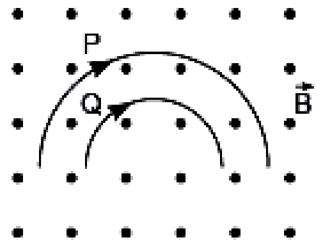
PRACTICE PAPER 04
CHAPTER 04 MOVING CHARGES AND MAGNETISM

SUBJECT: PHYSICS | **MAX. MARKS : 40**
CLASS : XII | **DURATION : 1½ hrs**

General Instructions:
(i). **All** questions are compulsory.
(ii). This question paper contains 2**0** questions divided into five Sections A, B, C, D and E.
(iii). **Section A** comprises of **10 MCQs** of **1 mark** each. **Section B** comprises of 4 questions of **2 marks** each. **Section C** comprises of 3 questions of **3 marks** each. **Section D** comprises of 1 question of **5 marks** each and **Section E** comprises of 2 Case Study Based Questions of **4 marks** each.
(iv). There is no overall choice.
(v). Use of Calculators is not permitted

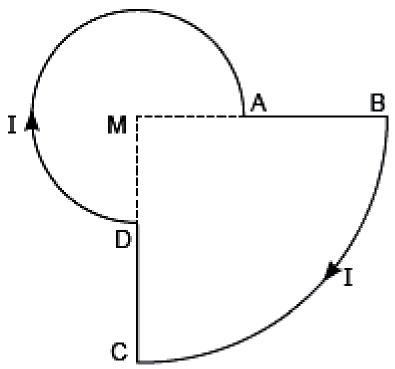
SECTION – A
Questions 1 to 10 carry 1 mark each.

1. Two charged particles each carrying same charge q, but of different masses m_p and mq enter the magnetic field B with speed V_p and V_q respectively.



For the trajectories followed by P and Q as shown, which of the following condition is true?
(a) $m_pV_p > m_qV_q$ (b) $m_pV_p <$ mqV_q (c) mpV_p = mqV_q (d) $m_p = m_q$ and $V_p = V_q$

2. A current I is flowing through the loop as shown in the figure (MA = R, MB = 2R). The magnetic field at the centre of the loop is $\frac{\mu_0 I}{R}$ times:

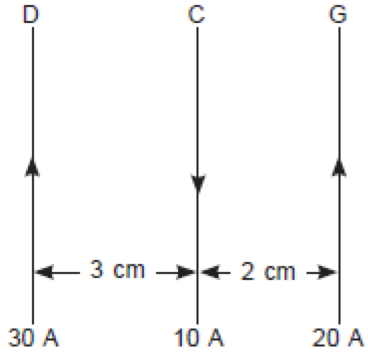


(a) $\frac{5}{16}$, into the plane of the paper (b) $\frac{5}{16}$, out of the plane of the paper
(c) $\frac{7}{16}$, out of the plane of the paper (d) $\frac{7}{16}$, into the plane of the paper

3. An electron is projected with velocity v along the axis of a current carrying long solenoid. Which one of the following statements is true?
(a) The path of the electron will be circular about the axis.
(b) The electron will be accelerated along the axis.

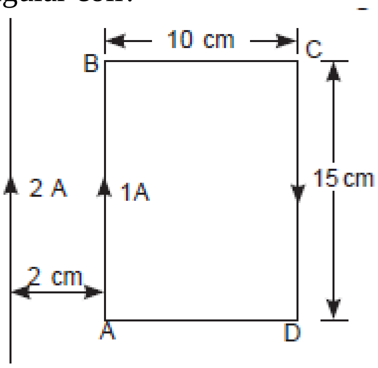
(c) The path of the electron will be helical.
(d) The electron will continue to move with the same velocity v along the axis of the solenoid.

4. Three long, straight parallel wires, carrying current are arranged as shown in the figure. The force experienced by a 25 cm length of wire C is



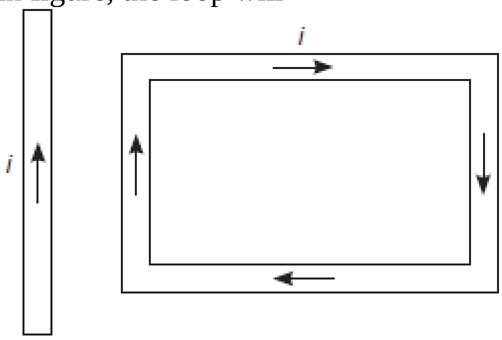
(a) 10^{-3} N (b) 2.5×10^{-3} N (c) zero (d) 1.5×10^{3} N

5. What is the net force on the rectangular coil?



(a) 25×10^{-7} N towards wire. (b) 25×10^{-7} N away from wire.
(c) 35×10^{-7} N towards wire. (d) 35×10^{-7} N away from wire.

6. A rectangular loop carrying a current i is situated near a long straight wire such that the wire is parallel to the one of the sides of the loop and is in the plane of the loop. If a steady current I is established in wire as shown in figure, the loop will



(a) rotate about an axis parallel to the wire.
(b) move away from the wire or towards right.
(c) move towards the wire.
(d) remain stationary.

7. An electron is projected with uniform velocity along the axis of a current carrying long solenoid. Which of the following is true?
(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.

8. A current carrying closed loop of an irregular shape lying in more than one plane when placed in uniform magnetic field, the force acting on it
(a) will be more in the plane where its larger position is covered.
(b) is zero.
(c) is infinite.
(d) may or may not be zero.

