientations.

b. can be in equilibrium in one orientation.

c. can be equilibrium in two orientations, both the equilibrium states are unstable.

d. can be in equilibrium in two orientations, one stable while the other is unstable.

Q 10. A circular loop of radius 3 cm is having a current of 12.5 A. The magnitude of magnetic field at a distance of 4 cm on its axis is:

a. 5.65×10^{-5} T b. 5.27×10^{-5} T

c. 6.54×10^{-5} T d. 9.20×10^{-5} T

Q 11. A circular current loop of magnetic moment *M* is in an arbitrary orientation in an external magnetic field $\vec{B}$. The work done to rotate the loop by 30° about an axis perpendicular to its plane is: *(NCERT EXEMPLAR)*

a. *MB* b. $\sqrt{3}\frac{MB}{2}$ c. $\frac{MB}{2}$ d. zero

Q 12. A current carrying circular loop of radius *R* is placed in the *X*-*Y* plane with centre at the origin. Half of the loop with $x > 0$ is now bent so that it now lies in the *Y*-*Z* plane. *(NCERT EXEMPLAR)*

a. The magnitude of magnetic moment now diminishes.

b. The magnetic moment does not change.

c. The magnitude of $\vec{B}$ at (0, 0, z), $z >> R$ increases.

d. The magnitude of $\vec{B}$ at (0, 0, z), $z >> R$ is unchanged.

Q 13. Ampere's circuital law is given by:

a. $\oint \vec{H} \cdot \vec{dl} = \mu_0 I_{enc}$ b. $\oint \vec{B} \cdot \vec{dl} = \mu_0 I_{enc}$

c. $\oint \vec{H} \cdot \vec{dl} = \mu_0 J$ d. $\oint \vec{B} \cdot \vec{dl} = \mu_0 J$

Q 14. A long straight wire in the horizontal plane carries a current of 75 A in north to south direction, magnitude and direction of field B at a point 3 m east of the wire is:

a. 4×10^{-6} T, vertical up
b. 5×10^{-6} T, vertical down
c. 5×10^{-6} T, vertical up
d. 4×10^{-6} T, vertical down

Q 15. An electron is projected with uniform velocity along the axis of a current carrying long solenoid. Which of the following is true? *(NCERT EXEMPLAR)*

a. The electron will be accelerated along the axis.
b. The electron path will be circular about the axis.
c. The electron will experience a force at 45° to the axis and hence execute a helical path.
d. The electron will continue to move with uniform velocity along the axis of the solenoid.

Q 16. A solenoid coil of 200 turns/m is carrying a current of 3 A. The length of the solenoid is 0.2 m and has a diameter of 1 cm. The magnitude of the magnetic field inside the solenoid is:

a. $12\pi \times 10^{-5}$ T
b. $24\pi \times 10^{-5}$ T
c. $12\pi \times 10^{-4}$ T
d. $48\pi \times 10^{-6}$ T

Q 17. An air-cored solenoid with length 30 cm, area of cross-section 25 cm^2 and number of turns 800, carries a current of 2.5 A. The current is suddenly switched off in a brief time of 10^{-3} s. Ignoring the variation in magnetic field near the ends of the solenoid, the average back emf induced across the ends of the open switch in the circuit would be:

a. zero
b. 3.125 V
c. 6.54 V
d. 16.74 V

Q 18. The two parallel conductors carry equal currents in the same direction. What is the nature of the force acting between them?

a. Repulsive
b. Attractive
c. Cannot predict
d. No force

Q 19. A small circular flexible loop of wire of radius r carries a current I. It is placed in a uniform magnetic field B. The tension in the loop will be doubled if:

a. I is doubled
b. B is halved
c. r is doubled
d. Both B and I are doubled

Q 20. Two concentric and coplanar circular loops P and Q have their radii in the ratio 2 : 3. Loop Q carries a current 9 A in the anticlockwise direction. For the magnetic field to be zero at the common centre, loop P must carry: *(CBSE SQP 2022-23)*

a. 3 A in clockwise direction
b. 9 A in clockwise direction
c. 6 A in anti-clockwise direction
d. 6 A in the clockwise direction

Q 21. A circular coil of 25 turns and radius 12 cm is placed in a uniform magnetic field of 0.5 T normal to the plane of the coil. If the current in the coil is 6 A, then total torque acting on the coil is:

a. zero
b. 3.4 N-m
c. 3.8 N-m
d. 4.4 N-m

Q 22. An ammeter of resistance 0.81 ohm reads up to 1 A. The value of the required shunt to increase the range to 10 A is: *(CBSE SQP 2023-24)*

a. 0.9 ohm
b. 0.09 ohm
c. 0.03 ohm
d. 0.3 ohm

Q 23. Which of the following expressions is applicable to the moving coil galvanometer?

a. $\vec{F}_m = q(\vec{V} \times \vec{B})$
b. $B = B_0 \tan\theta$
c. $\vec{\tau} = \vec{M} \times \vec{B}$
d. None of these

Q 24. In a moving coil galvanometer, the deflecting torque τ acting on the coil is related to the current I flowing through it as: *(CBSE 2023)*

a. $\tau \propto I^3$
b. $\tau \propto I^2$
c. $\tau \propto I$
d. $\tau \propto \sqrt{I}$

Q 25. Current sensitivity of a moving coil galvanometer is 5 div/mA and its voltage sensitivity is 20 div/V. The resistance of the galvanometer is:

a. 25 Ω
b. 250 Ω
c. 40 Ω
d. 500 Ω

Q 26. A galvanometer of resistance 10 Ω gives full-scale deflection when 1mA current passes through it. The resistance required to convert it into a voltmeter reading up to 2.5 V is:

a. 24.9 Ω
b. 249 Ω
c. 2490 Ω
d. 24900 Ω

Q 27. The coil of a moving coil galvanometer is wound over a metal frame in order to: *(CBSE SQP 2021 Term-1)*

a. reduce hysteresis
b. increase sensitivity
c. increase moment of inertia
d. provide electromagnetic damping

Q 28. The current sensitivity of a galvanometer increased by 20%. If its resistance also increases by 25%, the voltage sensitivity will: *(CBSE SQP 2021 Term-1)*

a. decrease by 1%
b. increase by 5%
c. increase by 10%
d. decrease by 4%

Assertion & Reason Type Questions

Directions (Q.Nos. 29-37): *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

Q 29. Assertion (A): If an electron is not deflected while passing through a certain region of space, then only possibility is that there is no magnetic region.
Reason (R): Force is inversely proportional to the magnetic field applied.

Q 30. Assertion (A): The magnetic field intensity at the centre of a circular coil carrying current changes, if the current through the coil is doubled.
Reason (R): The magnetic field intensity is dependent on current in conductor.

Q 31. Assertion (A): Ampere's circuital law holds for steady currents which do not fluctuate with time.
Reason (R): Ampere's circuital law is similar to that of Biot-Savart's law.

Q 32. Assertion (A): Magnetic field due to current carrying solenoid is independent of its length and cross-sectional area.
Reason (R): The magnetic field inside the solenoid is uniform.

Q 33. Assertion (A): The magnetic field at the ends of a very long current carrying solenoid is half of that at the centre.
Reason (R): If the solenoid is sufficiently long, the field within it is uniform.

Q 34. Assertion (A): The deflecting torque on a current carrying loop is zero when its plane is perpendicular to the direction of magnetic field.
Reason (R): The deflecting torque acting on a loop of magnetic moment $\vec{m}$ in a magnetic field $\vec{B}$ is given by the dot product of $\vec{m}$ and $\vec{B}$. *(CBSE 2023)*

Q 35. Assertion (A): When current is represented by a straight line, the magnetic field will be circular.
Reason (R): According to Fleming's left hand rule, direction of force is parallel to the magnetic field.

Q 36. Assertion (A): When radius of a circular loop carrying a steady current is doubled, its magnetic moment becomes four times.
Reason (R): The magnetic moment of a circular loop carrying a steady current is proportional to the area of the loop. *(CBSE 2023)*

Q 37. Assertion (A): On increasing the current sensitivity of a galvanometer by increasing the number of turns, may not necessarily increase its voltage sensitivity.
Reason (R): The resistance of the coil of galvanometer increases on increasing the number of turns.

Fill in the Blanks Type Questions

Q 38. Electric current flows through a thick wire. Magnetic field at a point on its surface is ($B = \mu_0 I/2\pi R$) and is .... on its axis.

Q 39. When a coil carrying current is set with its plane perpendicular to the direction of magnetic field, the torque on the coil is ....

Q 40. An electron passes undeflected when passes through region with electric and magnetic fields. When electric field is switched off, its path will change to ....

Q 41. A linear conductor carrying current is placed parallel to the direction of magnetic field, then it experiences .... force.

Q 42. When a magnetic dipole of moment $\vec{M}$ rotates freely about its axis from unstable equilibrium to stable equilibrium in a magnetic $\vec{B}$, the rotational kinetic energy gained by it is ....

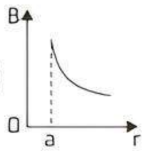
Q 43. Two linear parallel conductors carrying currents in the opposite direction .... each other.

Q 44. The path of charged particle moving perpendicularly with $\vec{B}$ is ....

