JEE Advanced

Single Correct Answer Type

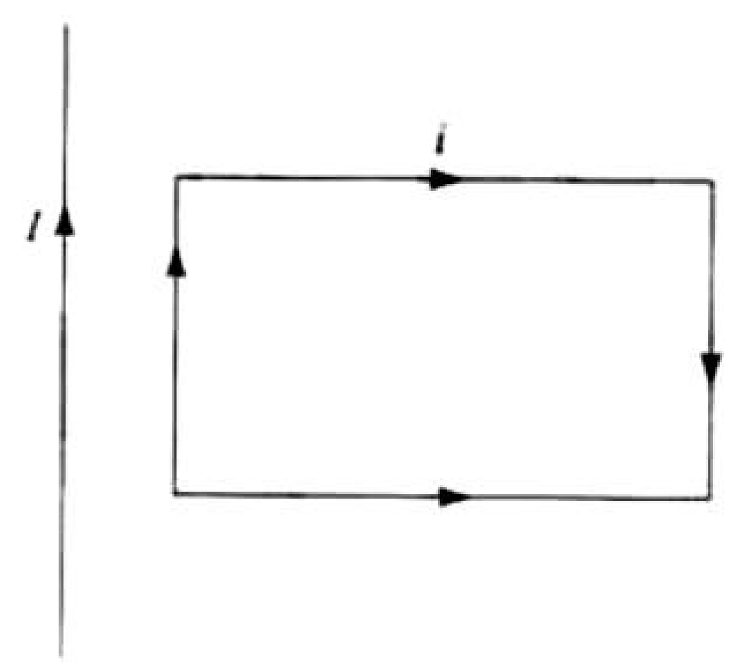
1. A magnetic needle is kept in a non-uniform magnetic field. It experiences

a. a force and a torque
b. a force but not a torque
c. a torque but not a force
d. neither a force nor a torque **(IIT-JEE 1982)**

2. A conducting circular loop of radius r carries a constant current i. It is placed in a uniform magnetic field $\vec{B}_0$ perpendicular to the plane of the loop. The magnetic force acting on the loop is

a. irB_0 **b.** $2\pi irB_0$ **c.** zero **d.** πirB_0
(IIT-JEE 1983)

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



a. rotate about an axis parallel to the wire
b. move away from the wire
c. move toward the wire
d. remain stationary **(IIT-JEE 1985)**

4. Two thin long parallel wires separated by a distance b are carrying a current I ampere each. The magnitude of the force per unit length exerted by one wire on the other is

a. $\frac{\mu_0 i^2}{b^2}$ **b.** $\frac{\mu_0 i^2}{2\pi b}$ **c.** $\frac{\mu_0 i}{2\pi b}$ **d.** $\frac{\mu_0 i}{2\pi b^2}$
(IIT-JEE 1986)

5. Two particles X and Y having equal charges, after being accelerated through the same potential difference, enter a region of uniform magnetic field and describe circular paths of radii R_1 and R_2, respectively. The ratio of the mass of X to that of Y is

a. $(R_1/R_2)^{1/2}$ **b.** R_2/R_1 **c.** $(R_1/R_2)^2$ **d.** R_1/R_2
(IIT-JEE 1988)

6. A current I flows along the length of an infinitely long, straight, thin walled pipe. Then

a. the magnetic field at all points inside the pipe is same, but not zero
b. the magnetic field at any point inside the pipe is zero
c. the magnetic field is zero only on the axis of the pipe
d. the magnetic field is different at different points inside the pipe **(IIT-JEE 1993)**

7. A battery is connected between two points A and B on the circumference of a uniform conducting ring of radius r and resistance R. One of the arcs AB of the ring subtends an angle θ at the center. The value of the magnetic induction at the center due to the current in the ring is

a. proportional to $2\,(180° - \theta)$
b. inversely proportional to r
c. zero, only if $\theta = 180°$
d. zero for all values of θ **(IIT-JEE 1995)**

8. A proton, a deuteron and an α-particle having the same kinetic energy are moving in circular trajectories in a constant magnetic field. If r_p, r_d and r_α denote, respectively, the radii of the trajectories of these particles, then

a. $r_\alpha = r_p < r_d$ **b.** $r_\alpha > r_d > r_p$
c. $r_\alpha = r_d > r_p$ **d.** $r_p = r_d = r_\alpha$
(IIT-JEE 1997)

9. Two particles, each of mass m and charge q, are attached to the two ends of a light rigid rod of length $2R$. The rod is rotated at constant angular speed about a perpendicular axis passing through its center. The ratio of the magnitudes of the magnetic moment of the system and its angular momentum about the center of the rod is

a. $q/2m$ **b.** q/m **c.** $2q/m$ **d.** $q/\pi m$
(IIT-JEE 1998)

10. Two very long, straight, parallel wires carry steady currents I and $-I$, respectively. The distance between the wires is d. At a certain instant of time, a point charge q is at a point equidistant from the two wires, in the plane of the wires. Its instantaneous velocity v is perpendicular to this plane. The magnitude of the force due to the magnetic field acting on the charge at this instant is

a. $\frac{\mu_0 Iqv}{2\pi d}$ **b.** $\frac{\mu_0 Iqv}{\pi d}$ **c.** $\frac{2\mu_0 Iqv}{\pi d}$ **d.** 0

(IIT-JEE 1998)

11. A charged particle is released from rest in a region of steady and uniform electric and magnetic fields which are parallel to each other. The particle will move in a

a. straight line **b.** circle
c. helix **d.** cycloid **(IIT-JEE 1999)**

12. A particle of charge q and mass m moves in a circular orbit of radius r with angular speed ω. The ratio of the magnitude of its magnetic moment to that of its angular momentum depends on

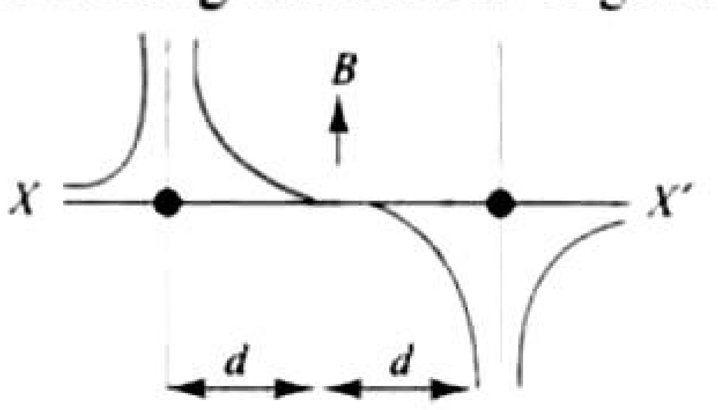
a. ω and q **b.** ω, q and m
c. q and m **d.** ω and m

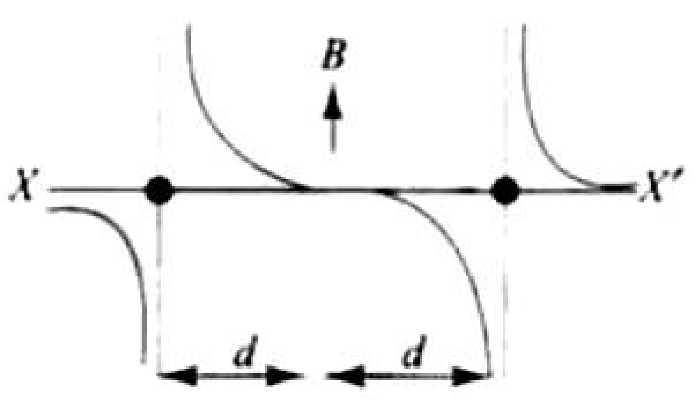
(IIT-JEE 2000)

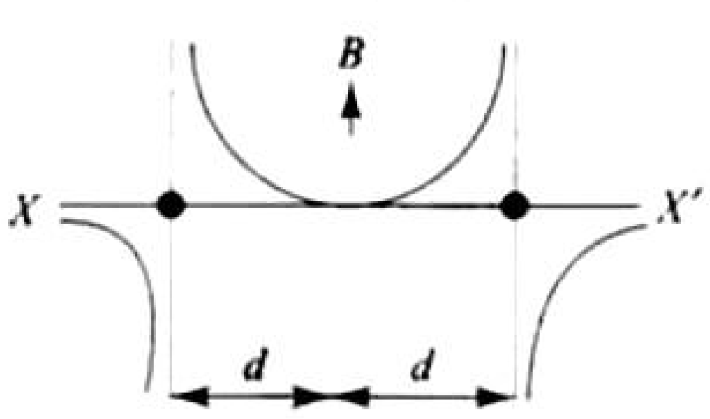
13. An ionized gas contains both positive and negative ions. If it is subjected simultaneously to an electric field along the $+x$ direction and a magnetic field along the $+z$ direction, then

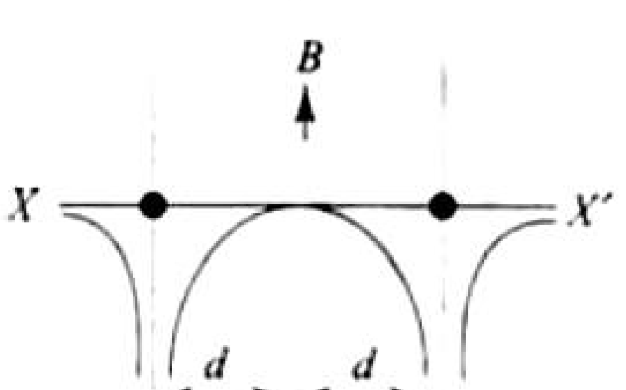
a. positive ions deflect towards $+y$ direction and negative ions towards $-y$ direction
b. all ions deflect towards $+y$ direction
c. all ions deflect towards $-y$ direction
d. positive ions deflect towards $-y$ direction and negative ions towards $+y$ direction **(IIT-JEE 2000)**

14. Two long parallel wires are at a distance $2d$ apart. They carry steady, equal currents flowing out of the plane of the paper, as shown (see figure). The variation of the magnetic field B along the line XX' is given by

a. 

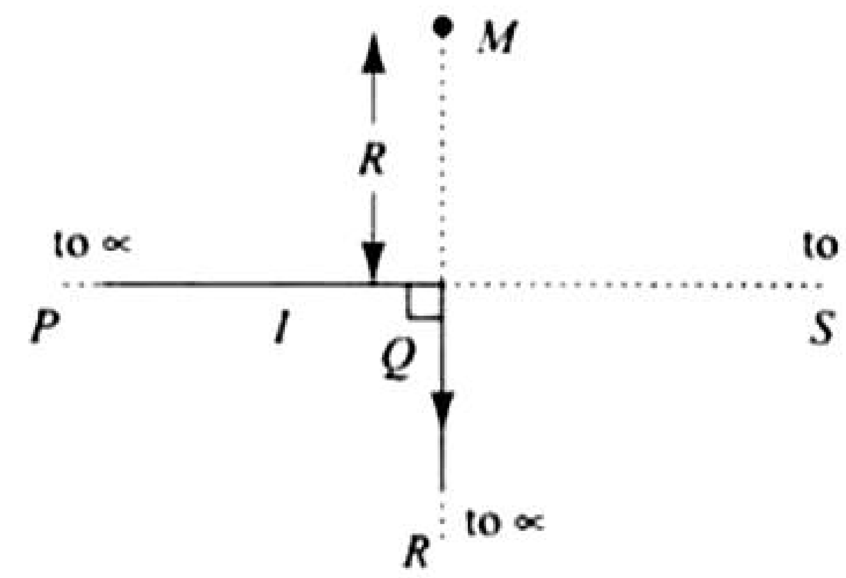
b. 

c. 

d. 