In the following questions 9 and 10, 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) Assertion (A) is false but reason (R) is true.

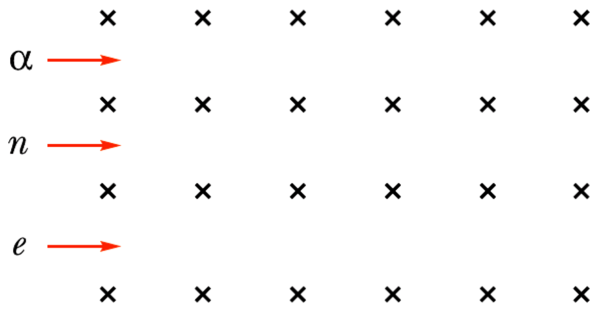
9. **Assertion (A):** Ampere's circuital law is not independent of the Biot-Savart law.
Reason (R): Ampere's circuital law can be derived from Biot-Savart law.

10. **Assertion (A):** The magnetic lines of force of a straight current carrying conductor are concentric circles with the wire at the centre and in a plane perpendicular to the wire.
Reason (R): If the current flows upwards, he lines of force have anticlockwise direction and if the current flows downwards, then the lines of force have clockwise direction.

SECTION – B

Questions 11 to 14 carry 2 marks each.

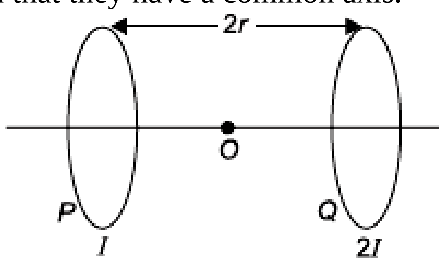
11. (i) Write the expression for the magnetic force acting on a charged particle moving with velocity v in the presence of magnetic field B.
(ii) A neutron, an electron and an alpha particle moving with equal velocities, enter a uniform magnetic field going into the plane of the paper as shown. Trace their paths in the field and justify your answer



12. Define the current sensitivity of a moving coil galvanometer. "Increasing the current sensitivity may not necessarily increase the voltage sensitivity." Justify this statement.

13. 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.

14. Two identical circular loops, P and Q, each of radius r and carrying currents I and 2I respectively are lying in parallel planes such that they have a common axis.

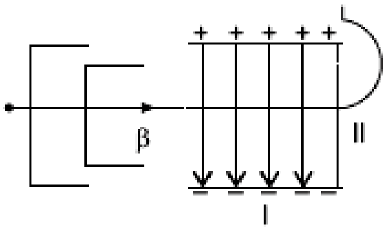


The direction of current in both the loops is clockwise as seen from O which is equidistant from both loops. Find the magnitude of the net magnetic field at point O.

SECTION – C

Questions 15 to 17 carry 3 marks each.

15. A fine pencil of β-particles, moving with a speed *v*, enters a region (reigon I), where a uniform electric field and a uniform magnetic field both are present. These β-particles then move into region II, where only the magnetic field, (out of the two fields present in region I) exists. The path of the β-particles, in the two regions is as shown in the figure.



(i) State the direction of the magnetic field.
(ii) State the relation between *E* and *B* in region *I*.
(iii) Derive the expression for the radius of the circular path of the β-particle in region II.

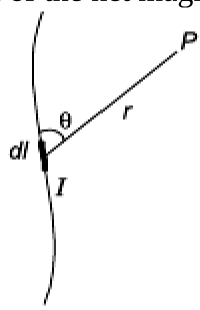
16. Deduce the expression for the magnetic dipole moment of an electron orbiting around the central nucleus.

17. A cell of emf ε and internal resistance r is connected across a variable load resistor R. Draw the plots of the terminal voltage V versus (i) R and (ii) the current I. It is found that when R = 4 Ω, the current is 1 A and when R is increased to 9 Ω, the current reduces to 0.5 A. Find the values of the emf ε and internal resistance r.

SECTION – D

Questions 18 carry 5 marks.

18. (a) State Biot-Savart's law and express this law in the vector form.
(b) Two identical circular coils, P and Q each of radius R, carrying currents 1 A and √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.

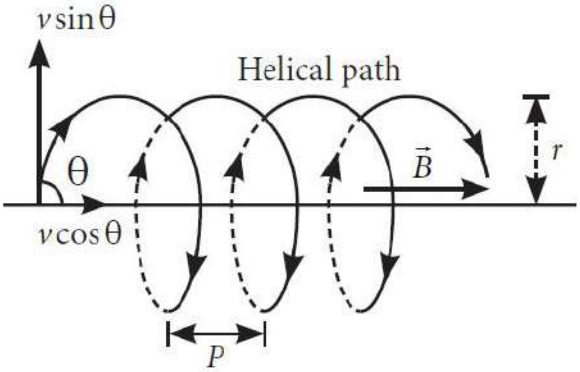


SECTION – E (Case Study Based Questions)

Questions 19 to 20 carry 4 marks each.

19. Helical Motion
The path of a charged particle in magnetic field depends upon angle between velocity and magnetic field.

If velocity v is at angle q to $\vec{B}$, component of velocity parallel to magnetic field (v cosθ) remains constant and component of velocity perpendicular to magnetic field (v sinθ) 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 = mvsinθ/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.