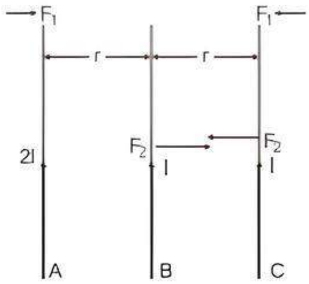
Q 45. Torque on a current carrying rectangular coil inside galvanometer is maximum and constant irrespective of its orientation as it is suspended inside .... magnetic field.

Q 46. To convert galvanometer into a voltmeter of given range, suitable high resistance should be connected in .... with the galvanometer.

Answers

1. (b) Along – *Z*-axis
2. (d) For a static charge, the magnetic force is maximum. If charge is not moving, then the magnetic force is zero. Since $\vec{F}_m = q(\vec{v} \times \vec{B})$
As $\vec{v} = 0$, for stationary charge
$\therefore \vec{F}_m = 0$
3. (c)


4. (d) $\left(\frac{\mu_0 I}{\pi r}\right)$ vertically downward
5. (a) Zero
Let F_1 is force per unit length between *A* and *C*.
$$\therefore \quad F_1 = \frac{\mu_0}{4\pi}\frac{2I \times I}{2r}$$
Let F_2 is force per unit length between *B* and *C*.
$$\therefore \quad F_2 = \frac{\mu_0}{4\pi}\frac{I \times I}{r}$$

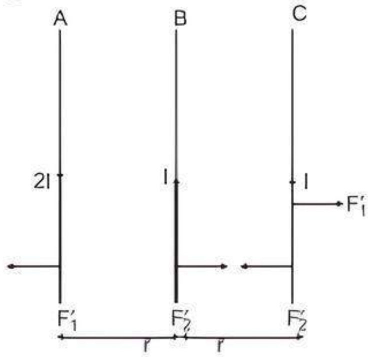


Now net force on 'C' per unit length is

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

$$= \frac{2\mu_0}{4\pi}\frac{I^2}{r} = F \quad \text{(given)}$$

Now fig.



$F_1' =$ Repulsive force between A and $C = \frac{\mu_0}{4\pi}\frac{2I^2}{2r}$

$F_2' = F_2 =$ A reactive force between B and C

$\therefore$ Net force on 'C', $F_1' - F_2' = 0 \quad \left[\because F_1' = F_2' = \frac{\mu_0}{4\pi}\frac{2I^2}{2r}\right]$

$\therefore$ Net force on 'C' is zero.

6. (a) $\vec{B} \perp \vec{v}$

Magnetic field produced by charges moving with velocity $\vec{v}$, at a distance r is $\vec{B} = \left(\frac{\mu_0}{4\pi}\right) \cdot q\frac{\vec{v}\times\hat{r}}{r^2}$

Therefore $\vec{B} \perp \vec{v}$.

7. (c) 5.0×10^{-8} T

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

Here, $dl = \Delta x = 0.05$ m, $I = 10$A, $r = 1$ m

$\sin\theta = \sin 90° = 1$

$$dB = 10^{-7} \times \frac{10 \times 0.05 \times 1}{(1)^2}$$

$$= 0.50 \times 10^{-7} = 5.0 \times 10^{-8} \text{ T}$$

8. (a) 10^{-5} T

Here, $I = 1$ A, $x = 2$ cm $= 0.02$m

Magnetic field, $B = \frac{\mu_0 I}{2\pi x}$

$$= \frac{4\pi \times 10^{-7} \times 1}{2\pi \times 0.02} = 100 \times 10^{-7} = 10^{-5} \text{ T}$$

9. (d) can be in equilibrium in two orientations, one stable while the other is unstable.

10. (a) 5.65×10^{-5} T

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

Here, $I = 12.5$ A, $R = 3$ cm $= 3 \times 10^{-2}$m

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

$$B = \frac{4\pi \times 10^{-7} \times 12.5 \times (3 \times 10^{-2})^2}{2\left[(3\times10^{-2})^2 + (4\times10^{-2})^2\right]^{3/2}}$$

$$= 5.65 \times 10^{-5} \text{ T}$$

11. (d) zero

Rotation of loop by 30° about an axis perpendicular to its plane does not change the angle between magnetic moment and magnetic field. Hence, no work is done.

12. (a) The magnitude of magnetic moment now diminishes

13. (b) $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc}$

14. (c) 5×10^{-6} T, vertical up

From Ampere circuital law,

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc}$$

$$B \times 2\pi R = \mu_0 I_{enc}$$

$$B = \frac{\mu_0 I_{enc}}{2\pi R}$$

$$= 2\times10^{-7} \times \frac{75}{3} = 5 \times 10^{-6} \text{ T}$$

The direction of field at the given point will be vertical up determined by the screw rule or right hand rule.

15. (d) The electron will continue to move with uniform velocity along the axis of the solenoid.

16. (b) $24\pi \times 10^{-5}$ T.

$$B = \mu_0 nI$$

$$= 4\pi\times10^{-7} \times 200 \times 3 = 24\pi \times 10^{-5} \text{ T}$$

17. (d) 16.74 V

Given, length of solenoid $l = 30$ cm

area of cross-section $A = 25$ cm^2

number of turns $N = 800$

current $I = 2.5$ A

Time $dt = 10^{-3}$s

Magnetic field inside a solenoid,

$$B = \mu_0 \frac{N}{l} I$$

Flux linked with 'N' turns,

Initial flux $\phi_1 = NBA = N\mu_0 \frac{N}{l} IA$

$$= \mu_0 \frac{N^2}{l} IA$$

$$= \frac{4\pi \times 10^{-7} \times 800 \times 800 \times 2.5 \times 25 \times 10^{-4}}{0.30}$$

$$= 16.74 \times 10^{-3} \text{ Wb}$$

Final flux, $\phi_2 = 0$

Average back emf, $|e| = \frac{d\phi}{dt} = \frac{16.74 \times 10^{-3} - 0}{10^{-3}} = 16.74$ V

18. (b) Attractive

TiP

Parallel currents attract and anti-parallel current repel in nature.

19. (a) I is doubled

$\because$ Magnetic moment $M = IA$

When I is doubled, M is also doubled.

Also, $\tau = MB \sin\theta$, when M is doubled, torque is also doubled, hence tension is doubled.

20. (d) 6 A in the clockwise direction

We know that,

$$|B_1| = |B_2|$$

$$\left|\frac{\mu_0 I_1}{2r_1}\right| = \left|\frac{\mu_0 I_2}{2r_2}\right|$$

Given, $r_1/r_2 = 2/3$, $I_2 = 9$ A

Then, $I_1/I_2 = r_1/r_2$

or $I_1 = \frac{2 \times 9}{3} = 6$ A in the clockwise direction.

21. (a) zero

The torque acting on the coil

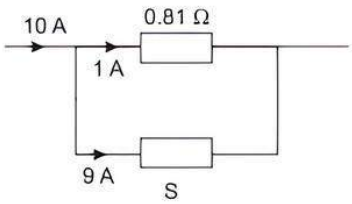
$$|\vec{\tau}| = |\vec{M} \times \vec{B}| = MB\sin\theta$$

Here the circular coil is placed normal to the direction of magnetic field, then the angle between the direction of magnetic moment $(\vec{M})$ and magnetic field $(\vec{B})$ is zero, then

$$\tau = MB\sin\theta = MB\sin 0° = 0$$

$\therefore \tau = 0$

22. (b) 0.09 ohm



$$S = \frac{I_g G}{I - I_g} = \frac{1 \times 0.81}{10 - 1} = 0.09\ \Omega$$

23. (c) $\vec{\tau} = \vec{M} \times \vec{B}$

24. (c) $\tau \propto I$

25. (b) 250 Ω

$$\text{Resistance} = \frac{\text{Current sensitivity}}{\text{Voltage sensitivity}}$$

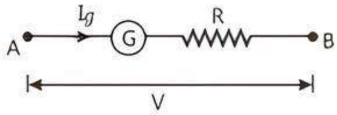
$$= \frac{5000 \text{ div / A}}{20 \text{ div / A}} = 250\ \Omega$$

26. (c) 2490 Ω

Here, $I_g = 1$ mA $= 1 \times 10^{-3}$ A, $R_G = 10\ \Omega$

$V = 2.5$V

From the figure,



$$V = I_g(R_G + R) \Rightarrow R = \frac{V}{I_g} - R_G$$

Substituting the given values, we get

$$R = \frac{2.5\text{V}}{1 \times 10^{-3}\text{ A}} - 10\Omega = 2500\ \Omega - 10\ \Omega = 2490\ \Omega$$

27. (d) provide electromagnetic damping

The coil of a moving coil galvanometer is wound over metallic frame to provide electromagnetic damping, so it becomes dead beat galvanometer.

28. (d) decrease by 4%

According to the question,

$$I'_g = I_g + \frac{20}{100} I_g$$

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

and $R' = R + \frac{25}{100} R = \frac{125}{100} R = 1.25R$

Then $V'_g = \frac{I'_g}{R'} = \frac{1.2 I_g}{1.25 R}$

$$= \frac{120}{125} V_g = \frac{24}{25} V_g$$

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

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

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

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

Thus, the voltage sensitivity will decrease by 4%.