(IIT-JEE 2000)

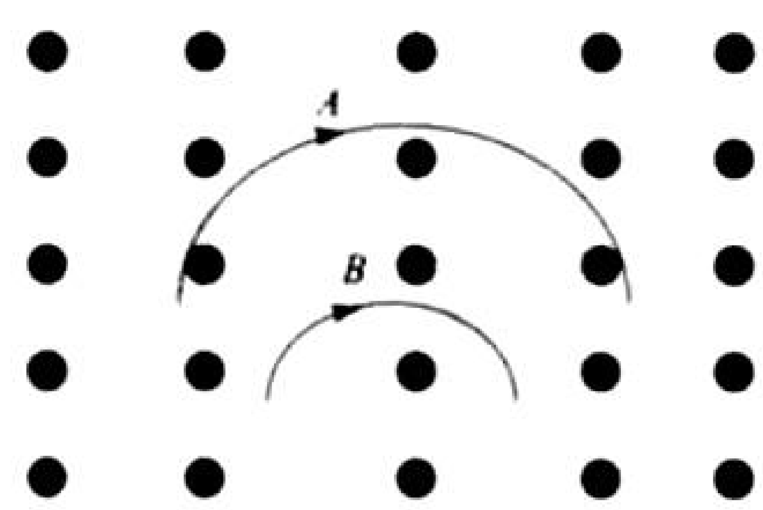
15. An infinitely long conductor PQR is bent to form a right angle as shown in the figure. A current I flows through PQR. The magnetic field due to this current at the point M is H_1. Now, another infinitely long straight conductor QS is connected to Q so that current is $I/2$ in QR as well as in QS, the current in PQ remaining unchanged. The magnetic field at M is now H_2. The ratio H_1/H_2 is given by



a. 1/2 **b.** 1 **c.** 2/3 **d.** 2

(IIT-JEE 2000)

16. Two particles A and B of masses m_A and m_B, respectively, and having the same charge are moving in a plane. A uniform magnetic field exists perpendicular to this plane. The speeds of the particles are v_A and v_B, respectively and the trajectories are as shown in the figure. Then



a. $m_A v_A < m_B v_B$
b. $m_A v_A > m_B v_B$
c. $m_A < m_B$ and $v_A < v_B$
d. $m_A = m_B$ and $v_A = v_B$ **(IIT-JEE 2001)**

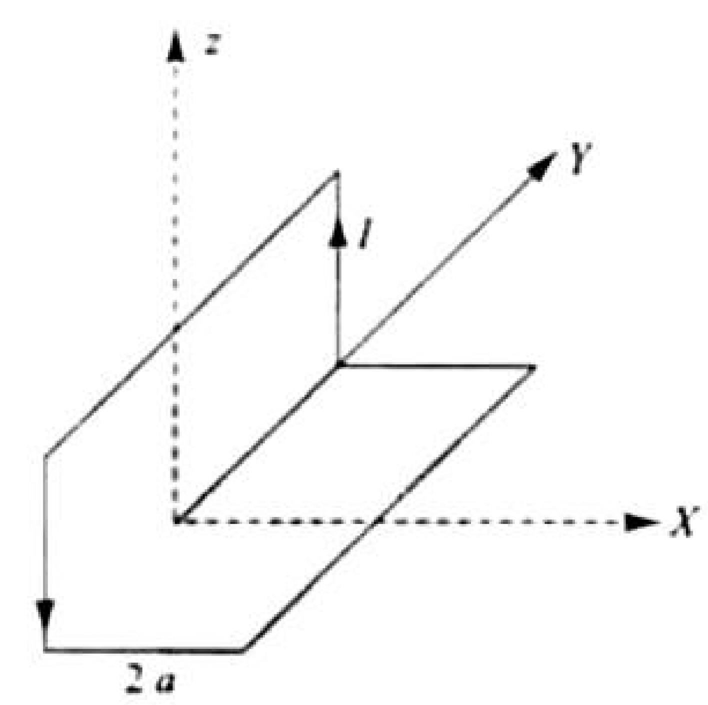
17. A non-planar loop of conducting wire carrying a current I is placed as shown in the figure. Each of the straight sections of the loop is of length $2a$. The magnetic field due to this loop at the point $P(a, 0, a)$ points in the direction

a. $\frac{1}{\sqrt{2}}(-\hat{j}+\hat{k})$

b. $\frac{1}{\sqrt{3}}(-\hat{j}+\hat{k}+\hat{i})$

c. $\frac{1}{\sqrt{3}}(\hat{j}+\hat{k}+\hat{i})$

d. $\frac{1}{\sqrt{2}}(\hat{i}+\hat{k})$



(IIT-JEE 2001)

18. A coil having N turns is wound tightly in the form of a spiral with inner and outer radii a and b, respectively. When a current I passes through the coil, the magnetic field at the center is

a. $\frac{\mu_0 NI}{b}$ **b.** $\frac{2\mu_0 NI}{a}$

c. $\frac{\mu_0 NI}{2(b-a)}\ln\frac{b}{a}$ **d.** $\frac{\mu_0 I^N}{2(b-a)}\ln\frac{b}{a}$

(IIT-JEE 2001)

19. A particle of mass m and charge q moves with a constant velocity v along the positive x direction. It enters a region containing a uniform magnetic field B directed along the

negative z direction, extending from $x = a$ to $x = b$. The minimum value of v required so that the particle can just enter the region $x > b$ is

a. $\frac{qbB}{m}$ b. $\frac{q(b-a)B}{m}$

c. $\frac{qaB}{m}$ d. $\frac{q(b+a)B}{2m}$

(IIT-JEE 2002)

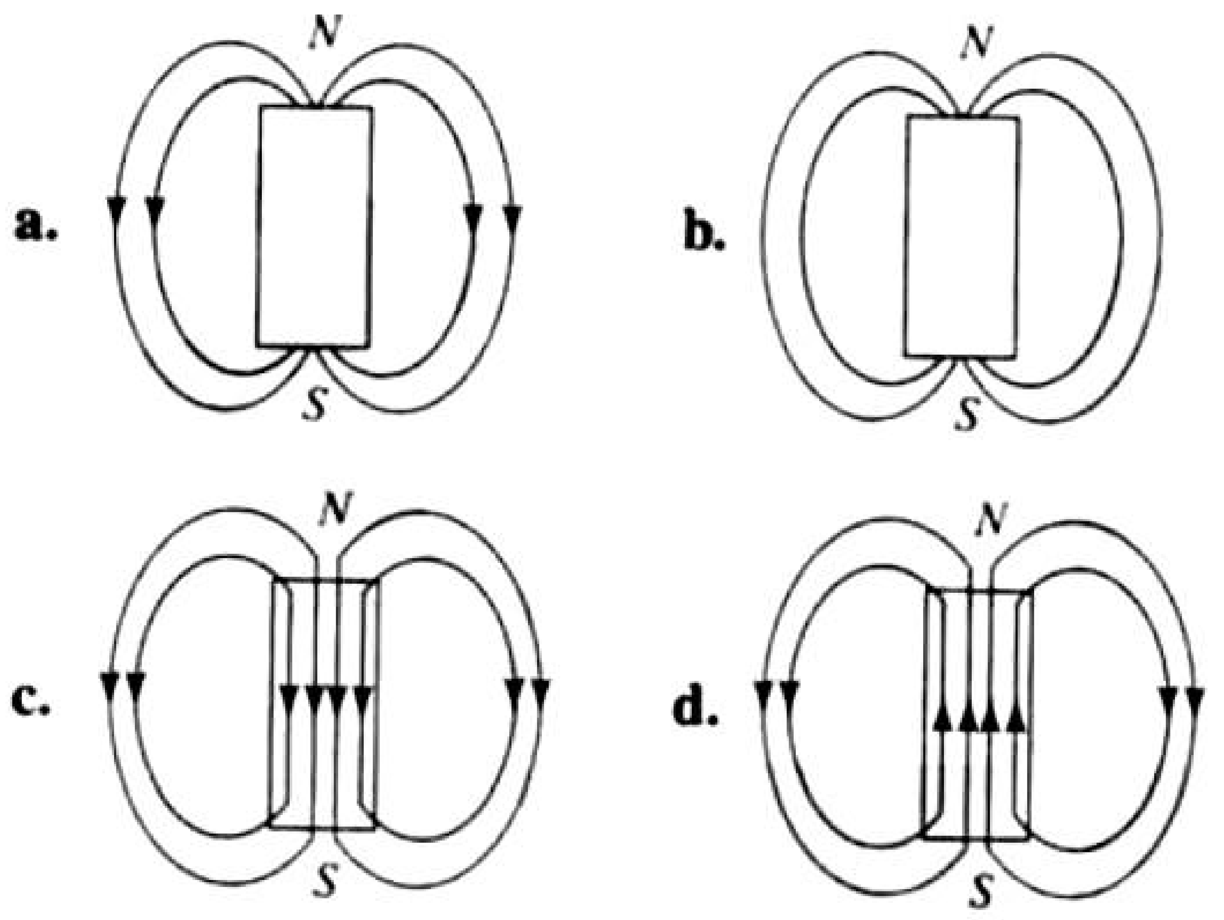
20. A long straight wire along the z-axis carries a current I in the negative z-direction. The magnetic vector field $\vec{B}$ at a point having coordinates (x, y) in the $z = 0$ plane is

a. $\frac{\mu_0 I(y\hat{i} - x\hat{j})}{2\pi(x^2 + y^2)}$ b. $\frac{\mu_0 I(x\hat{i} + y\hat{j})}{2\pi(x^2 + y^2)}$

c. $\frac{\mu_0 I(x\hat{j} - y\hat{i})}{2\pi(x^2 + y^2)}$ d. $\frac{\mu_0 I(x\hat{i} - y\hat{j})}{2\pi(x^2 + y^2)}$

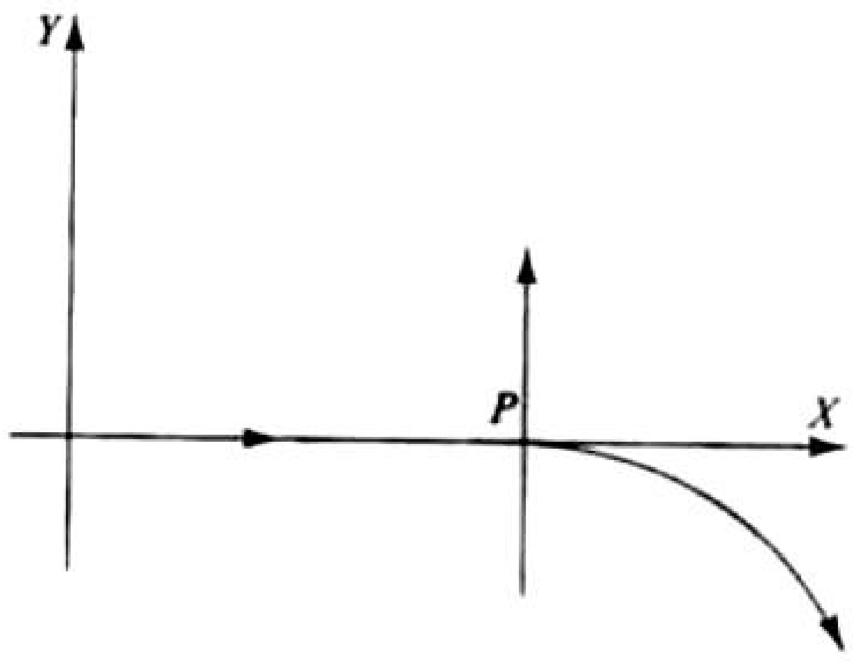
(IIT-JEE 2002)

21. The magnetic field lines due to a bar magnet are correctly shown in



(IIT-JEE 2002)

22. For a positively charged particle moving in a x–y plane initially along the x-axis, there is a sudden change in its path due to the presence of electric and/or magnetic fields beyond P. The curved path is shown in the x–y plane and is found to be non-circular. Which one of the following combinations is possible ?