(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) (i) only (b) (i) or (ii) (c) (i) or (iii) (d) any one of (i), (ii) and (iii)

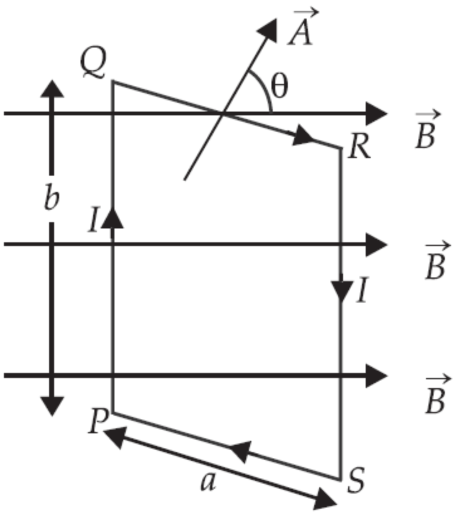
(ii) Two charged particles A and B having the same charge, mass and speed enter into a magnetic field in such a way that the initial path of A makes an angle of 30° and that of B makes an angle of 90° with the field. Then the trajectory of
(a) B will have smaller radius of curvature than that of A
(b)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

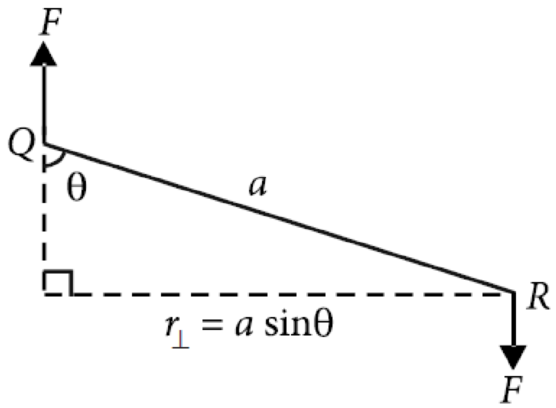
(iii) An electron having momentum 2.4×10^{-23} kg m/s enters a region of uniform magnetic field of 0.15 T. The field vector makes an angle of 30° with the initial velocity vector of the electron. The radius of the helical path of the electron in the field shall be
(a) 2 mm (b) 1 mm (c) √3/2 mm (d) 0.5 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 is 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 of proton = 1.67×10^{-27} kg)
(a) 0.053 m (b) 0.136 m (c) 0.157 m (d) 0.236 m

20. Torque on a Rectangular Loop Placed in Uniform Magnetic Field

When a rectangular loop PQRS of sides '*a*' and '*b*' carrying current I is placed in uniform magnetic field B, such that area vector $\vec{A}$ makes an angle θ with direction of magnetic field, then forces on the arms QR and SP of loop are equal, opposite and collinear, thereby perfectly cancel each other, whereas forces on the arms PQ and RS of loop are equal and opposite but not collinear, so they give rise to torque on the loop.





Force on side PQ or RS of loop is F = IbB sin 90° = Ib B and perpendicular distance between two non-collinear forces is $r_\perp = a \sin\theta$

So, torque on the loop, t = IAB sinθ

In vector form torque, $\vec{\tau} = \vec{M} \times \vec{B}$

Where $\vec{M} = NI\vec{A}$ is called magnetic dipole moment of current loop and is directed in direction of area vector $\vec{A}$ i.e., normal to the plane of loop.

(i) A circular loop of area 1 cm^2, carrying a current of 10 A is placed in a magnetic field of 0.1 T perpendicular to the plane of the loop. The torque on the loop due to the magnetic field is

(a) zero (b) 10^{-4} N m (c) 10^{-2} N m (d) 1 N m

(ii) Relation between magnetic moment and angular velocity is

(a) $M \propto \omega$ (b) $M \propto \omega^2$ (c) $M \propto \sqrt{\omega}$ (d) none of these

(iii) A current loop in a magnetic field

(a) can be in equilibrium in two orientations, both the equilibrium states are unstable

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

(c) experiences a torque whether the field is uniform or non uniform in all orientations

(d) can be in equilibrium in one orientation.

(iv) The magnetic moment of a current I carrying circular coil of radius r and number of turns N varies as

(a) $1/r^2$ (b) $1/r$ (c) r (d) r^2

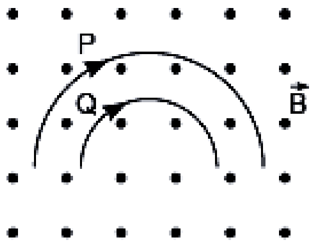
PRACTICE PAPER 04
CHAPTER 04 MOVING CHARGES AND MAGNETISM
(ANSWERS)

SUBJECT: PHYSICS | **MAX. MARKS : 40**
CLASS : XII | **DURATION : 1½ hrs**

General Instructions:
(i). **All** questions are compulsory.
(ii). This question paper contains 2**0** questions divided into five Sections A, B, C, D and E.
(iii). **Section A** comprises of **10 MCQs** of **1 mark** each. **Section B** comprises of 4 questions of **2 marks** each. **Section C** comprises of 3 questions of **3 marks** each. **Section D** comprises of 1 question of **5 marks** each and **Section E** comprises of 2 Case Study Based Questions of **4 marks** each.
(iv). There is no overall choice.
(v). Use of Calculators is not permitted

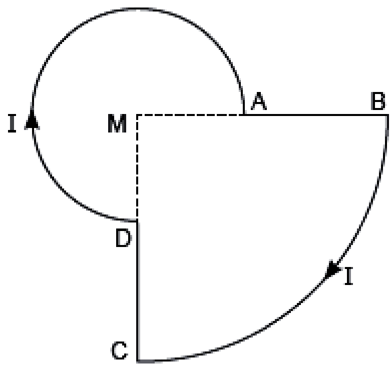
SECTION – A
Questions 1 to 10 carry 1 mark each.