29. (d) In this case, we cannot be sure about the absence of the magnetic field because if the electron moving parallel to the direction of magnetic field, the angle between velocity and applied magnetic field is zero ($F = 0$). Then, also electron passes without deflection. Also $F = eVB\sin\theta \Rightarrow F \propto B$.

30. (a) The magnetic field at the centre of circular coil is given by,

$$B = \frac{\mu_0}{4\pi} \frac{2\pi nI}{a}$$

So if current through coil is doubled, then magnetic field is $B' = 2B$.

The magnetic field also gets doubled. The magnetic field is directly proportional to the current in conductor.

31. (b) Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).

32. (b) Magnetic field due to a solenoid having n number of turns per metre and carrying current I is $B = \mu_0 nI$ which is independent of the length and area of cross-section of the solenoid.

The magnetic field inside the solenoid is uniform.

33. (b) The magnetic field of a solenoid is given by,

$$B = \frac{1}{2}\mu_0 nI(\cos\theta_1 - \cos\theta_2)$$

For a long current carrying solenoid, the magnetic field at the ends of a very long solenoid is given by,

$$B = \frac{1}{2}\mu_0 nI = \frac{1}{2} \times \text{Magnetic field at the centre}$$

$$[\because \theta_1 = 90^\circ, \theta_2 = 180^\circ]$$

34. (c) When a plane of loop is perpendicular to the direction of the magnetic field, the angle between the magnetic moment vector and the magnetic field vector is 90°. In this case, the vector product of the two vectors becomes maximum in magnitude and deflecting torque becomes maximum. However, the dot product of two vectors becomes zero.

35. (c) When current is straight, it means the current is passing through a straight conductor, the magnetic field produced due to current through a straight conductor is in the form of concentric circular magnetic lines of force whose centres lie on the linear conductor and are in a plane perpendicular to the plane of linear conductor. It means the magnetic field is circular.

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

= Ampere turns × Area of the coil

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

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

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

37. (a) When we increase current sensitivity by increasing number of turns, then resistance of coil also increases. So, increasing current sensitivity does not necessarily imply that voltage sensitivity will increase because

$$V_g = \frac{I_g}{R}$$

If I_g increase and R increase by different amounts, then V_g may increase or decrease.

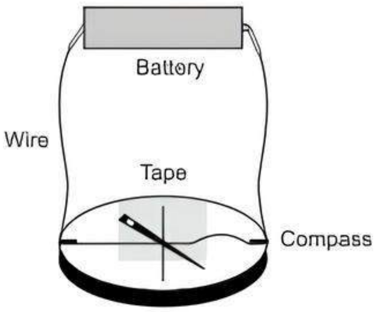
38.	zero	**39.**	zero	**40.**	circular
41.	no	**42.**	$2\vec{M}\,\vec{B}$	**43.**	repel
44.	circular	**45.**	radial	**46.**	series

Case Study Based Questions

Case Study 1

In 1820, A Danish physicist, Hans Christian Oersted, discovered that there is a relationship between electricity and magnetism. By setting up a compass through a wire carrying an electric current, Oersted showed that moving electrons can create a magnetic field. Oersted found that, for a straight wire carrying a steady current (DC), the magnetic field lines encircle the current-carrying wire.

The magnetic field lines lie in a plane perpendicular to the wire. If the direction of the current is reversed, the direction of the magnetic force reverses. The strength of the field is directly proportional to the magnitude of the current. The strength of the field at any point is inversely proportional to the distance of the point from the wire.



Read the given passage carefully and give the answer of the following questions:

Q 1. Who was the first to discover the relation between electric and magnetic fields?

a. H.C. Oersted
b. Charles William Oersted
c. Charles Maxwell
d. Andre Marie Ampere

Q 2. If magnitude of the current in the wire increases, strength of magnetic field:

a. increases
b. decreases
c. remains unchanged
d. None of these

Q 3. Which of the following statements is true?

a. There is no relationship between electricity and magnetism
b. An electric current produces a magnetic field
c. A compass is not affected by electricity
d. A compass is not affected by a magnet

Q 4. A compass needle is placed below a straight conducting wire. If current is passing through the conducting wire from north to south, then the deflection of the compass is:

a. towards west
b. towards east
c. keeps oscillating in east-west direction
d. no deflection

Q 5. Charges at rest can produce:

a. static electric field
b. magnetic field
c. induced current
d. conventional current

Answers

1. (a) H.C. Oersted
Hans Christian Oersted discovered that there is a relationship between electricity and magnetism.
2. (a) increases
$$B \propto I$$
3. (b) An electric current produces a magnetic field Magnetism is related to electricity according to Oersted
4. (b) towards east
5. (a) static electric field
Charges at rest can produce static electric field.

Case Study 2

A magnetic field can be produced by moving, charges or electric currents. The basic equation governing the magnetic field due to a current distribution is the Biot-Savart's law.

Finding the magnetic field resulting from a current distribution involves the vector product and is inherently a calculus problem when the distance from the current to the field point is continuously changing.

According to this law, the magnetic field at a point due to a current element of length $d\vec{l}$ carrying current I, at a distance r from the element is

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

Biot-Savart's law has certain similarities as well as difference with Coulomb's law for electrostatic field. *e.g.* There is an angle dependence in Biot-Savart's law which is not present in electrostatic case.

Read the given passage carefully and give the answer of the following questions:

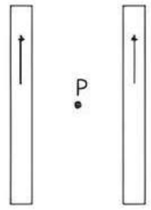
Q 1. The direction of magnetic field $d\vec{B}$ due to a current element $d\vec{l}$ at a point of distance $\vec{r}$ from it, when a current I passes through a long conductor is in the direction:

a. of position vector $\vec{r}$ of the point
b. of current element $d\vec{l}$
c. perpendicular to both $d\vec{l}$ and $\vec{r}$
d. perpendicular to $d\vec{l}$

Q 2. The magnetic field due to a current in a straight wire segment of length L at a point on its perpendicular bisector at a distance r ($r >> L$):

a. decreases as $\frac{1}{r}$
b. decreases as $\frac{1}{r^2}$
c. decreases as $\frac{1}{r^3}$
d. approaches a finite limit as $r \to \infty$

Q 3. Two long straight wires are set parallel to each other. Each carries a current i in the same direction and the separation between them is $2r$. The intensity of the magnetic field midway between them is:



a. $\mu_0 i/r$ b. $4\mu_0 i/r$
c. zero d. $\mu_0 i/4r$

Q 4. A long straight wire carries a current along the z-axis for any two points in the x-y plane. Which of the following is always false?

a. The magnetic fields are equal
b. The directions of the magnetic fields are the same
c. The magnitudes of the magnetic fields are equal
d. The field at one point is opposite to that at the other point

Q 5. Biot-Savart's law can be expressed alternatively as:

a. Coulomb's Law b. Ampere's circuital law
c. Ohm's Law d. Gauss's Law

Answers

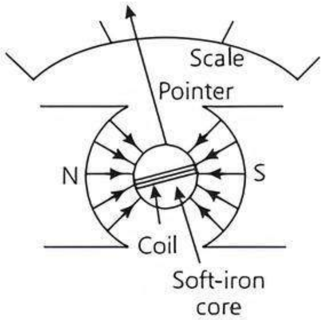
1. (c) perpendicular to both $d\vec{l}$ and $\vec{r}$
According to Biot-Savart's law, the magnetic induction due to a current element is given by
$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I d\vec{l} \times \vec{r}}{r^3}$$
Thus, it is perpendicular to both $d\vec{l}$ and $\vec{r}$.
2. (b) decreases as $\frac{1}{r^2}$
From Biot-Savart's law,
$$dB = \frac{\mu_0}{4\pi}\frac{Idl}{r^2} \text{ i.e., } dB \propto \frac{1}{r^2}$$
3. (c) zero
$$B = \frac{\mu_0}{2\pi}\cdot\frac{i}{r} - \frac{\mu_0}{2\pi}\cdot\frac{i}{r} = 0$$
4. (a) The magnetic fields are equal
5. (b) Ampere's circuital law

Case Study 3

Moving coil galvanometer operates on Permanent Magnet Moving Coil (PMMC) mechanism and was designed by the scientist d'Arsonval. Moving coil galvanometers are of two types:

(i) Suspended coil

(ii) Pivoted coil type or tangent galvanometer.



Its working is based on the fact that when a current carrying coil is placed in a magnetic field, it experiences a torque. This torque tends to rotate the coil about its axis of suspension in such a way that the magnetic flux passing through the coil is maximum.