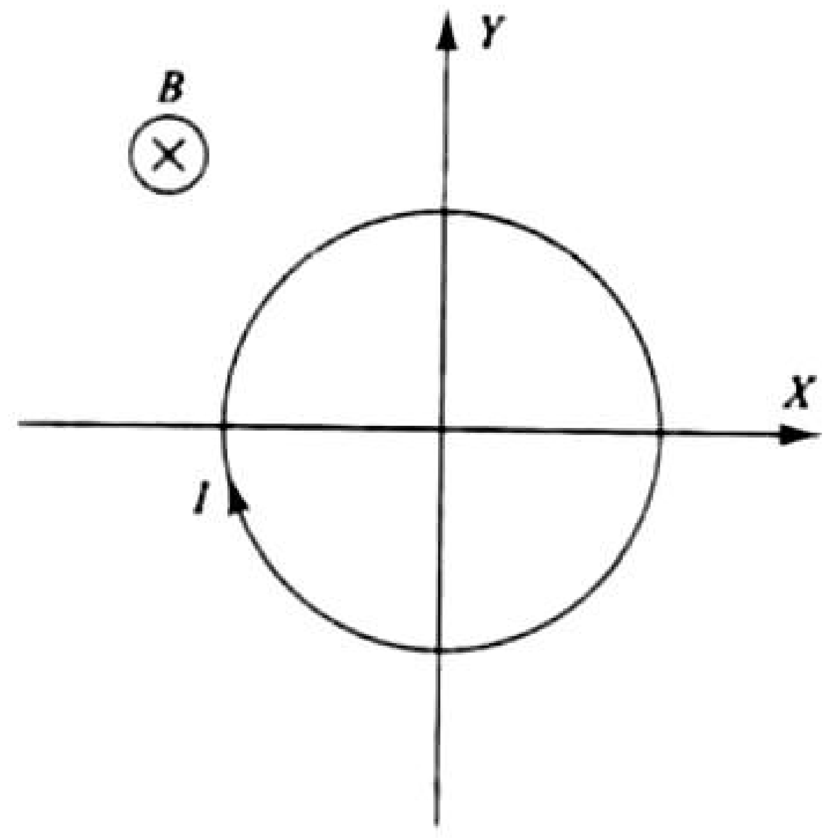


a. $\vec{E} = 0; \vec{B} = b\hat{i} + c\hat{k}$ b. $\vec{E} = a\hat{i}; \vec{B} = c\hat{k} + a\hat{i}$

c. $\vec{E} = 0; \vec{B} = c\hat{j} + b\hat{k}$ d. $\vec{E} = a\hat{i}; \vec{B} = c\hat{k} + b\hat{j}$

(IIT-JEE 2003)

23. A conducting loop carrying a current I is placed in a uniform magnetic field pointing into the plane of the paper as shown in the figure. The loop will have a tendency to



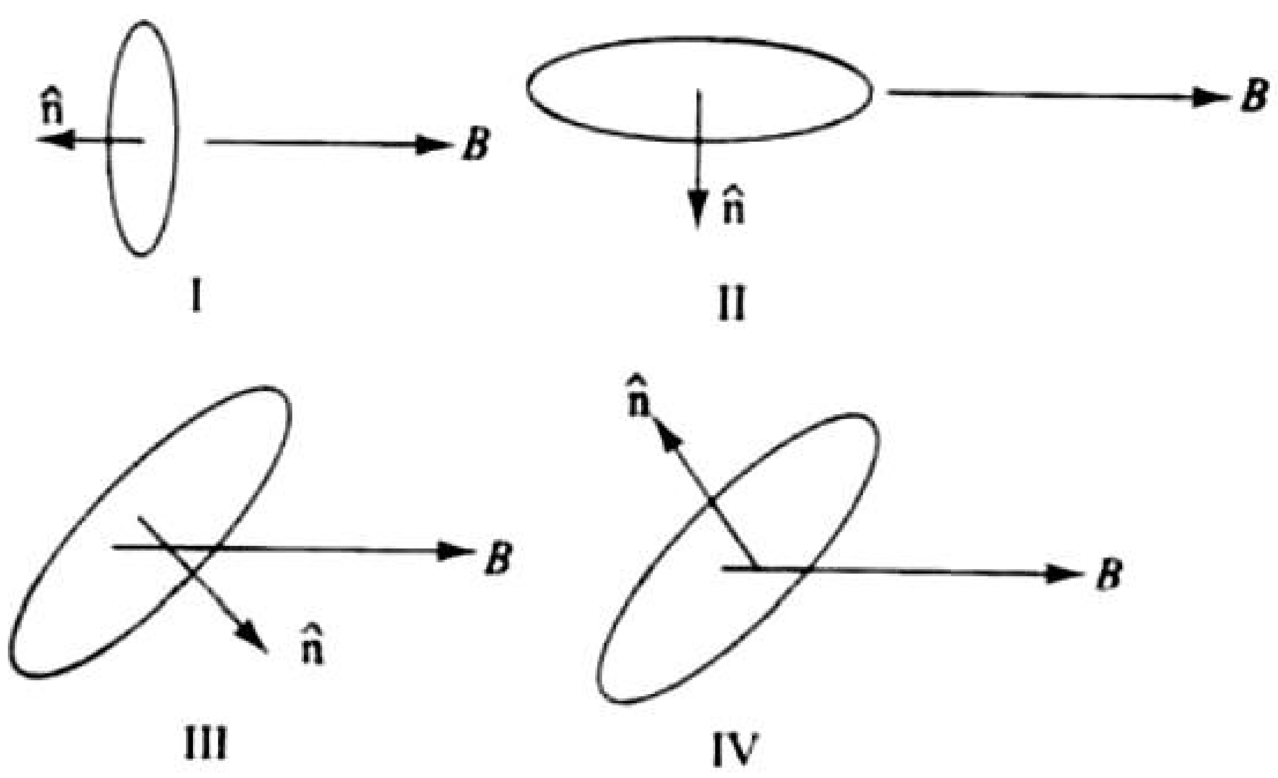
a. contract

b. expand

c. move toward +ve x-axis

d. move toward –ve x-axis **(IIT-JEE 2003)**

24. A current carrying loop is placed in a uniform magnetic field in four different orientations; I, II, III, and IV, arrange them in the decreasing order of potential energy.

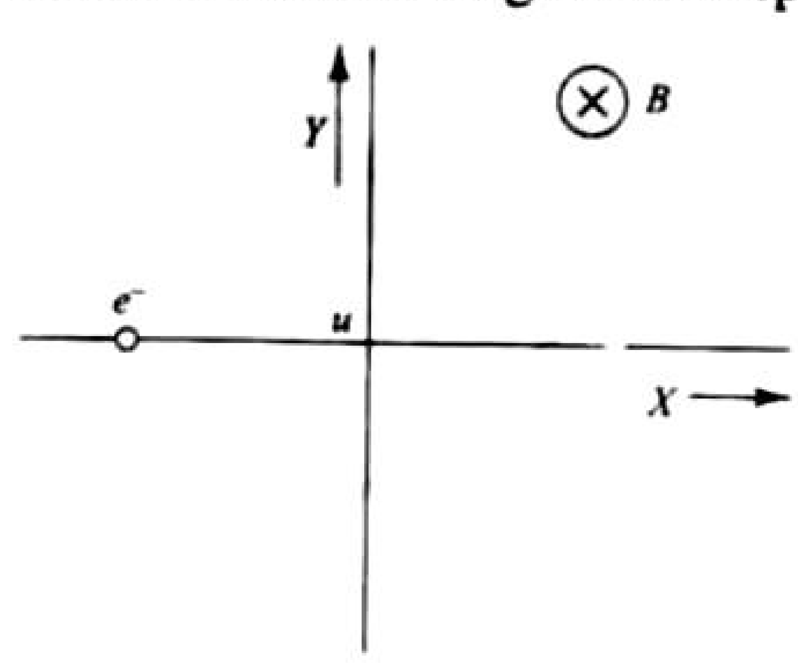


a. I > III > II > IV b. I > II > III > IV

c. I > IV > II > III d. III > IV > I > II

(IIT-JEE 2003)

25. An electron travelling with a speed u along the positive x-axis enters into a region of magnetic field where $B = -B_0 \hat{k}$ $(x > 0)$. It comes out of the region with speed v. Then