1. Two charged particles each carrying same charge q, but of different masses m_p and mq enter the magnetic field B with speed V_p and V_q respectively.



For the trajectories followed by P and Q as shown, which of the following condition is true?
(a) $m_pV_p > m_qV_q$ (b) $m_pV_p <$ mqV_q (c) mpV_p = mqV_q (d) $m_p = m_q$ and $V_p = V_q$
Ans. (a) $m_pV_p > m_qV_q$
Radius of the trajectory followed by a moving charged particle in a magnetic field is r = mv/qB, that is, the radius of the path followed is directly proportional to the momentum (mv) of the charged particle. So more the momentum of the charged particle, greater is the radius of the path followed.

2. A current I is flowing through the loop as shown in the figure (MA = R, MB = 2R). The magnetic field at the centre of the loop is $\frac{\mu_0 I}{R}$ times:

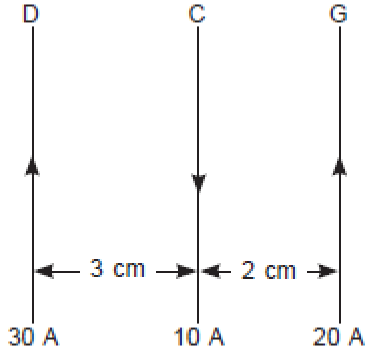


(a) $\frac{5}{16}$, into the plane of the paper (b) $\frac{5}{16}$, out of the plane of the paper
(c) $\frac{7}{16}$, out of the plane of the paper (d) $\frac{7}{16}$, into the plane of the paper

Ans. (d) $\frac{7}{16}$, into the plane of the paper

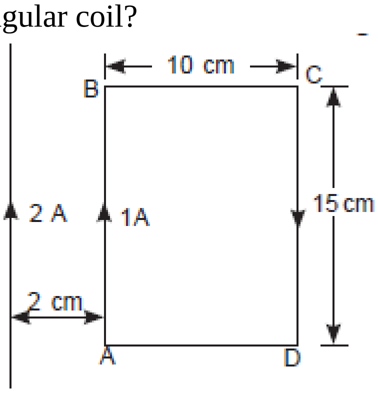
3. An electron is projected with velocity v along the axis of a current carrying long solenoid. Which one of the following statements is true?
(a) The path of the electron will be circular about the axis.
(b) The electron will be accelerated along the axis.
(c) The path of the electron will be helical.
(d) The electron will continue to move with the same velocity v along the axis of the solenoid.
Ans. (d) The electron will continue to move with the same velocity v along the axis of the solenoid.

4. Three long, straight parallel wires, carrying current are arranged as shown in the figure. The force experienced by a 25 cm length of wire C is



(a) 10^{-3} N (b) 2.5×10^{-3} N (c) zero (d) 1.5×10^{3} N
Ans. (c) zero
Force of repulsion by wire D and G on wire C is equal and opposite.

5. What is the net force on the rectangular coil?



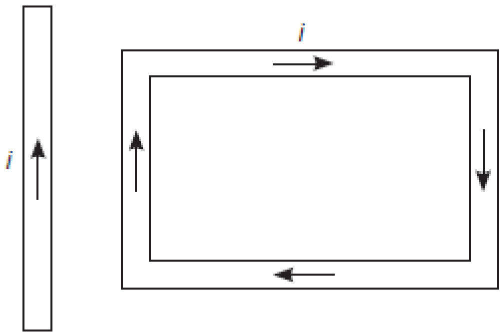
(a) 25×10^{-7} N towards wire. (b) 25×10^{-7} N away from wire.
(c) 35×10^{-7} N towards wire. (d) 35×10^{-7} N away from wire.
Ans. (a) 25×10^{-7} N towards wire.
Since force,

$$F_{AB} = \frac{\mu_0 I_1 I_2}{2\pi r} l = 30 \times 10^{-7} \text{ N (attractive)}$$

$$F_{CD} = 5 \times 10^{-7} \text{ N (repulsive)}$$

$$F_{net} = F_{AB} - F_{CD} = 25 \times 10^{-7} \text{ N towards wire}$$

6. A rectangular loop carrying a current i is situated near a long straight wire such that the wire is parallel to the one of the sides of the loop and is in the plane of the loop. If a steady current I is established in wire as shown in figure, the loop will



(a) rotate about an axis parallel to the wire.
(b) move away from the wire or towards right.
(c) move towards the wire.
(d) remain stationary.
Ans. (c) move towards the wire.

7. An electron is projected with uniform velocity along the axis of a current carrying long solenoid. Which of the following is true?
(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.
Ans. (d) The electron will continue to move with uniform velocity along the axis of the solenoid.
F = –evB sin 180° = 0 (i.e 0= 0°or 180° in both cases F = 0). The electron will continue to move with uniform velocity or will go undeflected along the axis of the solenoid.

8. A current carrying closed loop of an irregular shape lying in more than one plane when placed in uniform magnetic field, the force acting on it
(a) will be more in the plane where its larger position is covered.
(b) is zero.
(c) is infinite.
(d) may or may not be zero.
Ans. (b) is zero.
A current carrying closed loop of any shape when placed in a uniform magnetic field does not experience any force.