Read the given passage carefully and give the answer of the following questions:

Q 1. A moving coil galvanometer is an instrument which:

a. is used to measure emf
b. is used to measure potential difference
c. is used to measure resistance
d. is a deflection instrument which gives a deflection when a current flows through its coil

Q 2. To make the field radial in a moving coil galvanometer:

a. number of turns of coil is kept small
b. magnet is taken in the form of horse-shoe
c. poles are of very strong magnets
d. poles are cylindrically cut

Q 3. The deflection in a moving coil galvanometer is:

a. directly proportional to torsional constant of spring
b. directly proportional to the number of turns in the coil
c. inversely proportional to the area of the coil
d. inversely proportional to the current in the coil

Q 4. In a moving coil galvanometer, a coil of *N*-turns of area *A* and carrying current *I* is placed in a radial field of strength *B* is:

a. NA^2B^2I b. $NABI^2$
c. N^2ABI d. $NABI$

Q 5. To increase the current sensitivity of a moving coil galvanometer, we should decrease:

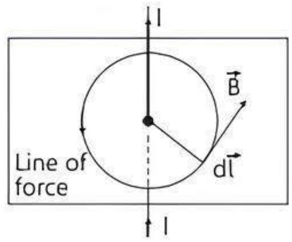
a. strength of magnet
b. torsional constant of spring
c. number of turns in coil
d. area of coil

Answers

1. (d) is a deflection instrument which gives a deflection when a current flows through its coil
A moving coil galvanometer is a sensitive instrument which is used to measure a deflection when a current flows through its coil.
2. (d) poles are cylindrically cut
Uniform field is made radial by cutting pole pieces cylindrically.
3. (b) directly proportional to the number of turns in the coil
The deflection in a moving coil galvanometer,
$$\phi = \frac{NAB}{k} I$$
or $\phi \propto N$, where N is number of turns in a coil, B is magnetic field and A is area of cross-section.
4. (d) $NABI$
The deflecting torque acting on the coil is
$$\tau_{deflection} = NIAB$$
5. (b) torsional constant of spring
Current sensitivity of galvanometer
$$\frac{\phi}{I} = S_I = \frac{NBA}{k}$$
Hence, to increase (current sensitivity) S_p (torsional constant of spring), k must be decreased.

Case Study 4

Ampere's law gives a method to calculate the magnetic field due to given current distribution. According to this, the circulation $\oint \vec{B} \cdot d\vec{l}$ of the resultant magnetic field along a closed plane curve is equal to μ_0 times the total current crossing the area bounded by the closed curve provided the electric field inside the loop remains constant. Ampere's law is more useful under certain symmetrical conditions. Consider one such case of a long straight wire with circular cross-section (radius R) carrying current I uniformly distributed across this cross-section.



Read the given passage carefully and give the answer of the following questions:

Q 1. What is the magnetic field at a radial distance *r* from the centre of the wire in the region *r* > *R*?

Q 2. What is the magnetic field at a distance *r* in the region *r* < *R*?

Q 3. A long straight wire of a circular cross-section (radius *a*) carries a steady current *I* and the current *I* is uniformly distributed across this cross-section. Plot the graph which represent the variation of magnitude of magnetic field *B* with distance *r* from the centre of the wire.

Q 4. **A long straight wire of radius R carries a steady current I. The current is uniformly distributed across its cross-section. What is the ratio of magnetic field at $R/2$ and $2R$?**

Q 5. **If a long straight wire in the horizontal plane carries a current of 40 A, calculate the magnitude of the field B at a point 15 cm away from the wire.**

Answers

1. Magnetic field due to a long current carrying wire at r is

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

2. Let I' be the current in the region $r < R$.

Then, $$I' = \frac{I}{\pi R^2}\pi(r^2) \text{ or } I' = \frac{Ir^2}{R^2}$$

So, magnetic field, $$B = \frac{\mu_0 I'}{2\pi r} = \frac{\mu_0 I r^2}{2\pi R^2 r} = \frac{\mu_0 I r}{2\pi R^2}$$

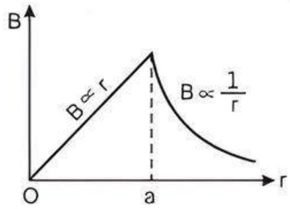
3. Magnetic field due to a long straight wire of radius a carrying current I at a point distant r from the centre of the wire is given as follows:

$$B = \frac{\mu_0 I r}{2\pi a^2} \text{ for } r < a$$

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

$$B = \frac{\mu_0 I}{2\pi r} \text{ for } r > a$$

The variation of magnetic field B with distance r from the centre of wire is shown in the figure.



4. Let the magnetic fields due to a long straight wire of radius R carrying a steady current I at a distance r from the centre of the wire are

$$B_1 = \frac{\mu_0 I r}{2\pi R^2} \text{ (for } r < R)$$

and $$B_2 = \frac{\mu_0 I}{2\pi R} \text{ (for } r > R)$$

So, the magnetic field at $r = \frac{R}{2}$ is

$$B_1 = \frac{\mu_0 I}{2\pi R^2}\left(\frac{R}{2}\right) = \frac{\mu_0 I}{4\pi R}$$

and at $r = 2R$, $$B_2 = \frac{\mu_0 I}{2\pi(2R)} = \frac{\mu_0 I}{4\pi R}$$

∴ Their corresponding ratio is

$$\frac{B_1}{B_2} = \frac{(\mu_0 I/4\pi R)}{(\mu_0 I/4\pi R)} = 1 \Rightarrow B_1 : B_2 = 1:1$$

5. Given that

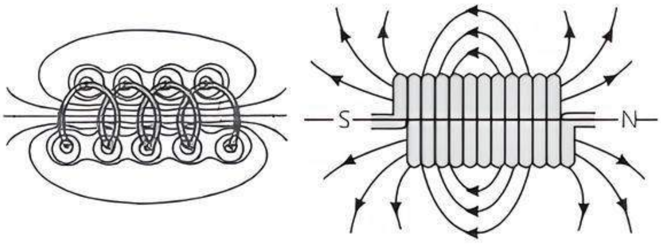
$$I = 40\text{A}$$
$$r = 15\text{cm} = 15 \times 10^{-2}\text{ m}$$

$$B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} \times 40}{2\pi \times 15 \times 10^{-2}} = \frac{80 \times 10^{-5}}{15}$$
$$= 5.34 \times 10^{-5}\text{ T}$$

Case Study 5

A solenoid is a long coil of wire tightly wound in the helical form. Solenoid consists of closely stacked rings electrically insulated from each other wrapped around a non-conducting cylinder.

Figure below shows the magnetic field lines of a solenoid carrying a steady current I. We see that if the turns are closely spaced, the resulting magnetic field inside the solenoid becomes fairly uniform, provided that the length of the solenoid is much greater than its diameter. For an ideal solenoid, which is infinitely long with turns tightly packed, the magnetic field inside the solenoid is uniform and parallel to the axis, and vanishes outside the solenoid.



Read the given passage carefully and give the answer of the following questions:

Q 1. **A long solenoid has 800 turns per metre length of solenoid. A current of 1.6 A flows through it. Calculate the magnetic induction at the end of the solenoid on its axis.**

Q 2. **What is the nature of magnetic field lines passing through the centre of current carrying solenoid?**

Q 3. **What is the magnetic field (B) inside a long solenoid having n turns per unit length and carrying current I when iron core is kept in it (μ_0 = permeability of vacuum, χ = magnetic susceptibility)?**

Q 4. **A solenoid of length l and having n turns carries a current I in anti-clockwise direction. What is the magnetic field?**

Answers

1. As $B = \frac{\mu_0 nI}{2} = \frac{(4\pi \times 10^{-7}) \times 800 \times 1.6}{2} = 8 \times 10^{-4}$ T

2. Magnetic field lines at the centre of the solenoid are straight lines as magnetic field inside a solenoid is uniform.

3. Magnetic field inside a long solenoid with an iron core inside it is $B = \mu nI$

But $\mu = \mu_0(1 + \chi)$

$\therefore$ $B = \mu_0(1 + \chi)nI$

4. A solenoid of length l and having n turns carries a current I in anti-clockwise direction. The magnetic field is $\frac{\mu_0 nI}{l}$. Its direction will be along the axis of solenoid.

Very Short Answer Type Questions

Q 1. Write the relation for the force acting on a charged particle q moving with velocity $\vec{v}$ in the presence of a magnetic field $\vec{B}$. *(CBSE 2019)*

Ans. When a charged particle q moves with velocity $\vec{v}$ in a uniform magnetic field $\vec{B}$, then the force acting on it is given by

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

Q 2. Write the expression, in vector form, for the Lorentz magnetic force $\vec{F}$ due to a charge moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$. What is the direction of the magnetic force? *(CBSE 2016)*

Ans. Expression is $\vec{F} = q(\vec{v} \times \vec{B})$.

The direction of magnetic force is perpendicular to the plane containing velocity and magnetic field vectors.

Q 3. Under what condition is the force acting on a charge moving through a uniform magnetic field minimum?

Ans. When it moves parallel or anti-parallel to the direction of magnetic field.

TiP

$F = Bqv \sin\theta$

$\Rightarrow$ when $\theta = 0°$ or $\theta = 180°$, $F = 0 = F_{min}$

Q 4. Under what condition is the force acting on a charge (or an electron) moving through a uniform magnetic field maximum?

Ans. When it moves perpendicular to the direction of magnetic field.

TiP

$F = Bqv \sin\theta$ $\Rightarrow$ when $\theta = 90°$, $F = F_{max}$

Q 5. State the condition under which a charged particle moving with velocity $\vec{v}$ goes undeflected in a magnetic field $\vec{B}$. *(CBSE 2017)*

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

The charge will go undeflected when $F_m = 0$, *i.e.*, if $\vec{v}$ is parallel or anti-parallel to $\vec{B}$, *i.e.*, either $\theta = 0°$ or $\theta = 180°$.

Q 6. When a charge q is moving in the presence of electric $(\vec{E})$ and magnetic fields $(\vec{B})$ which are perpendicular to each other and also perpendicular to the velocity $\vec{v}$ of the particle, write the relation expressing (v) in terms of (E) and (B).