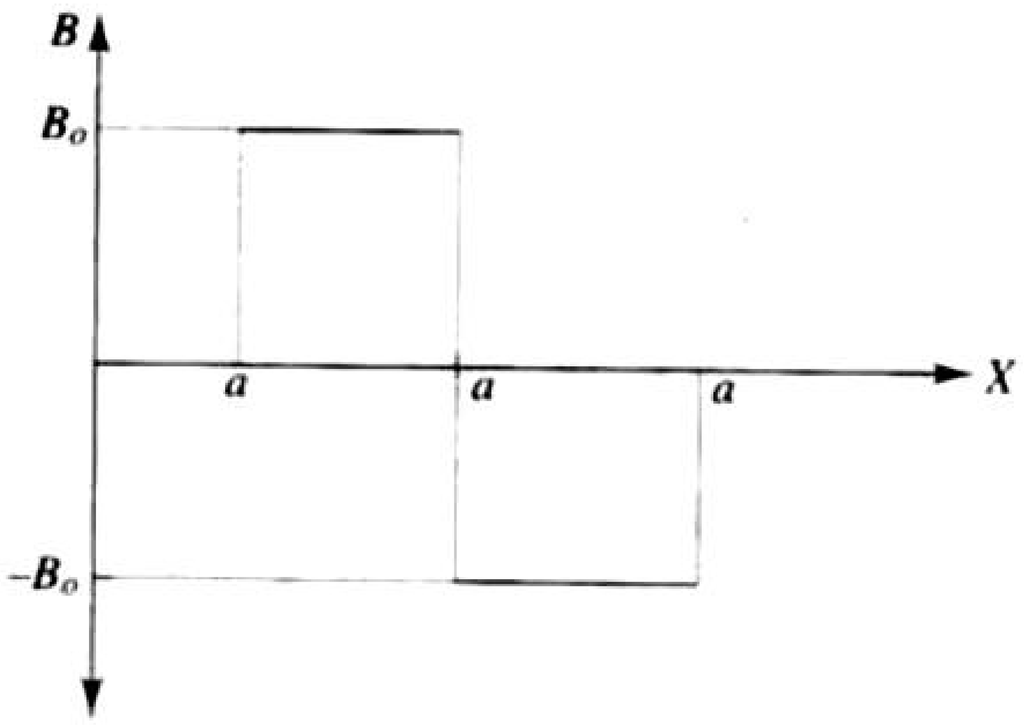


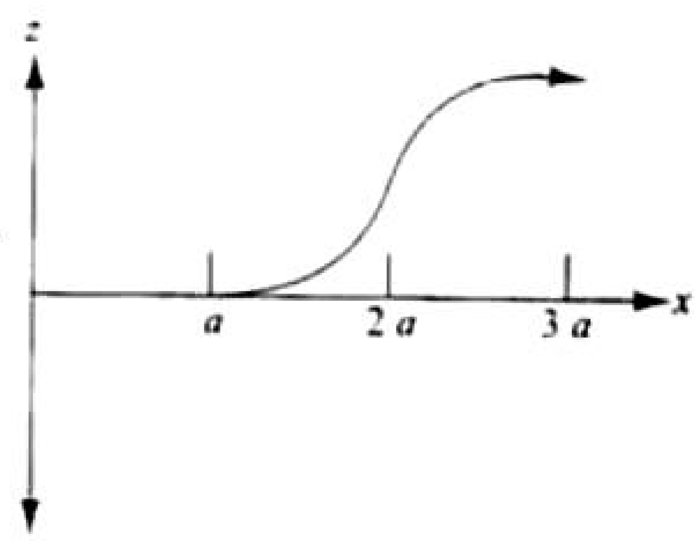
a. $v = u$ at $y > 0$ b. $v = u$ at $y < 0$

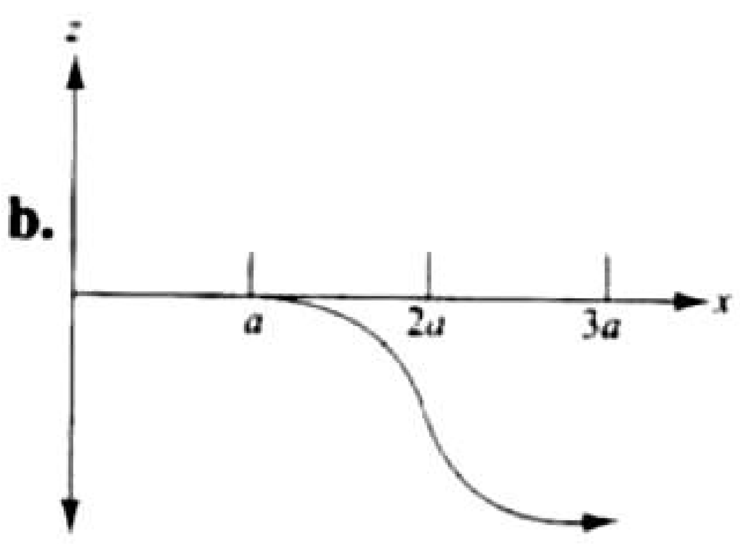
c. $v > u$ at $y > 0$ d. $v > u$ at $y < 0$

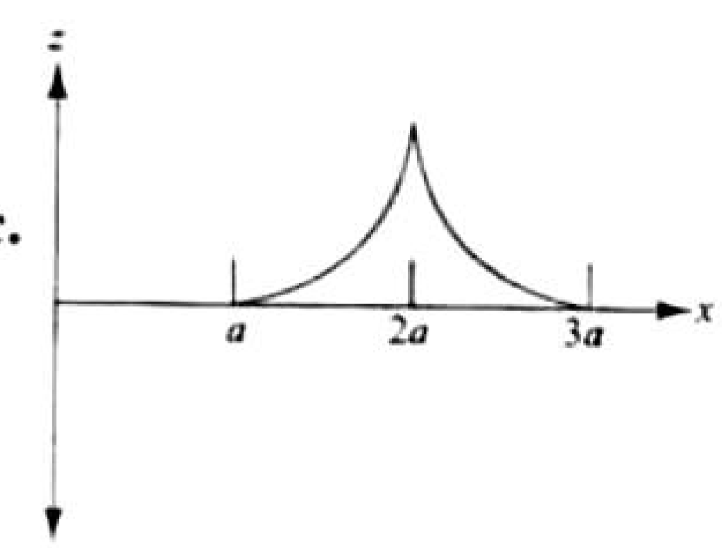
(IIT-JEE 2004)

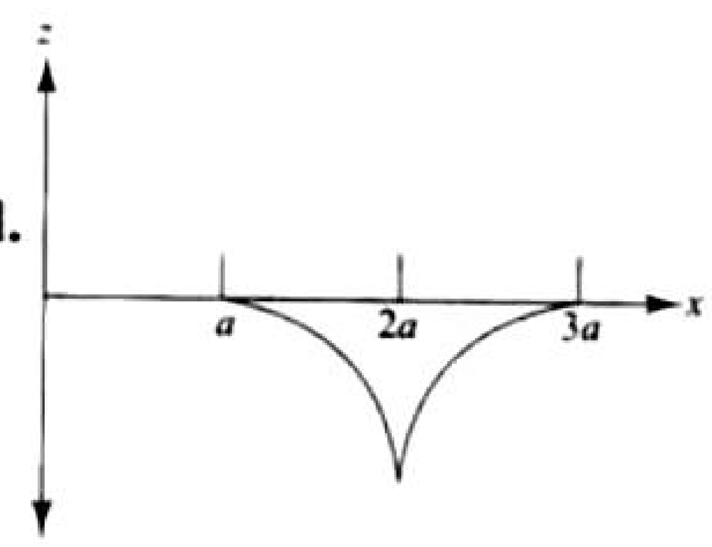
26. A magnetic field $\vec{B} = B_0\hat{j}$ exists in the region $a < x < 2a$ and $\vec{B} = -B_0\hat{j}$, in the region $2a < x < 3a$, where B_0 is a positive constant. A positive point charge moving with a velocity $\vec{v} = v_0\hat{i}$, where v_0 is a positive constant, enters the magnetic field at $x = a$. The trajectory of the charge in this region can be like



a. 

b. 

c. 

d. 

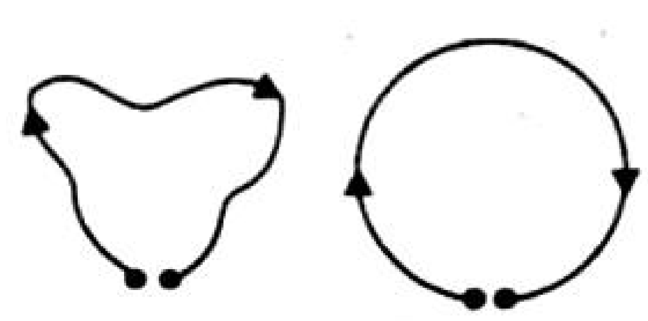
(IIT-JEE 2007)

27. A steady current I goes through a wire loop PQR having shape of a right angle triangle with $PQ = 3x$, $PR = 4x$, and $QR = 5x$. If the magnitude of the magnetic field at P due to this loop is $k\left(\frac{\mu_0 I}{48\pi x}\right)$, the value of k is

a. 5 **b.** 8 **c.** 7 **d.** 10

(IIT-JEE 2009)

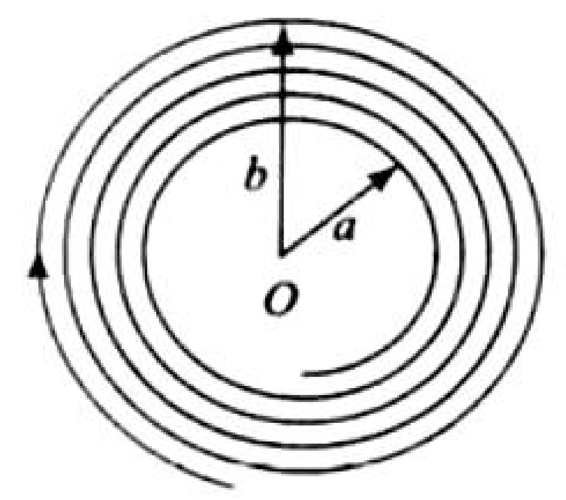
28. A thin flexible wire of length L is connected to two adjacent fixed points and carries a current I in the clockwise direction, as shown in the figure. When the system is put in a uniform magnetic field of strength B going into the plane of the paper, the wire takes the shape of a circle. The tension in the wire is



a. IBL **b.** $\frac{IBL}{\pi}$

c. $\frac{IBL}{2\pi}$ **d.** $\frac{IBL}{4\pi}$ **(IIT-JEE 2010)**

29. A long insulated copper wire is closely wound as a spiral of N turns. The spiral has inner radius a and outer radius b. The spiral lies in the X–Y plane and a steady current I flows through the wire. The Z-component of the magnetic field at the center of the spiral is



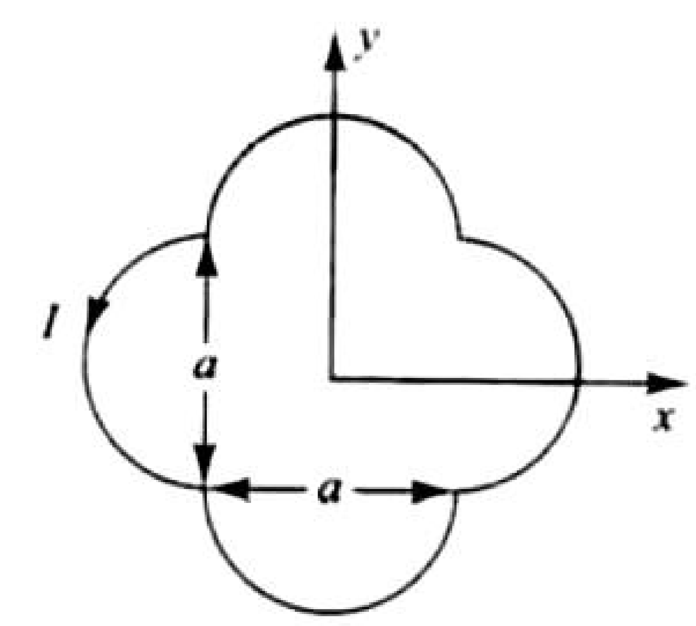
a. $\frac{\mu_0 N I}{2(b-a)}\ln\left(\frac{b}{a}\right)$

b. $\frac{\mu_0 N I}{2(b-a)}\ln\left(\frac{b+a}{b-a}\right)$

c. $\frac{\mu_0 N I}{2b}\ln\left(\frac{b}{a}\right)$

d. $\frac{\mu_0 N I}{2b}\ln\left(\frac{b+a}{b-a}\right)$ **(IIT-JEE 2011)**

30. A loop carrying current I lies in the x–y plane as shown in figure. The unit vector $\hat{k}$ is coming out of the plane of the paper. The magnetic moment of the current loop is