In the following questions 9 and 10, 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) Assertion (A) is false but reason (R) is true.

9. **Assertion (A):** Ampere’s circuital law is not independent of the Biot-Savart law.
Reason (R): Ampere’s circuital law can be derived from Biot-Savart law.
Ans. (a) If both Assertion and Reason are true and Reason is correct explanation of Assertion.
Ampere's circuital law can be derived from Biot-Savart law and is not independent of Biot-Savart law.

10. **Assertion (A):** The magnetic lines of force of a straight current carrying conductor are concentric circles with the wire at the centre and in a plane perpendicular to the wire.
Reason (R): If the current flows upwards, he lines of force have anticlockwise direction and if the current flows downwards, then the lines of force have clockwise direction.
Ans. (b) If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.

For an infinitely long current carrying conductor,

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

where, a is the perpendicular distance from the wire. Then,

$B \propto 1/a$

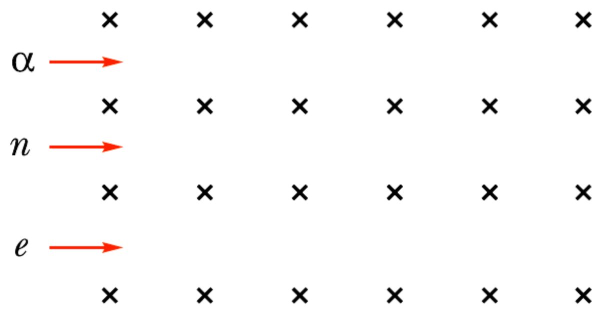
So, the magnitude of the magnetic field will be same at all points located at the same distance from the current carrying conductor.

SECTION – B

Questions 11 to 14 carry 2 marks each.

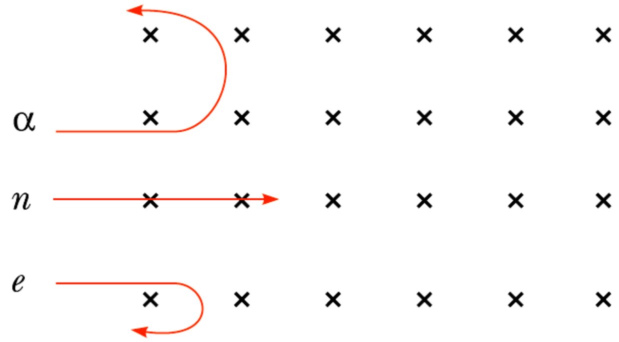
11. (i) Write the expression for the magnetic force acting on a charged particle moving with velocity v in the presence of magnetic field B.

(ii) A neutron, an electron and an alpha particle moving with equal velocities, enter a uniform magnetic field going into the plane of the paper as shown. Trace their paths in the field and justify your answer



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

(ii) Force on alpha particle and electron are opposite to each other, magnitude of mass per charge ratio of alpha particle is more than electron $\left(i.e., r \propto \frac{m}{q}\right)$ hence radius of alpha particle is more than radius of electron.



12. Define the current sensitivity of a moving coil galvanometer. "Increasing the current sensitivity may not necessarily increase the voltage sensitivity." Justify this statement.

Ans. Current Sensitivity: It is defined as the deflection produced in a coil per unit current passed through it.

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

$$\because \text{ If } N \to 2N, \text{ then } l \to 2l \text{ and } R \to 2R \Rightarrow I_s' = \frac{BA(2N)}{k} = 2I_s$$

$$\text{But voltage sensitivity} = V_s' = \frac{BA(2N)}{k(2R)} = \frac{BAN}{kR} = V_s$$

i.e. if the current sensitivity is doubled, say by doubling the number of turns, then the voltage sensitivity may not be increased because it will increase the resistance of the galvanometer and the voltage sensitivity may remain the same.

13. 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.

Ans. Magnetic moment of the coil having N turns and radius R carrying current I is

$M_o = NI\pi R^2$

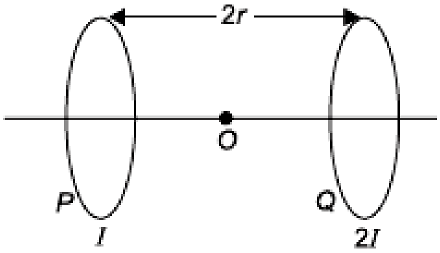
As the length of the wire making the coil remains same on reducing the radius to R/2, the number of turns increases to 2 N.

On passing the same amount of current, magnetic moment is

$$M_n = 2NI\pi\frac{R^2}{4} = \frac{NI\pi R^2}{2} \quad \ldots(ii)$$

Thus, $$\frac{M_n}{M_o} = \frac{1}{2}$$

14. Two identical circular loops, P and Q, each of radius r and carrying currents I and 2I respectively are lying in parallel planes such that they have a common axis.



The direction of current in both the loops is clockwise as seen from O which is equidistant from both loops. Find the magnitude of the net magnetic field at point O.

Ans.