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

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

The force between the electric and magnetic field is opposite. Now if we adjust the force such that the force due to electric and magnetic field are same, then the particle moves undeflected.

$\therefore$ $qE = qvB$

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

Q 7. Write the mathematical form of Ampere-Maxwell circuital law. *(CBSE 2020)*

Or **State Ampere's circuital law.** *(CBSE 2016)*

Ans. Ampere's circuital law states that the line integral of the magnetic field, around a closed loop, equals μ_0 times the total current passing through the surface enclosed by that loop.

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

Q 8. What do you mean by solenoid?

Ans. A solenoid consists of an insulating long wire closely would in the form of a helix. Its length is very large as compared to its diameter.

Q 9. Write the formula for magnetic field due to a solenoid.

Ans. Magnetic field due to a solenoid is given by

$$B = \mu_0 nI$$

where, n = number of turns per unit length

μ_0 = permeability of free space.

Q 10. Define moving coil galvanometer.

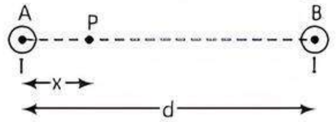
Ans. Moving coil galvanometer is a device used to detect the small electrical current in the circuit.

Q 11. Current sensitivity and voltage sensitivity of galvanometer depend on which parameters?

Ans. The current sensitivity and voltage sensitivity of galvanometer depend on number of turns of coil, magnetic field, area of the coil and torsion constant K of the spring or suspension wire.

Short Answer Type-I Questions

Q 1. Two long straight parallel wires A and B separated by a distance d, carry equal current I flowing in same direction as shown in the figure.



(i) Find the magnetic field at a point P situated between them at a distance x from one wire.

(ii) Show graphically the variation of the magnetic field with distance x for $0 < x < d$. *(CBSE 2020)*

Sol. (i) Magnetic field at P due to the wire A,

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

Similarly, magnetic field at P due to the wire B,

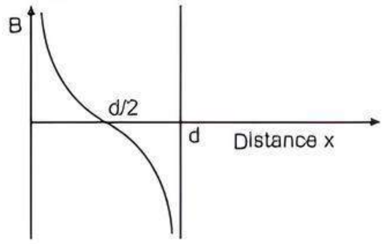
$$B_2 = \frac{\mu_0 I}{2\pi(d-x)}$$

Net magnetic field at P will be,

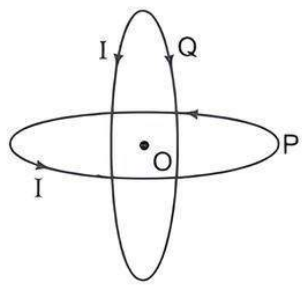
$$B_P = B_1 - B_2 = \frac{\mu_0 I}{2\pi x} - \frac{\mu_0 I}{2\pi(d-x)}$$

$$= \frac{\mu_0 I(d-2x)}{2\pi(d-x)x}$$

(ii) Graph showing variation of the magnetic field with distance is given below:



Q 2. Two identical circular loops P and Q each of radius R carrying current I are kept in perpendicular planes such that they have a common centre O as shown in the figure.



Find the magnitude and direction of the net magnetic field at point O. *(CBSE 2023)*

Sol. The magnetic field due to circular loop at point O is given as

$$B_P = \frac{\mu_0 I}{2R} \text{ and } B_Q = \frac{\mu_0 I}{2R}$$

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

$$= B_P\sqrt{2} \qquad [\because B_P = B_Q]$$

$$= \frac{\mu_0 I}{2R} \times \sqrt{2} = \frac{\mu_0 I}{R\sqrt{2}}$$

and $\tan\theta = \frac{B_P}{B_Q} = \frac{B_P}{B_P} = 1$

$$\theta = 45°$$

Q 3. Two wires of equal lengths are shaped in the form of a square loop and a circular loop. Both loops are suspended in a uniform magnetic field. Prove that for the same current, the circular loop will experience larger torque. *(CBSE 2023)*

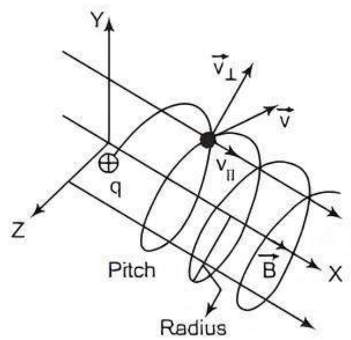
Ans. For the given length, the area enclosed by circular loop is greater than the area enclosed by square shaped loop. The torque acting on area A, carrying current I suspended into a uniform magnetic field B is $\tau = IBA\sin\theta$ i.e., $\tau \propto A$. Therefore, the torque on circular loop will be more than that on square shaped loop.

Q 4. A charged particle q is moving in the presence of a magnetic field B which is inclined at 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. *(CBSE 2019)*

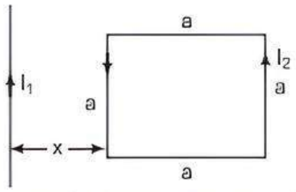
Ans. When a charge particle q enters a uniform magnetic field at an angle of 30°, then its path becomes helix of radius,

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

For Figure and Description: If a charged particle has a velocity not perpendicular to $\vec{B}$, then component of velocity along $\vec{B}$ 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 $\vec{B}$ is as before a circular one, thereby producing a helical motion.

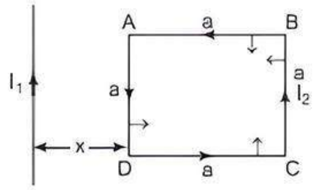


Q 5. **A square loop of side a carrying a current I_2 is kept at distance x from an infinitely long straight wire carrying a current I_1 as shown in the figure. Obtain the expression for the resultant force acting on the loop.** *(CBSE 2019)*



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

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



Force on BC is

$$F_2 = \frac{\mu_0 I_1 I_2 a}{2\pi(x+a)} \text{ (towards left)}$$

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

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

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

Q 6. **An ammeter of resistance 0.8 Ω can measure current up to 1.0 A.**

(i) What must be the value of shunt resistance to enable the ammeter to measure current up to 5.0 A?

(ii) What is the combined resistance of the ammeter and the shunt?

Sol. (i) $S = \frac{I_g \times G}{(I - I_g)} = \frac{1 \times 0.8}{(5.0 - 1.0)} = 0.2\ \Omega$

(ii) $R_A = \frac{S \times G}{S + G} = \frac{0.2 \times 0.8}{0.2 + 0.8} = 0.16\ \Omega$

Short Answer Type-II Questions

Q 1. **State Biot-Savart's law and express this law in the vector form.** *(CBSE 2017, 16)*

Ans. **Biot-Savart's law:** It states that magnetic field $d\vec{B}$ due to a current element, $I\,d\vec{l}$, at a point, having a position vector $\vec{r}$ relative to the current element, is found to depend

(i) directly on the current element. $(B \propto |I\,d\vec{l}|)$

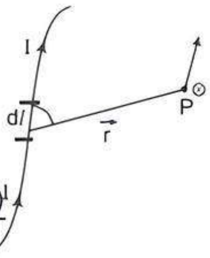
(ii) inversely on the square of the distance.

$$\left(B \propto \frac{1}{|\vec{r}|^2}\right)$$

(iii) directly on the sine of angle between the current element and the position vector $\vec{r}$. $(B \propto \sin\theta)$

i.e., $dB \propto \frac{Idl\sin\theta}{r^2}$

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



In vector form, $d\vec{B} = \frac{\mu_0}{4\pi}\frac{(I\,d\vec{l} \times \vec{r})}{r^3}$

Q 2. **(i) Write an expression of magnetic moment associated with a current (I) carrying circular coil of radius r having N turns.**

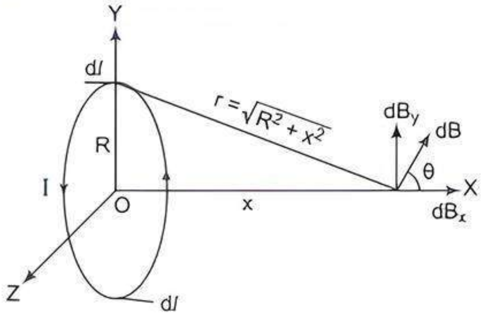
(ii) Consider the above mentioned coil placed in YZ plane with its centre at the origin. Derive expression for the value of magnetic field due to it at point $(x, 0, 0)$.