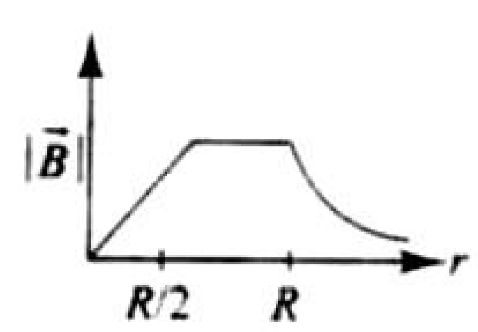
a. $a^2 I\hat{k}$

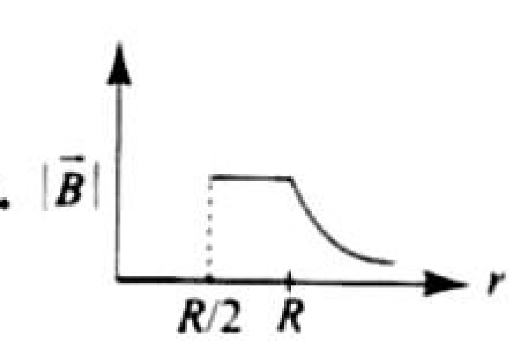
b. $\left(\frac{\pi}{2}+1\right)a^2 I\hat{k}$

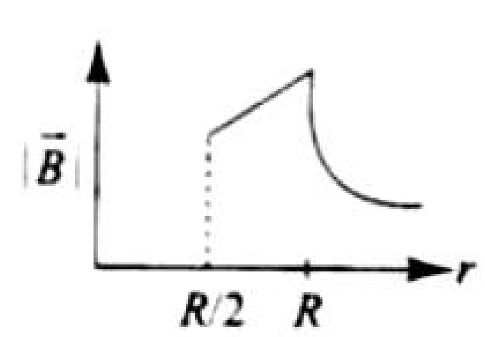
c. $-\left(\frac{\pi}{2}+1\right)a^2 I\hat{k}$

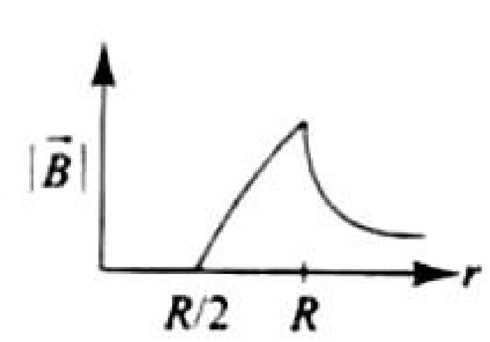
d. $(2\pi+1)a^2 I\hat{k}$ **(IIT-JEE 2012)**

31. An infinitely long hollow conducting cylinder with inner radius $R/2$ and outer radius R carries a uniform current density along length. The magnitude of the magnetic field, $|\vec{B}|$ as a function of the radial distance r from the axis is best represented by

a. 

b. 

c. 

d. 

(IIT-JEE 2012)

Multiple Correct Answers Type

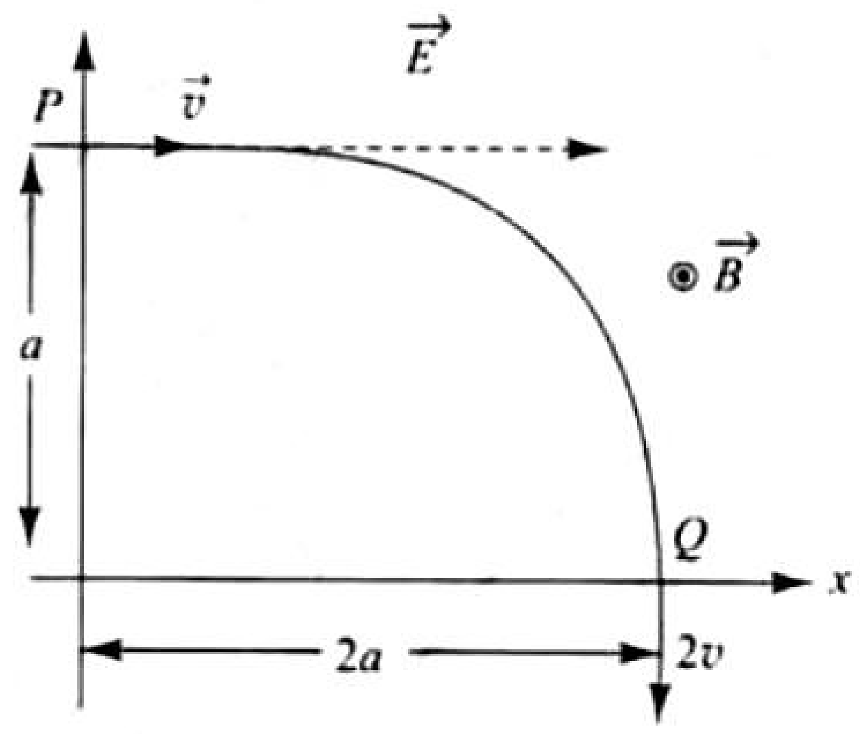
1. A proton moving with a constant velocity passes through a region of space without any change in its velocity. If E and B represent the electric and magnetic fields respectively, this region of space may have

a. $E = 0, B = 0$ **b.** $E = 0, B \neq 0$

c. $E \neq 0, B = 0$ **d.** $E \neq 0, B \neq 0$

(IIT-JEE 1985)

2. A particle of charge $+q$ and mass m moving under the influence of a uniform electric field $E\hat{i}$ and uniform magnetic field $B\hat{k}$ follows a trajectory from P to Q as shown in the figure. The velocities at P and Q are $v\hat{i}$ and $-2v\hat{j}$ which of the following statement(s) is/are correct?



a. $E = \frac{3}{4}\left[\frac{mv^2}{qa}\right]$

b. Rate of work done by the electric field at P is $\frac{3}{4}\left[\frac{mv^3}{a}\right]$

c. Rate of work done by the electric field at P is zero

d. Rate of work done by both the fields at Q is zero

(IIT-JEE 1991)

3. H^+, He^+, and O^{2+} all having the same kinetic energy pass through a region in which there in a uniform magnetic field perpendicular to their velocity. The masses of H^+, He^+, and O^{2+} are 1, 4, and 16 amu, respectively. Then,

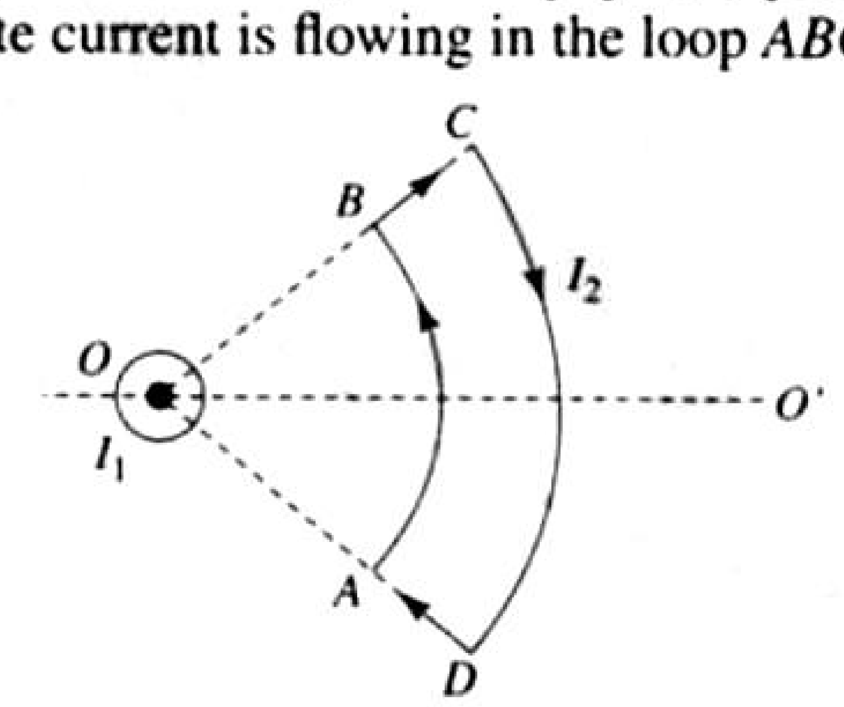
a. H^+ will be deflected most

b. O^{2+} will be deflected most

c. He^+ and O^{2+} will be deflected equally

d. All will be deflected equally **(IIT-JEE 1994)**

4. A long current carrying wire, carrying current such that it is flowing out from the plane of paper, is placed at O. A steady state current is flowing in the loop $ABCD$. Then,



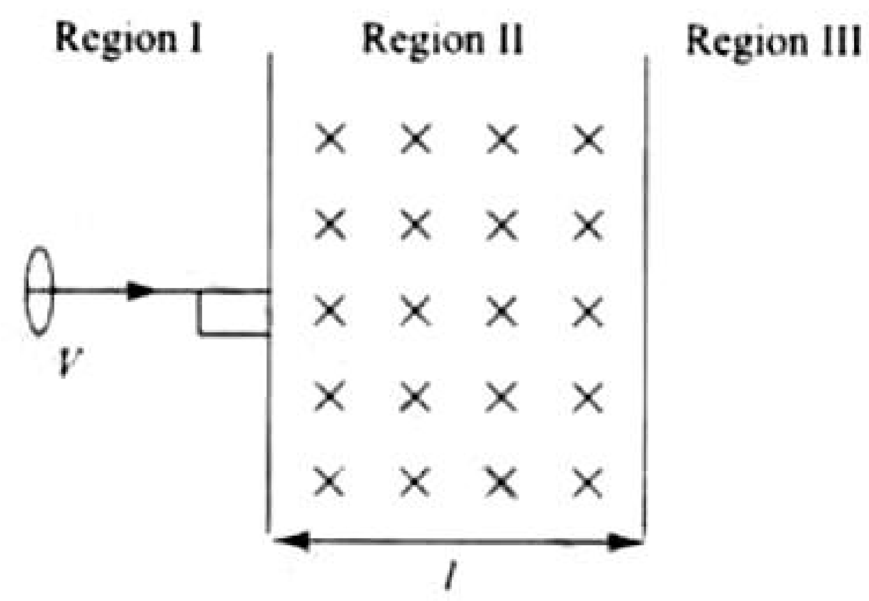
a. the net force is zero

b. the net torque is zero

c. as seen from O, the loop will rotate in clockwise direction along axis OO'

d. as seen from O, the loop will rotate in anticlockwise direction along axis OO' **(IIT-JEE 2006)**

5. A particle of mass m and charge q, moving with velocity V enters Region II normal to the boundary as shown in the figure. Region II has a uniform magnetic field B perpendicular to the plane of the paper. The length of the Region II is l. Choose the correct choice(s).



a. The particle enters Region III only if its velocity $V > \frac{qlB}{m}$

b. The particle enters Region III only if its velocity $V < \frac{qlB}{m}$

c. Path length of the particle in Region II is maximum when velocity $V = \frac{qlB}{m}$

d. Time spent in Region II is same for any velocity V as long as the particle returns to Region I

(IIT-JEE 2008)

6. An electron and a proton are moving on straight parallel paths with same velocity. They enter a semi-infinite region of uniform magnetic field perpendicular to the velocity. Which of the following statement(s) is/are true?

a. They will never come out of the magnetic field region.

b. They will come out travelling along parallel paths.

c. They will come out at the same time.

d. They will come out at different times.