Magnetic field at O due to current in loop P is given by

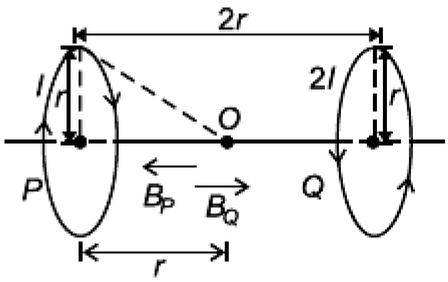
$$B_P = \frac{\mu_0 r^2 I}{2(r^2+r^2)^{3/2}} = \frac{\mu_0 I}{4\sqrt{2}r}$$

(pointing towards P)

Magnetic field at O due to current in loop Q is given by $B_Q = \dfrac{2\mu_0 I}{4\sqrt{2}r}$ (pointing towards) Q

Net magnetic field at O is calculated as

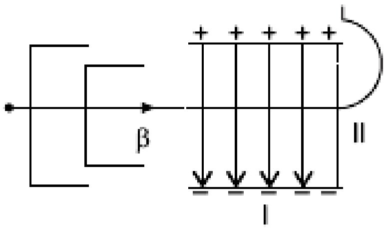
$$\vec{B} = \vec{B_Q} + \vec{B_P} = \frac{\mu_0 I}{4\sqrt{2}r}\hat{i}$$



SECTION – C

Questions 15 to 17 carry 3 marks each.

15. A fine pencil of β-particles, moving with a speed *v*, enters a region (reigon I), where a uniform electric field and a uniform magnetic field both are present. These β-particles then move into region II, where only the magnetic field, (out of the two fields present in region I) exists. The path of the β-particles, in the two regions is as shown in the figure.



(i) State the direction of the magnetic field.

(ii) State the relation between *E* and *B* in region *I*.

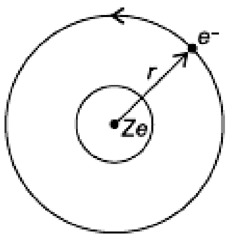
(iii) Derive the expression for the radius of the circular path of the β-particle in region II.
Ans. (i) According to the Fleming's-left hand rule, the magnetic field acts perpendicular to the plane of paper and is directed inwards.
(ii) In region I, As the beam goes undeflected, the magnitude of electrostatic force is equal to the magnitude of magnetic force.

$$\therefore \quad |\vec{F_e}| = |\vec{F_m}|$$
$$qE = qvB$$
$$\therefore \quad v = \frac{E}{B} \quad \ldots(1)$$

(iii) In region II,
The magnetic field provides a centripetal force.

$$\therefore \quad qvB = \frac{mv^2}{r}$$
$$r = \frac{mv}{qB} = \frac{mE}{qB^2} \quad \left[\because v = \frac{E}{B}\right] \ldots(2)$$

16. Deduce the expression for the magnetic dipole moment of an electron orbiting around the central nucleus.
Ans.



Consider an electron revolving around the nucleus of an atom. The electron is in a uniform circular motion around the nucleus of charge $+Ze$. This constitutes a current.

$$\therefore \quad I = \frac{e}{T} \quad \ldots(i)$$

If r is the orbital radius of the electron and 'v' is the orbital speed, then the time period is given as

$$T = \frac{2\pi r}{v} \quad \ldots(ii)$$

From equations (i) and (ii), we get

$$I = \frac{ev}{2\pi r} \quad \ldots(iii)$$

As the magnetic moment is given by

$$\mu_l = I\pi r^2$$

We have
$$\mu_l = \left(\frac{ev}{2\pi r}\right)\pi r^2 = \frac{evr}{2}$$

Multiplying and dividing by m_e in above equation, we get

$$\mu_l = \frac{evm_e r}{2m_e} = \frac{e}{2m_e} l$$

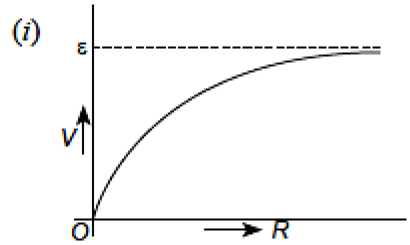
where l is the angular momentum of the electron. According to the Bohr hypothesis, the angular momentum can have discrete values only.

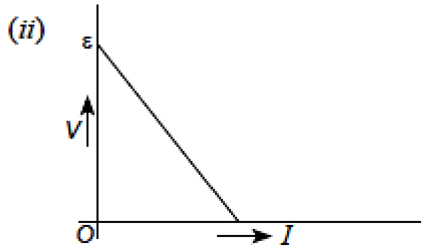
i.e.
$$l = \frac{nh}{2\pi}$$

So,
$$\mu_l = \frac{enh}{2\pi(2m)} = \frac{neh}{4\pi m}$$

In this case it is directed into the plane of the paper.

17. A cell of emf ε and internal resistance r is connected across a variable load resistor R. Draw the plots of the terminal voltage V versus (i) R and (ii) the current I. It is found that when R = 4 Ω, the current is 1 A and when R is increased to 9 Ω, the current reduces to 0.5 A. Find the values of the emf ε and internal resistance r.
Ans.





Given: $R_1 = 4\ \Omega$, I1 = 1 A, $R_2 = 9\ \Omega$, $I_2 = 0.5$ A

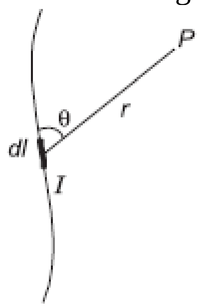
$$I = \frac{\varepsilon}{R + r}$$

⇒ e = I(R + r)
e = 1 × (4 + r) = 4 + r ...(i)
When R is increased then
e = 0.5(9 + r) = 4.5 + 0.5 r ...(ii)
From equations (i) and (ii), we get
4 + r = 4.5 + 0.5 r
⇒ 0.5r = 0.5 ⇒ r = 1 W
e = 1 × (4 + 1) = 5 V

SECTION – D

Questions 18 carry 5 marks.