Ans. (i) Magnetic moment associated with a current (I) carrying circular coil of radius r having N turns, can be given as,

$$M = NIA$$

$\Rightarrow$ $$M = NI\pi r^2$$

(ii) According to Biot-Savart's law,



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

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

$dB_\perp$ components due to diametrically opposite components cancel out. Only dB_x components refrain.

$$dB_x = \frac{\mu_0 Idl}{4\pi r^2}\cdot\cos\theta$$

$$B = \int dB_x$$

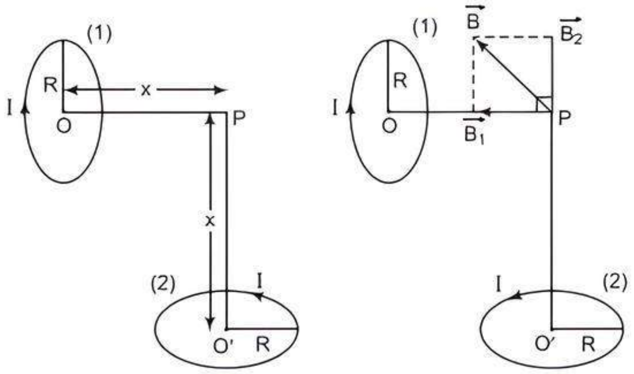
After solving,

$$B = \frac{\mu_0 IR^2}{2(R^2 + x^2)^{3/2}}, \text{ along } X\text{-axis}$$

Q 3. **Two identical circular loops (1) and (2) of radius R and carrying the same current are kept in perpendicular planes such that they have a common centre at P as shown in the figure. Find the magnitude and direction of the net magnetic field at the point P due to the loops.**

Sol. According to the question,

$$B_1 = B_2 = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{3/2}}$$



$$\Rightarrow \; B = \sqrt{B_1^2 + B_1^2} = B_1\sqrt{2} = \frac{\mu_0 I R^2 \sqrt{2}}{2(R^2 + x^2)^{3/2}} \quad [\because B_1 = B_2]$$

$$\tan\theta = \frac{B_X}{B_Y} = 1$$

$\Rightarrow \; q = 45°$ with either B_1 or B_2.

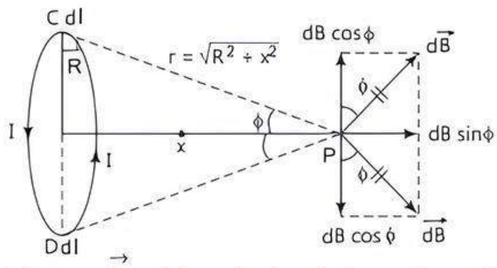
Q 4. Using Biot-Savart's law, deduce the expression for the magnetic field at a point (*x*) on the axis of a circular current carrying loop of radius *R*. How is the direction of the magnetic field determined at this point? *(CBSE 2023, 17, 16)*

Sol. **Magnetic field due to a current carrying loop at a point on its axis:**

According to Biot-Savart's law, the magnetic field at *P* due to current element $I\,d\vec{l}$ at *C*,

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

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



Resolving $\vec{dB}$ into horizontal and vertical components, resultant magnetic field at *P*,

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

$$= \frac{\mu_0}{4\pi}\frac{I}{r^2}\sin\phi \int dl$$

Also, $\sin\phi = \dfrac{R}{\sqrt{R^2 + x^2}}$

$dl = 2\pi r$

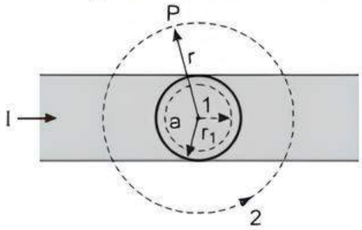
$$B = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{3/2}} \quad [\because r = \sqrt{(R^2 + x^2)}]$$

For a coil of *N* turns,

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

Direction of the magnetic field at this point *P* can be determined by the right hand thumb rule.

Q 5. The given figure shows a long straight wire of a circular cross-section (radius *a*) carrying steady current *I*. The current *I* is uniformly distributed across this cross-section. Calculate the magnetic field in the region *r* < *a* and *r* > *a*. *(CBSE SQP 2023-24)*



Sol. (i) Consider the case $r > a$. The Amperian loop, labelled 2, is a circle concentric with the cross-section.

For this loop, $L = 2\pi r$

Using Ampere circuital law, we can write,

$$B(2\pi r) = \mu_0 I, \; B = \frac{\mu_0 I}{2\pi r}, \quad B \propto \frac{1}{r} \quad (r > a)$$

(ii) Consider the case $r < a$. The Amperian loop is circle labelled 1. For this loop, taking the radius of the circle to be *r*, $L = 2\pi r$

Now the current enclosed I_e is not *I*, but is less than this value. Since the current distribution is uniform, the current enclosed is,

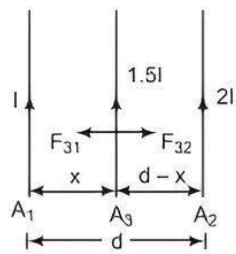
$$I_e = I\left(\frac{\pi r^2}{\pi a^2}\right) = \frac{I r^2}{a^2}$$

Using Ampere's law, $B(2\pi r) = \mu_0 \dfrac{I r^2}{a^2}$

$$B = \left(\frac{\mu_0 I}{2\pi a^2}\right) r, \quad B \propto r \quad (r < a)$$

Q 6. Two infinitely long straight wires A_1 and A_2 carrying currents *I* and 2*I* 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? *(CBSE 2019)*

Sol. 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

$$F_{31} = \frac{\mu_0}{2\pi} \cdot \frac{I \times 1.5I \times l}{x}$$

where, l = unit length of conductor wire A_2
and x = distance between A_1 and A_3
Similarly, force on A_3 due to A_2 is

$$F_{32} = \frac{\mu_0}{2\pi} \cdot \frac{1.5I \times 2I \times l}{(d-x)}$$

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

$$\Rightarrow \quad \frac{\mu_0}{2\pi} \cdot \frac{1.5I^2 l}{x} = \frac{\mu_0}{2\pi} \frac{3I^2}{(d-x)} l$$

$$\Rightarrow \quad \frac{1.5}{x} = \frac{3}{d-x}$$

$$\Rightarrow \quad d - x = 2x$$

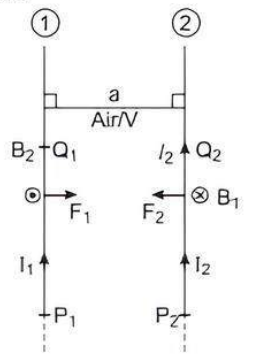
or $$x = \frac{d}{3}$$

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

Q 7. Two long straight parallel current carrying conductors are kept 'a' distant apart in air. The direction of current in both the conductors is same. Find the magnitude of force per unit length and direction of the force between them. Hence define one ampere. *(CBSE SQP 2023-24)*

Sol. The magnetic induction B_1 set up by the current I_1 flowing in first conductor at a point somewhere in the middle of second conductor is

$$B_1 = \frac{\mu_0 I_1}{2\pi a} \quad ...(1)$$



The magnetic force acting on the portion P_2Q_2 of length l_2 of second conductor is

$$F_2 = I_2 l_2 B_1 \sin 90^\circ \quad ...(2)$$

From eqs. (1) and (2),

$$F_2 = \frac{\mu_0 I_1 I_2 l_2}{2\pi a}, \quad \text{towards first conductor}$$

$$\frac{F_2}{l_2} = \frac{\mu_0 I_1 I_2}{2\pi a} \quad ...(3)$$

The magnetic induction B_2 set up by the current I_2 flowing in second conductor at point somewhere in the middle of first conductor is

$$B_2 = \frac{\mu_0 I_2}{2\pi a} \quad ...(4)$$

The magnetic force acting on the portion P_1Q_1 of length l_2 of first conductor is

$$F_1 = I_1 l_1 B_2 \sin 90^\circ \quad ...(5)$$

From eqs. (3) and (5),

$$F_1 = \frac{\mu_0 I_1 I_2 l_1}{2\pi a}, \quad \text{towards second conductor}$$

$$\frac{F_1}{l_1} = \frac{\mu_0 I_1 I_2}{2\pi a} \quad ...(6)$$

The standard definition of 1A

If $I_1 = I_2 = 1$ A, $l_1 = l_2 = 1$ m, $a = 1$m in V/A

then $\frac{F_1}{l_1} = \frac{F_2}{l_2} = \frac{\mu_0 \times 1 \times 1}{2\pi \times a} = 2 \times 10^{-7}$ N/m

Thus, one ampere is that electric current which when flows in each one of the two infinitely long straight parallel conductors placed 1 m apart in vacuum causes each one of them to experience a force of 2×10^{-7} N/m.

Q 8. (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.

(CBSE 2020, 19)

Sol. (i) **Working Principle:** If a current carrying coil is freely suspended or pivoted in a uniform magnetic field, it experiences a deflecting torque.

As pivoted coil is placed in a radial magnetic field, hence on passing current I through it, a deflecting torque acts on the coil which is given by

$$\tau = NAIB$$

where, N = total number of turns in the coil,
A = area of the coil, B = magnetic field

(ii) Reasons:

(a) Galvanometer is a very sensitive device and gives a full scale deflection for a current of the order of a few μA. Hence, it cannot be used to measure current.

(b) Resistance of galvanometer is not very small, hence it will change the value of current in the circuit branch when connected in series in that branch.

(iii) (a) Voltage sensitivity: It is defined as the deflection produced in the galvanometer when unit voltage is applied across the coil of the galvanometer.

$$V_s = \frac{\phi}{V} = \left(\frac{NBA}{K}\right) \times \frac{1}{R} \text{ radian volt}^{-1}$$

where, R = resistance of the coil.

(b) Current sensitivity: It is defined as the deflection produced per unit current in the galvanometer when $I_s = \frac{\phi}{I} = \left(\frac{NBA}{K}\right)$ radian ampere^{-1}.

where, N = number of turns in the galvanometer,
K = restoring couple per unit twist or torsional constant.