(IIT-JEE 2011)

7. Consider the motion of a positive point charge in a region where are simultaneous uniform electric and magnetic field $\vec{E} = E_0\hat{j}$ and $\vec{B} = B_0\hat{j}$. At time $t = 0$, this charge has velocity $\vec{v}$ in the x-y plane, making an angle θ with the x-axis. Which of the following option(s) is(are) correct for time $t > 0$?

a. If $\theta = 0°$, the charge moves in a circular path in the x-z plane

b. If $\theta = 0°$, the charge undergoes helical motion with constant pitch along the y-axis

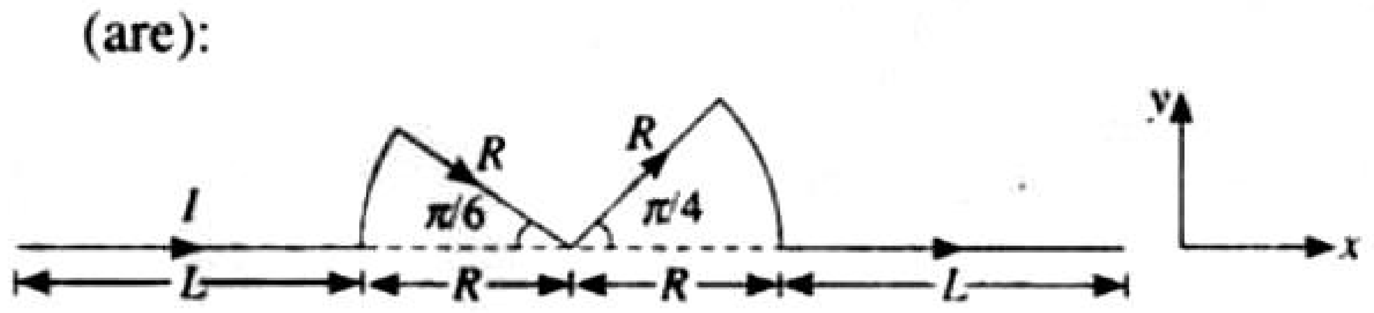
c. If $\theta = 10°$, the charge undergoes helical motion with its pitch increasing with time, along the y-axis

d. If $\theta = 90°$, the charge undergoes linear but accelerated motion along the y-axis **(IIT-JEE 2012)**

8. A particle of mass M and positive charge Q, moving with a constant velocity $u_1 = 4\hat{i}\ \text{m s}^{-1}$, enters a region of uniform static magnetic field normal to the x-y plane. The region of the magnetic field extends from $x = 0$ to $x = L$ for all values of y. After passing through this region, the particle emerges on the other side after 10 milliseconds with a velocity $\vec{u}_2 = 2(\sqrt{3}\hat{i} + \hat{j})\ \text{m s}^{-1}$. The correct statement(s) is (are)
   a. The direction of the magnetic field is $-z$ direction.
   b. The direction of the magnetic field is $+z$ direction.
   c. The magnitude of the magnetic field $\dfrac{50\pi M}{3Q}$ units
   d. The magnitude of the magnetic field is $\dfrac{100\pi M}{3Q}$ units
   (JEE Advanced 2013)

9. A steady current I flows along an infinitely long hollow cylindrical conductor of radius R. This cylinder is placed coaxially inside an infinite solenoid of radius $2R$. The solenoid has n turns per unit length and carries a steady current I. Consider a point P at a distance r from the common axis. The correct statement(s) is(are)
   a. In the region $0 < r < R$, the magnetic field is non-zero
   b. In the region $R < r < 2R$, the magnetic field is along the common axis.
   c. In the region $R < r < 2R$, the magnetic field is tangential to the circle of radius r, centered on the axis.
   d. In the region $r > 2R$, the magnetic field is non-zero.
   (JEE Advanced 2013)

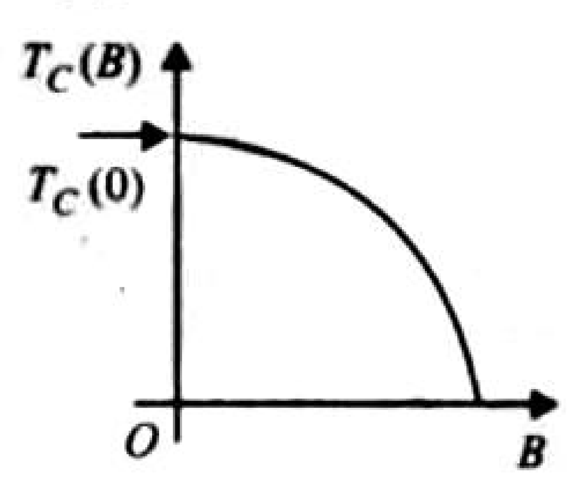
10. A conductor (shown in the figure) carrying constant current I is kept in the x-y plane in a uniform magnetic field $\vec{B}$. If F is the magnitude of the total magnetic force acting on the conductor, then the correct statement(s) is (are):



   a. If $\vec{B}$ is along $\hat{z}$, $F \propto (L + R)$
   b. If $\vec{B}$ is along $\hat{x}$, $F = 0$
   c. If $\vec{B}$ is along $\hat{y}$, $F \propto (L + R)$
   d. If $\vec{B}$ is along $\hat{z}$, $F = 0$ **(JEE Advanced 2015)**

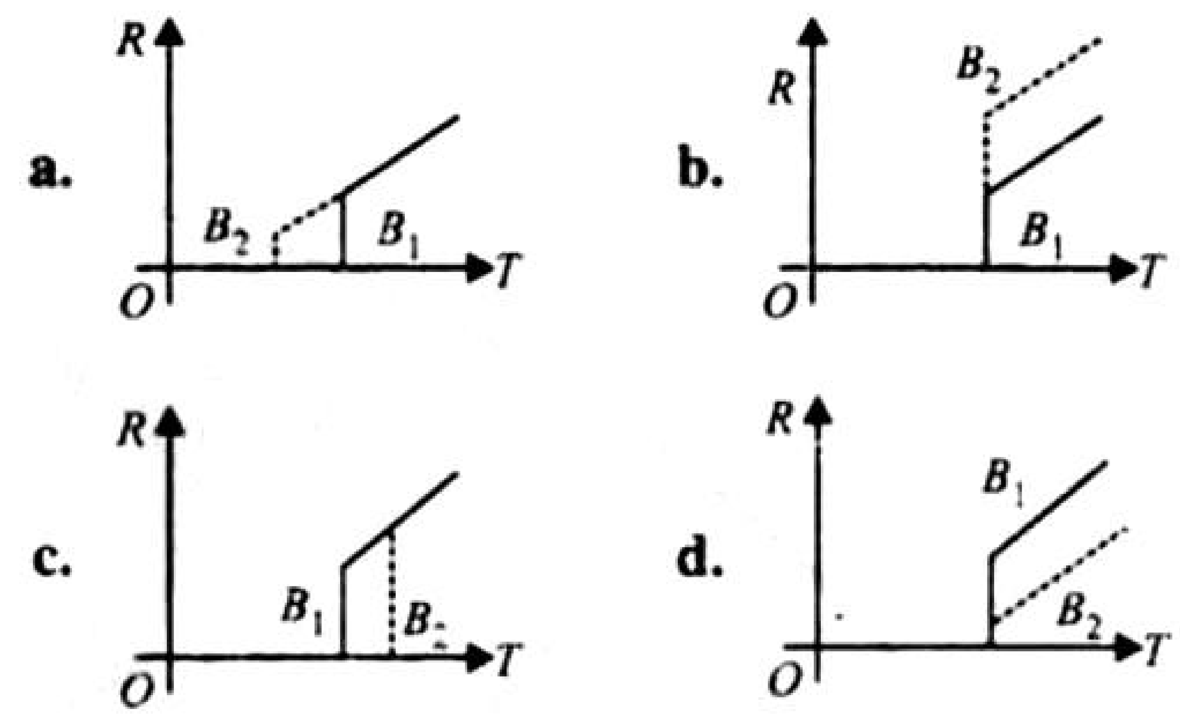
Linked Comprehension Type

Paragraph for Questions 1 and 2



Electrical resistance of certain materials, known as superconductors, changes abruptly from a nonzero value to zero as their temperature is lowered below a critical temperature $T_c(0)$. An interesting property of superconductors is that their critical temperature becomes smaller than $T_c(0)$ if they are placed in a magnetic field, i.e., the critical temperature $T_c(B)$ is a function of the magnetic field strength B. The dependence of $T_c(B)$ on B is shown in the figure. **(IIT-JEE 2010)**

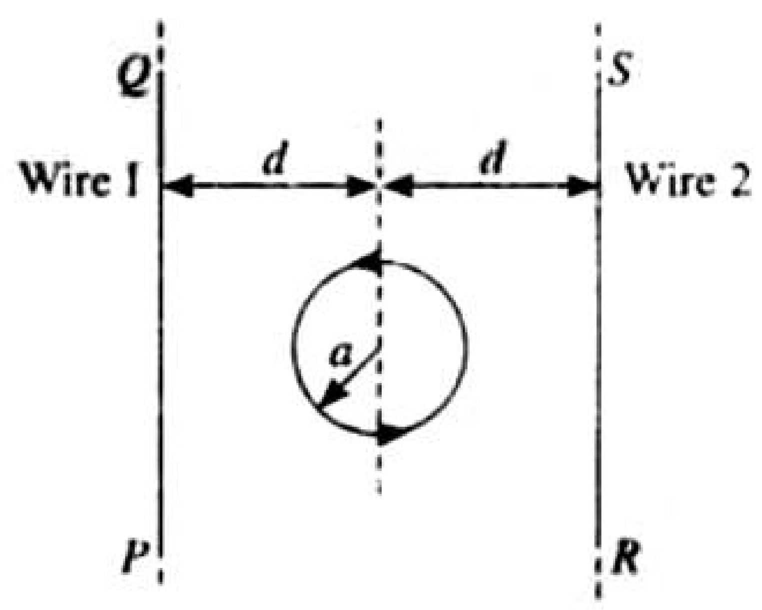
1. In the graphs below, the resistance R of a superconductor is shown as a function of its temperature T for two different magnetic fields B_1 (solid line) and B_2 (dashed line). If B_2 is larger than B_1, which of the following graphs shows the correct variation of R with T in these fields?