18. (a) State Biot-Savart's law and express this law in the vector form.
(b) Two identical circular coils, P and Q each of radius R, carrying currents 1 A and √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.



Ans. (a) Biot-Savart law states that the magnitude of the magnetic field dB at any point due to a small current element dl is given by

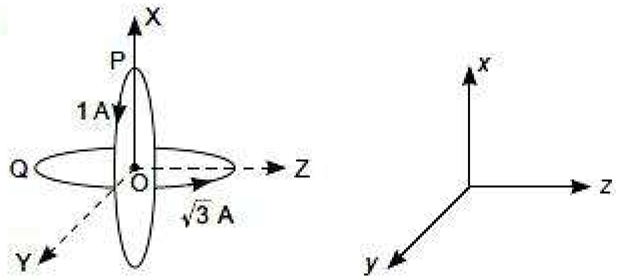
$$dB = \frac{\mu_0}{4\pi} \frac{I\, dl \sin\theta}{r^2}$$

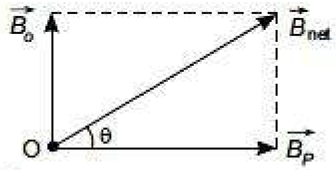
where I is the magnitude of current, dl is the length of element, θ is the angle between the length of element and the line joining the element to the point of observation, and r is the distance of the point from the element.

In vector notation, $$\vec{dB} = \frac{\mu_0}{4\pi} \frac{I(\vec{dl} \times \vec{r})}{r^3}$$

Its SI unit is tesla. Its direction is perpendicular to the plane in which $\vec{dl}$ and $\vec{r}$ lie.

(b)





At centre *O*

Magnetic field due to coil, $P = \vec{B}_P = \frac{\mu_o I}{2R}\hat{k}$

$$\vec{B}_P = \frac{4\pi \times 10^{-7} \times 1}{2R}\hat{k}$$

Magnetic field due to coil,

$$Q = \vec{B}_Q = \frac{4\pi \times 10^{-7} \times \sqrt{3}}{2R}\hat{i}$$

$$\therefore \quad \vec{B}_{net} = \vec{B}_P + \vec{B}_Q = \frac{4\pi \times 10^{-7}}{2R}\left[\hat{k} + \sqrt{3}\,\hat{i}\right]$$

$$\therefore \quad |\vec{B}_{net}| = \frac{4\pi \times 10^{-7}}{2R}\sqrt{1+3} = \frac{4\pi \times 10^{-7}}{R}\text{ T}$$

Direction of $\vec{B}_{net}$ $\theta = \tan^{-1}\left(\frac{B_Q}{B_P}\right)$

$$= \tan^{-1}(\sqrt{3}) = \frac{\pi}{6}\text{ rad w.r.t. } z\text{-axis.}$$

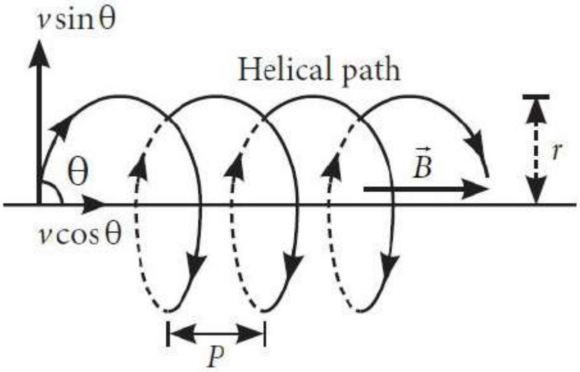
SECTION – E (Case Study Based Questions)

Questions 19 to 20 carry 4 marks each.

19. Helical Motion

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

If velocity v is at angle q to $\vec{B}$, component of velocity parallel to magnetic field (v cosθ) remains constant and component of velocity perpendicular to magnetic field (v sinθ) 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 = mvsin-θ/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.

(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) (i) only (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) √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 is 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 of proton = 1.67×10^{-27} kg)

(a) 0.053 m (b) 0.136 m (c) 0.157 m (d) 0.236 m

Ans.

(i) (d)

(ii) (a): Using, $qvB\sin\theta = \frac{mv^2}{r}$

$r \propto \frac{1}{\sin\theta}$ for the same values of m, v, q and B

$\therefore \quad \frac{r_A}{r_B} = \frac{\sin 90°}{\sin 30°} = 2$ or $r_A = 2r_B$ or $r_B < r_A$

(iii) (d): The radius of the helical path of the electron in the uniform magnetic field is

$$r = \frac{mv_\perp}{eB} = \frac{mv\sin\theta}{eB} = \frac{(2.4\times10^{-23}\text{ kg m/s})\times\sin 30°}{(1.6\times10^{-19}\text{ C})\times 0.15\text{ T}}$$

$$= 5\times10^{-4}\text{ m} = 0.5\times10^{-3}\text{ m} = 0.5\text{ mm}$$

(iv) (c): Here, $\vec{B} = 8.35\times10^{-2}\hat{i}$ T

$\vec{v} = 2\times10^5\hat{i} + 4\times10^5\hat{j}$ m/s, $m = 1.67\times10^{-27}$ kg