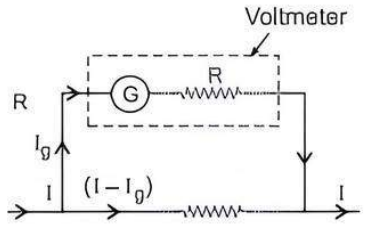
Q 9. How is a galvanometer converted into a voltmeter and an ammeter? Draw the relevant diagrams and find the resistance of the arrangement in each case. Take resistance of galvanometer as *G*.

(CBSE 2020, 16)

Ans. **(i) Conversion of Galvanometer into Voltmeter:** A galvanometer can be converted into a voltmeter by connecting a very high resistance in series to it.

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

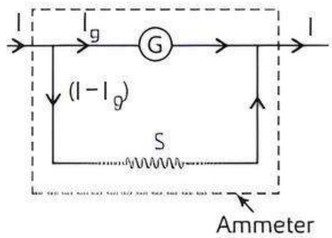
$$\Rightarrow \quad R = \frac{V}{I_g} - G$$



Effective resistance of voltmeter.

$$R_V = R + G \Rightarrow R_V > G \text{ (always)}$$

(ii) **Conversion of Galvanometer into Ammeter:** A galvanometer is converted into an ammeter by connecting a very small resistance (called shunt resistance) in parallel with it.



$$(I - I_g) \times S = I_g \times G \quad \Rightarrow \quad S = \frac{I_g \times G}{(I - I_g)}$$

Effective resistance of ammeter

$$\frac{1}{R_A} = \frac{1}{S} + \frac{1}{G} \quad \Rightarrow \quad R_A = \frac{SG}{S+G}$$

$$\Rightarrow \quad R_A < G \text{ (always)}$$

Long Answer Type Questions

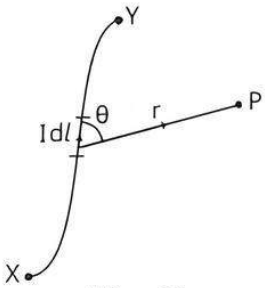
Q 1. State Biot-Savart's law and give the mathematical expression for it. Use this law to derive the expression for the magnetic field due to a circular coil carrying current at a point along its axis. How does a circular loop carrying current behave as a magnet?

Sol. According to Biot-Savart's law, the magnetic field due to small current carrying element *dl* at any nearby point *P* is given by

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

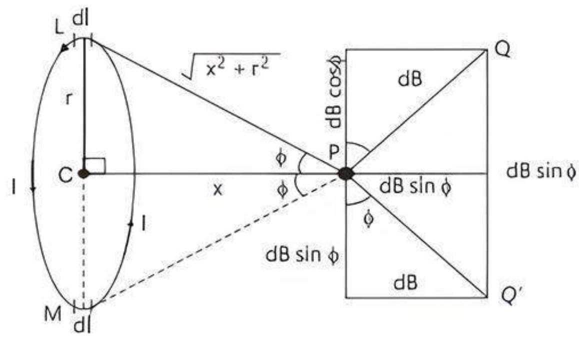
or $$dB = \frac{\mu_0}{4\pi} \cdot \frac{Idl \times r}{|r|^2}$$

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.

Magnetic field due to a circular coil carrying current at a point along its axis: 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 direction *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,

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

where, *r* = radius of circular loop, *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 ϕ components balance each other and net magnetic field is given by

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

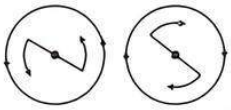
$$\left[\because \text{In } \Delta PCL, \sin\phi = \frac{a}{\sqrt{x^2 + r^2}}\right]$$

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

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

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

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.



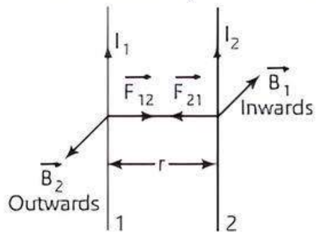
The anti-clockwise flow of current behaves like a North pole, whereas clockwise flow as South pole. Hence, loop behaves as a magnet.

Q 2. Derive an expression for the force per unit length between the two infinitely long straight parallel current carrying conductors. Hence define SI unit of current. *(CBSE 2016, 15)*

Ans. Magnetic field due to conductor '1' at any point on conductor '2' is

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

By right hand rule, $\vec{B_1}$ will act perpendicular to conductor '2' and into the plane of the paper.



Due to this magnetic field, force on length l of wire '2' is

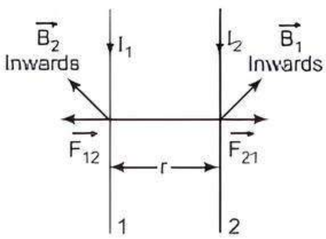
$$F_{21} = B_1 I_2 l \sin 90^\circ = \left(\frac{\mu_0 I_1}{2\pi r}\right) I_2 l$$

$$\Rightarrow \quad F_{21} = \frac{\mu_0 I_1 I_2 l}{2\pi r}$$

Similarly, force on length l of wire '1' is

$$F_{12} = B_2 I_1 l \sin 90^\circ = \left(\frac{\mu_0 I_2}{2\pi r}\right) I_1 l = \frac{\mu_0 I_1 I_2 l}{2\pi r}$$

$$\Rightarrow \quad F_{21} = F_{12} = \frac{\mu_0 I_1 I_2 l}{2\pi r} = F$$



Hence, force per unit length

$$f = \frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r} \qquad \text{...(1)}$$

By Fleming's left hand rule, $\vec{F}_{21}$ will act towards conductor, '1' and $\vec{F}_{12}$ will act towards conductor '2'. Obviously the two conductors will attract each other.

If the currents are in opposite directions, then there will be repulsion between the two conductors. The SI unit of the current is ampere.

One ampere is the current which when flowing through each of the two infinite long straight parallel conductors placed one metre apart from the each other in free space will exert a force of 2×10^{-7} N per metre of their length.

Q 3. State the principle of working of a galvanometer. A galvanometer of resistance G is converted into a voltmeter to measure up to V volts by connecting a resistance R_1 in series with the coil. If a resistance R_2 is connected in series with it, then it can measure up to $V/2$ volts. Find the resistance, in terms of R_1 and R required to be connected to convert it into a voltmeter that can read up to 2 V. Also, find the resistance G of the galvanometer in terms of R_1 and R_2.

Ans. Principle of Galvanometer: 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.

A high resistance is connected in series with the galvanometer to convert into voltmeter. The value of the resistance is given by $R = \dfrac{V}{I_g} - G$

where, V = potential difference across the terminals of the voltmeter, I_g = current through the galvanometer and G = resistance of the galvanometer.

When resistance R_1 is connected in series with the galvanometer, then $R_1 = (V/I_g) - G$. ...(1)

When resistance R_2 is connected in series with the galvanometer, then $R_2 = \dfrac{V}{2I_g} - G$. ...(2)

From eqs. (1) and (2), we get

$$R_1 - R_2 = V/2I_g \quad \text{and} \quad G = R_1 - 2R_2$$

The resistance R_3 required to convert the given galvanometer into voltmeter of range 0 to 2V is given by $R_3 = (2V/I_g) - G$

$$\Rightarrow \quad R_3 = 4(R_1 - R_2) - (R_1 - 2R_2)$$

$$= 3R_1 - 2R_2$$

G in terms of R_1 and R_2 is given by $G = R_1 - 2R_2$.

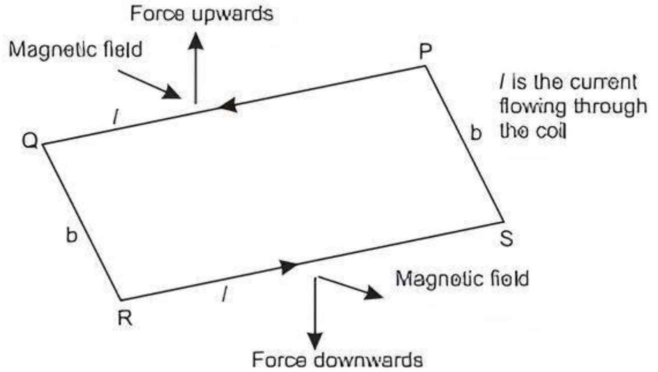
Q 4. (i) Write the principle and explain the working of a moving coil galvanometer. A galvanometer as such cannot be used to measure the current in a circuit. Why?

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

(CBSE 2023)

Ans. (i) Principle of Galvanometer: A current carrying coil placed in a magnetic field experiences a torque, the magnitude of which depends on the strength of current.

Working of Galvanometer: Consider a single turn of the rectangular coil *PQRS* whose length be l and breadth b. $PQ = RS = l$ and $QR = SP = b$. Let I be the electric current flowing through the rectangular coil *PQRS*. The horse-shoe magnet has hemispherical magnetic poles which produces a radial magnetic field.



Due to this radial field, the sides *QR* and *SP* are always parallel to the *B*-field (magnetic field) and experience no force. The sides *PQ* and *RS* are always parallel to the *B*-field and experience force and due to this, torque is produced.

For single turn, the deflection couple is

$\tau = bF = bBIl = (lb)\ BI = ABI$ since, area of the coil.