2. A superconductor has $T_c(0) = 100$ K. When a magnetic field of 7.5 T is applied, its T_c decreases to 75 K. For this material one can definitely say that when
   a. $B = 5$ T, $T_c(B) = 80$ K
   b. $B = 5$ T, 75 K $< T_c(B) <$ 100 K
   c. $B = 10$ T, 75K $< T_c(B) <$ 100 K
   d. $B = 10$ T, $T_c = 70$K

Paragraph for Questions 3 and 4

The figure shows a circular loop of radius a with two long parallel wires (numbered 1 and 2) all in the plane of the paper. The distance of each wire from the centre of the loop is d. The loop and the wires are carrying the same current I. The current in the loop is in the counterclockwise direction if seen from above.



(JEE Advanced 2014)

3. When $d \approx a$ but wires are not touching the loop, it is found that the net magnetic field on the axis of the loop is zero at a height h above the loop. In that case
   a. current in wire 1 and wire 2 is the direction PQ and RS, respectively and $h \approx a$
   b. current in wire 1 and wire 2 is the direction PQ and SR, respectively and $h \approx a$
   c. current in wire 1 and wire 2 is the direction PQ and SR, respectively and $h \approx 1.2a$
   d. current in wire 1 and wire 2 is the direction PQ and RS, respectively and $h \approx 1.2a$

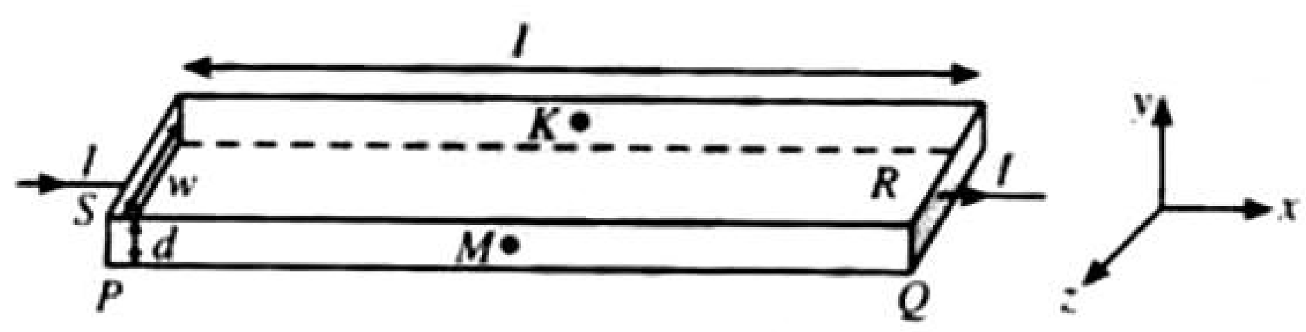
4. Consider $d >> a$, and the loop is rotated about its diameter parallel to the wires by 30° from the position shown in the figure. If the currents in the wires are in the opposite directions, the torque on the loop at its new position will be (assume that the net field due to the wires is constant over the loop)

a. $\frac{\mu_0 I^2 a^2}{d}$ b. $\frac{\mu_0 I^2 a^2}{2d}$

c. $\frac{\sqrt{3}\mu_0 I^2 a^2}{d}$ d. $\frac{\sqrt{3}\mu_0 I^2 a^2}{2d}$

Paragraph for Questions 5 and 6

In a thin rectangular metallic strip a constant current I flows along the positive x-direction, as shown in the figure. The length, width and thickness of the strip are l, w and d, respectively.



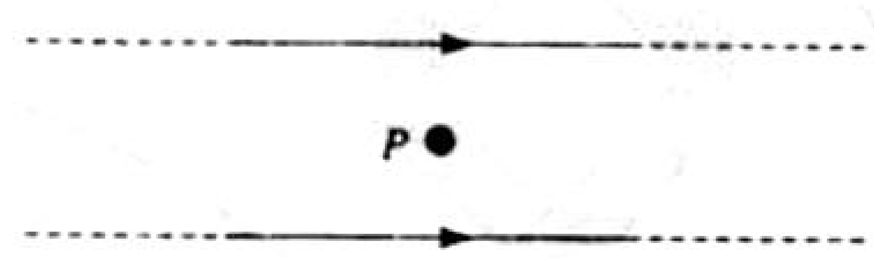
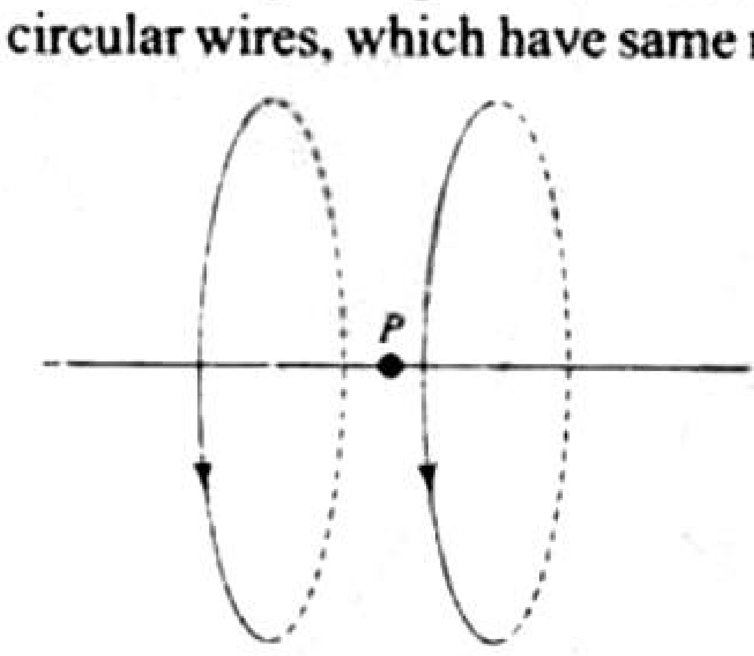
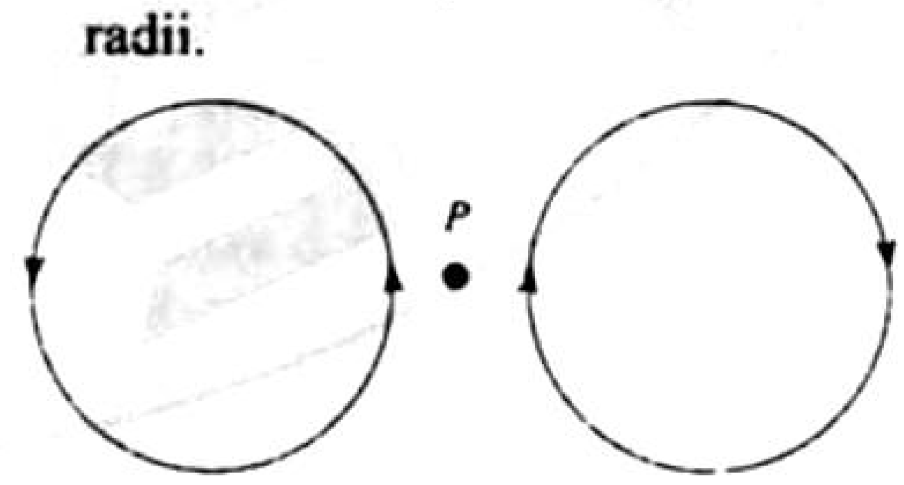
A uniform magnetic field $\vec{B}$ is applied on the strip along the positive y-direction. Due to this, the charge carriers experience a net deflection along the z-direction. This results in accumulation of charge carriers on the surface $PQRS$ and is appearance of equal and opposite charges on the face opposite to $PQRS$. A potential difference along the z-direction is thus developed. Charge accumulation continues until the magnetic force is balanced by the electric force. The current is assumed to be uniformly distributed on the cross section of the strip and carried by electrons. **(JEE Advanced 2015)**

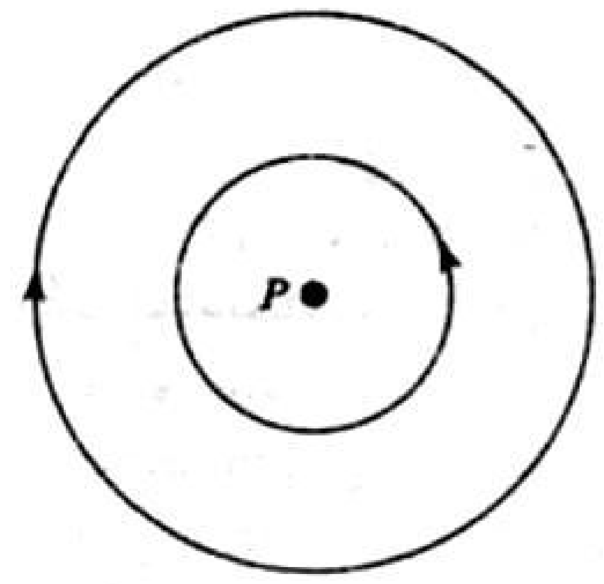
5. Consider two different metallic strips (1 and 2) of the same material. Their lengths are the same, width are w_1 and w_2 and thicknesses are d_1 and d_2, respectively. Two points K and M are symmetrically located on the opposite faces parallel to the x-y plane (see figure). V_1 and V_2 are the potential differences between K and M in strips 1 and 2, respectively. Then, for a given current I flowing through them in a given magnetic field strength B, the correct statement(s) is (are)
   a. If $w_1 = w_2$ and $d_1 = 2d_2$, then $V_2 = 2V_1$
   b. If $w_1 = w_2$ and $d_1 = 2d_2$, then $V_2 = V_1$
   c. If $w_1 = 2w_2$ and $d_1 = d_2$, then $V_2 = 2V_1$
   d. If $w_1 = 2w_2$ and $d_1 = d_2$, then $V_2 = V_1$

6. Consider two different metallic strips (1 and 2) of the same dimensions (length l, width w and thickness d) with carrier densities n_1 and n_2, respectively. Strip 1 is placed in magnetic field B_1 and strip 2 is placed in magnetic field B_2, both along positive y-directions. Then V_1 and V_2 are the potential differences developed between K and M in strips 1 and 2, respectively. Assuming that the current I is the same for both the strips, the correct option(s) is (are)
   a. If $B_1 = B_2$ and $n_1 = 2n_2$, then $V_2 = 2V_1$
   b. If $B_1 = B_2$ and $n_1 = 2n_2$, then $V_2 = V_1$
   c. If $B_1 = 2B_2$ and $n_1 = n_2$, then $V_2 = 0.5V_1$
   d. If $B_1 = 2B_2$ and $n_1 = n_2$, then $V_2 = V_1$