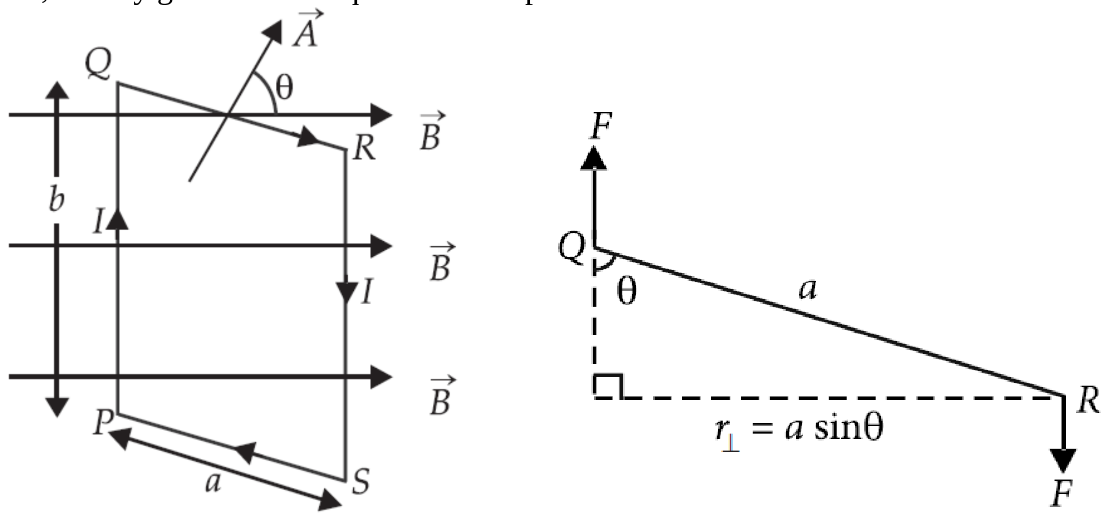
Pitch of the helix (*i.e.*, the linear distance moved along the magnetic field in one rotation) is given by

Pitch of the helix $= \frac{2\pi m v_{\|}}{qB}$

$$= \frac{2\times3.14\times1.67\times10^{-27}\times2\times10^5}{1.6\times10^{-19}\times8.35\times10^{-2}} = 0.157\text{ m}$$

20. Torque on a Rectangular Loop Placed in Uniform Magnetic Field

When a rectangular loop PQRS of sides '*a*' and '*b*' carrying current I is placed in uniform magnetic field B, such that area vector $\vec{A}$ makes an angle θ with direction of magnetic field, then forces on the arms QR and SP of loop are equal, opposite and collinear, thereby perfectly cancel each other, whereas forces on the arms PQ and RS of loop are equal and opposite but not collinear, so they give rise to torque on the loop.



Force on side PQ or RS of loop is F = IbB sin 90° = Ib B and perpendicular distance between two non-collinear forces is $r_\perp = a \sin\theta$

So, torque on the loop, t = IAB sinθ

In vector form torque, $\vec{\tau} = \vec{M} \times \vec{B}$

Where $\vec{M} = NI\vec{A}$ is called magnetic dipole moment of current loop and is directed in direction of area vector $\vec{A}$ i.e., normal to the plane of loop.

(i) A circular loop of area 1 cm^2, carrying a current of 10 A is placed in a magnetic field of 0.1 T perpendicular to the plane of the loop. The torque on the loop due to the magnetic field is

(a) zero (b) 10^{-4} N m (c) 10^{-2} N m (d) 1 N m

(ii) Relation between magnetic moment and angular velocity is

(a) $M \propto \omega$ (b) $M \propto \omega^2$ (c) $M \propto \sqrt{\omega}$ (d) none of these

(iii) A current loop in a magnetic field

(a) can be in equilibrium in two orientations, both the equilibrium states are unstable

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

(c) experiences a torque whether the field is uniform or non uniform in all orientations

(d) can be in equilibrium in one orientation.

(iv) The magnetic moment of a current I carrying circular coil of radius r and number of turns N varies as

(a) $1/r^2$ (b) $1/r$ (c) r (d) r^2

Ans.

(i) (a): Torque on a current carrying loop in magnetic field,

$$\tau = IBA \sin\theta$$

Here, $I = 10$ A, $B = 0.1$ T, $A = 1\ cm^2 = 10^{-4}\ m^2$, $\theta = 0°$

$\therefore \quad \tau = 10 \times 0.1 \times 10^{-4} \sin 0° = 0$

(ii) (a): Magnetic moment, $M = IA = I(\pi r^2) = \frac{q}{T} \times \pi r^2$

As $\omega = \frac{2\pi}{T} \quad \therefore \quad M = \frac{q\omega r^2}{2}$ or $M \propto \omega$

(iii) (b): When a current loop is placed in a magnetic field it experiences a torque. It is given by

$$\vec{\tau} = \vec{M} \times \vec{B}$$

where $\vec{M}$ is the magnetic moment of the loop and $\vec{B}$ is the magnetic field.

or $\tau = MB \sin\theta$ where θ is angle between M and B

When $\vec{M}$ and $\vec{B}$ are parallel (*i.e.* $\theta = 0°$) the equilibrium is stable and when they are antiparallel (*i.e.* $\theta = \pi$) the equilibrium is unstable.

(iv) (d): Magnetic moment, $M = NIA = NI\,\pi r^2$ *i.e.*, $M \propto r^2$