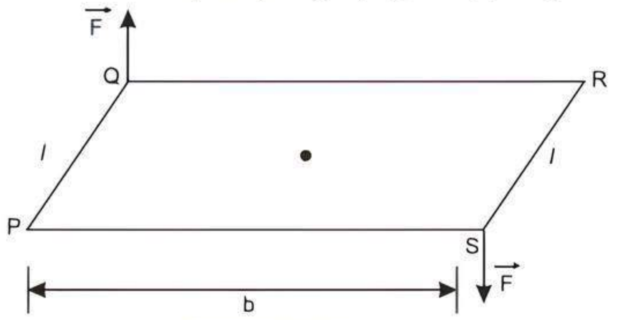
$A = lb$ for coil with N turns, we get $\tau = NABI$. ...(1)

Due to this deflecting torque, the coil gets twisted and restoring torque (also known as restoring couple) is developed. Hence, the magnitude of restoring couple is proportional to the amount of twist θ.

Thus $\tau = K\theta$ ...(2)

where, K is the restoring couples per unit twist or torsional constant of the spring. At equilibrium, the deflection couples is equal to the restoring couple.

Therefore, by comparing eqs. (1) and (2), we get



Deflection couple

$$NABI = K\theta \Rightarrow I = \frac{K}{NAB}\theta \qquad ...(3)$$

or $\quad I = G\theta$

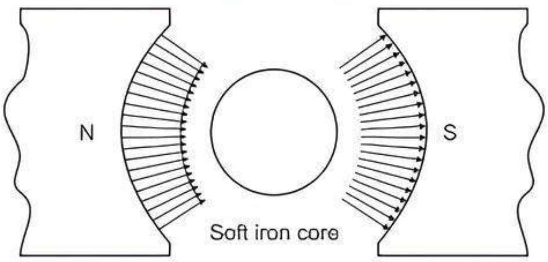
where, $G = \frac{K}{NAB}$ is called galvanometer constant or current reduction factor of the galvanometer.

Since, suspended moving coil galvanometer is very sensitive, we have to handle with high care while doing experiments. Most of the galvanometer, we use arc pointer type moving coil galvanometer.

(ii) The relation between the current flowing through the galvanometer coil and the angular deflection (ϕ) of the coil (from its equilibrium position), is

$$\phi = \left(\frac{NABI\sin\theta}{K}\right)$$

where θ is the angle between the magnetic field μ_m vector B and the equivalent magnetic moment vector of the current carrying coil. Thus I is not directly proportional to ϕ. We can ensure this proportionality by having $\theta = 90°$. This is possible only when the magnetic field vector B, is a radial magnetic field. In such a field, the plane of the rotating coil is always parallel to vector B. To get a radial magnetic field, the pole pieces of the magnet, are made concave in shape. Also, a soft iron cylinder is used as the core.



Chapter Test

Multiple Choice Questions

Q 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 $\vec{\ }$ at a/2 and $\vec{B_2}$ at distance 2*a* is:

(CBSE 2023)

a. 1/2 b. 1 c. 2 d. 4

Q 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.

Assertion and Reason Type Questions

Directions (Q.Nos. 3-4): *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

Q 3. Assertion (A): Increasing the current sensitivity of a galvanometer necessarily increases the voltage sensitivity.

Reason (R): Voltage sensitivity is inversely proportional to current sensitivity.

Q 4. Assertion (A): Two parallel conducting wires carrying currents in opposite direction, come close to each other.

Reason (R): Parallel currents repel and anti-parallel currents attract.

Fill in the blanks

Q 5. The magnetic effect of electric current was first noticed by......................

Q 6. A galvanometer acting as a voltmeter should have .... in series with its coil.

Case Study Based Question

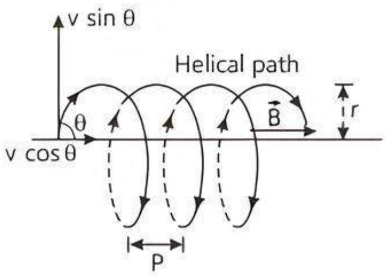
Q 7. The path of a charged particle in magnetic field depends upon angle between velocity and magnetic field.

If velocity $\vec{v}$ is at angle θ to $\vec{B}$, component of velocity parallel to magnetic field ($v \cos\theta$) is responsible for circular motion, thus the charge particle moves in a helical path.

The plane of the circle is perpendicular to the magnetic field and the axis of the helix is parallel to the magnetic field. The charged particle moves along helical path touching the line parallel to the magnetic field passing through the starting point after each rotation.

Radius of circular path is $r = \dfrac{mv\sin\theta}{qB}$

Hence, the resultant path of the charged particle will be a helix, with its axis along the direction of $\vec{B}$ as shown in figure.



Read the given passage carefully and give the answer of the following questions:

(i) When a positively charged particle enters into a uniform magnetic field with uniform velocity, its trajectory can be (i) a straight line, (ii) a circle, (iii) a helix.

a. Only (i)
b. (i) or (ii)
c. (i) or (iii)
d. Any one of (i), (ii) and (iii)

(ii) Two charged particles *A* and *B* having the same charge, mass and speed enter into a magnetic field in such a way that the initial path of *A* makes an angle of 30° and that of *B* makes an angle of 90° with the field. Then the trajectory of:

a. *B* will have smaller radius of curvature than that of *A*
b. both will have the same curvature
c. *A* will have smaller radius of curvature than that of *B*
d. both will move along the direction of their original velocities

(iii) An electron having momentum 2.4×10^{-23} kg m/s enters a region of uniform magnetic field of 0.15 T. The field vector makes an angle of 30° with the initial velocity vector of the electron. The radius of the helical path of the electron in the field shall be:

a. 2 mm
b. 1 mm
c. $\frac{\sqrt{3}}{2}$ mm
d. 0.5 mm

(iv) The magnetic field in a certain region of space is given by $\vec{B} = 8.35\times10^{-2}\,\hat{i}$ T. A proton shot into the field with velocity $\vec{v} = (2\times10^5\,\hat{i} + 4\times10^5\,\hat{j})$ m/s. The proton follows a helical path in the field. The distance moved by proton in the *X*-direction during the period of one revolution in the *YZ*-plane will be (Mass proton $= 1.67\times10^{-27}$ kg):

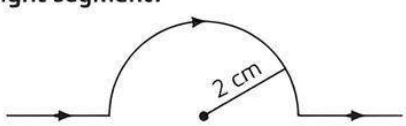
a. 0.053 m
b. 0.136 m
c. 0.157 m
d. 0.236 m

(v) The frequency of revolution of the particle is:

a. $\frac{m}{qB}$
b. $\frac{qB}{2\pi m}$
c. $\frac{2\pi R}{v\cos\theta}$
d. $\frac{2\pi R}{v\sin\theta}$

Very Short Answer Type Questions

Q 8. A straight wire carrying a current of 13 A is bent into a semi-circular arc of radius 2 cm as shown in figure. The magnetic field is 1.5×10^{-4} T at the centre of arc, then what is the magnetic field due to straight segment?

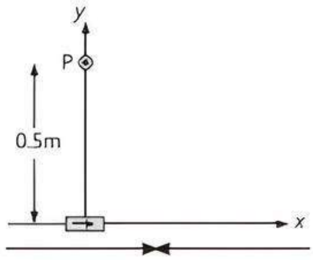


Q 9. Is the steady electric current the only source of magnetic field?

Q 10. A tightly wound 90 turn coil of radius 15 cm has a magnetic field of 4×10^{-4} T at its centre. What will be the current flowing through it?

Short Answer Type-I Questions

Q 11. An element $\Delta l = \Delta X \hat{i}$ is placed at the origin and carries a large current $I = 10$ A. What is the magnetic field on the Y-axis at a distance of 0.5 m and $\Delta X = 1$cm?



Q 12. Briefly explain why and how a galvanometer is converted into an ammeter. *(CBSE 2023)*

Short Answer Type-II Questions

Q 13. (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 its magnitude and direction. What is the nature and magnitude of the force between the two conductors?

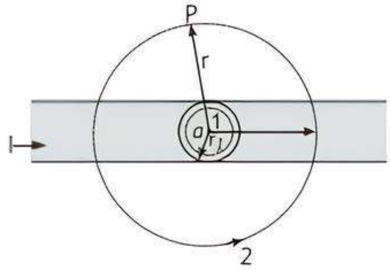
(ii) Show with the help of a diagram, how the force between the two conductors would change when the currents in them flow in the opposite directions?

Q 14. (i) State Ampere's circuital law.

(ii) Derive an expression for magnetic field inside along the axis of an air cored solenoid.

Long Answer Type Questions

Q 15. Figure shows a long straight wire of a circular cross-section (radius a) carrying steady current I. The current I is uniformly distributed across this cross-section. Calculate the magnetic field in the regions $r < a$ and $r > a$.



Q 16. A 100 turn closely wound circular coil of radius 10 cm carries a current of 3.2 A.

(i) What is the field at the centre of the coil?

(ii) What is the magnetic moment of this coil?

The coil is placed in a vertical plane and is free to rotate about a horizontal axis which coincides with its diameter. A uniform magnetic field of 2T in the horizontal direction exists such that initially the axis of the coil is in the direction of the field. The coil rotates through an angle of 90° under the influence of the magnetic field.

(iii) What are the magnitudes of the torques on the coil in the initial and final position?

(iv) What is the angular speed acquired by the coil when it has rotated by 90°? The moment of inertia of the coil is 0.1 kg m^2.