Matching Column Type

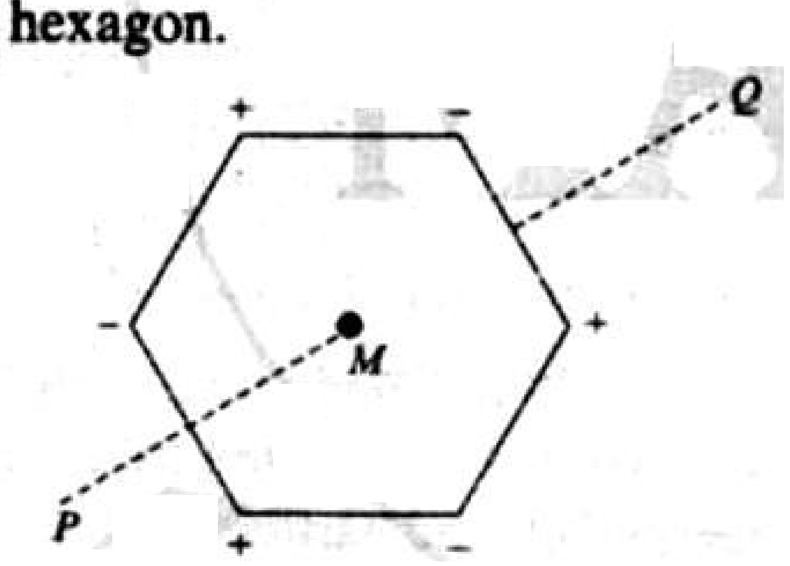
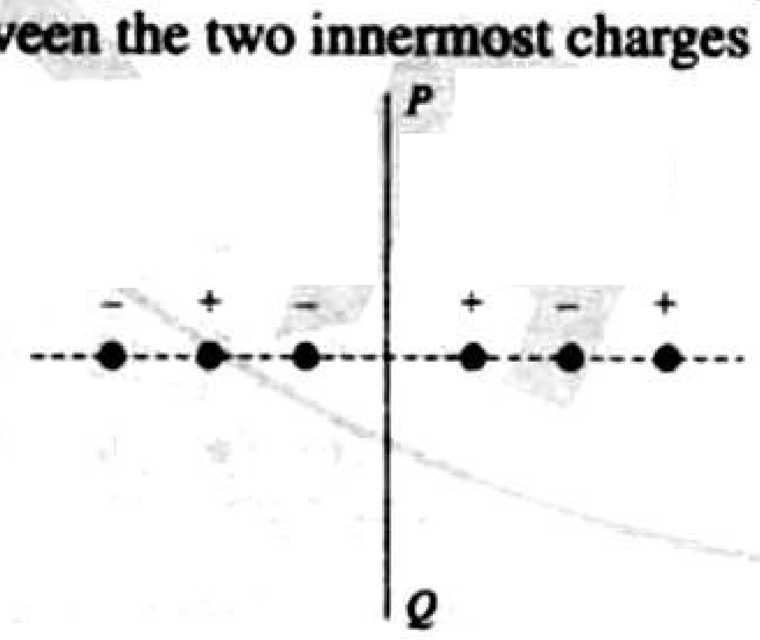
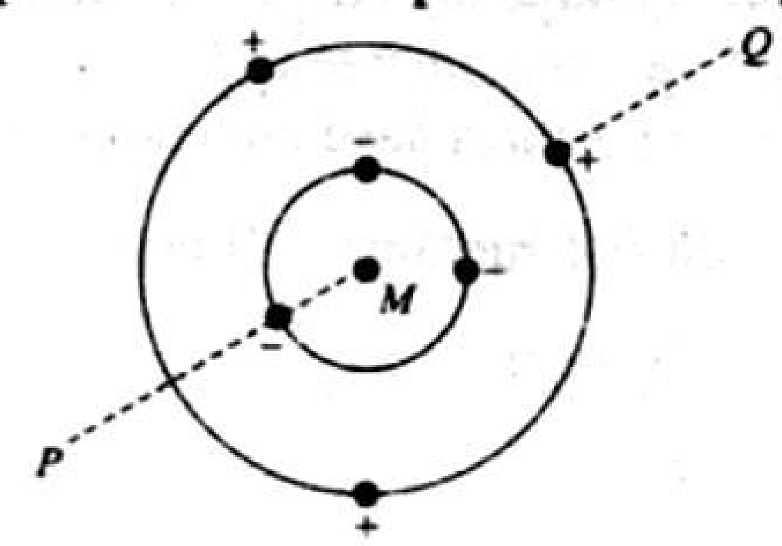
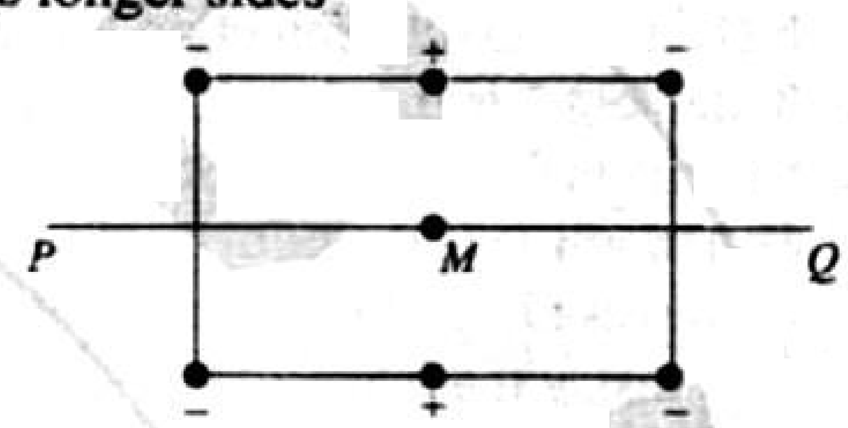
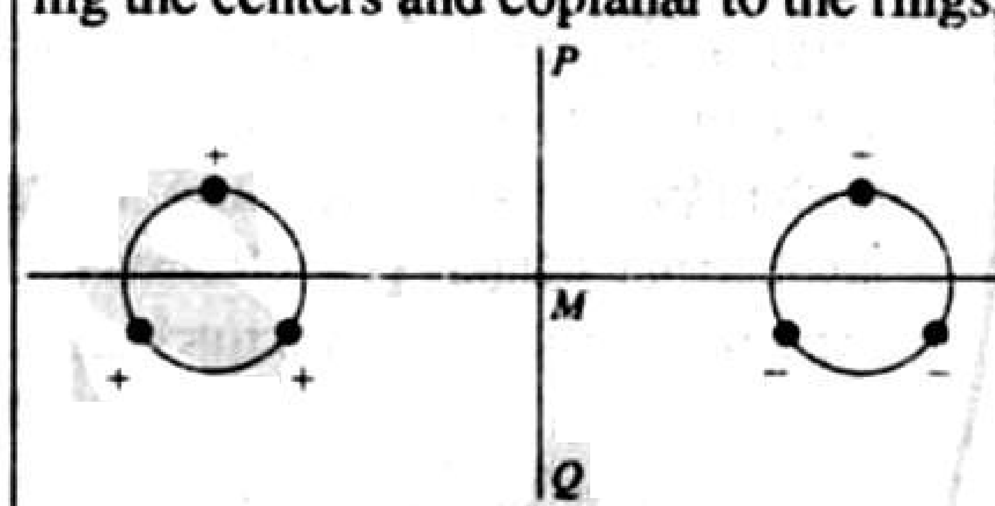
1. Two wires, each carrying a steady current I, are shown in four configuration in Column I. Some of the resulting effects are described in Column II. Match the statements in Column I with statements in Column II.

Column I	Column II
i. Point P is situated midway between the wires. 	a. The magnetic fields (B) at P due to the currents in the wires are in the same direction.
ii. Point P is situated at the midpoint of the line joining the centers of the circular wires, which have same radii. 	b. The magnetic fields (B) at P due to the currents in the wires are in opposite directions.
iii. Point P is situated at the midpoint of the line joining the center of the circular wires, which have same radii. 	c. There is no magnetic field at P.

iv. Point P is situated at the common center of the wires. 	**d.** The wires repel each other.

(IIT-JEE 2007)

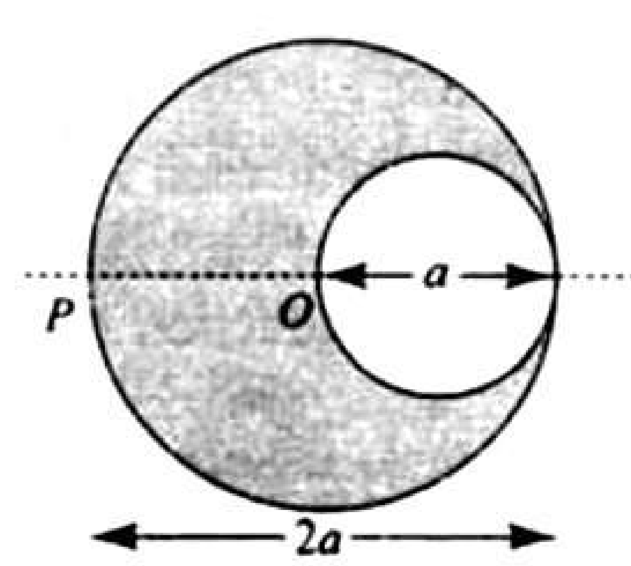
2. Six point charges, each of the same magnitude q, are arranged in different manners as shown in Column II. In each case, point M and line PQ passing through M are shown. Let E be the electric field and V be the electric potential at M (potential at infinity is zero) due to the given charge distribution when it is at rest. Now the whole system is set into rotation with a constant angular velocity about the line PQ. Let B be the magnetic field at M and μ be the magnetic moment of the system in this condition. Assume each rotating charge to be equivalent to a steady urrent.

Column I		Column II	
i.	$E=0$	**a.**	Charges are at the corners of a regular hexagon. M is at the center of the hexagon. PQ is perpendicular to the plane of the hexagon. 
ii.	$V\neq 0$	**b.**	Charges are on a line perpendicular to PQ at equal intervals. M is the midpoint between the two innermost charges 
iii.	$B=0$	**c.**	Charges are placed on two coplanar insulating rings at equal intervals. M is the common center of the rings. PQ is perpendicular to the plane of the rings 
iv.	$\mu\neq 0$	**d.**	Charges are placed at the corners of a rectangle of sides a and $2a$ and at the midpoints of the longer sides. M is at the center of the rectangle. PQ is parallel to the longer sides 
		e.	Charges are placed on two coplanar, identical insulating rings at equal intervals. M is the midpoint between the centers of the rings. PQ is perpendicular to the line joining the centers and coplanar to the rings. 

(IIT-JEE 2009)

Integer Answer Type

1. A cylindrical cavity of diameter a exists inside a cylinder of diameter $2a$ as shown in the figure. Both the cylinder and the cavity are infinitely long. A uniform current density J flows along the length. If the magnitude of the magnetic field at point P is given by $\frac{N}{12}\mu_0$ aJ, then the value of N is **(IIT-JEE 2012)**



2. Two parallel wires in the plane of the paper are distance X_0 apart. A point charge is moving with speed u between the wires in the same plane at a distance X_1 from one of the wires. When the wires carry current of magnitude I in the same direction, the radius of curvature of the path of the point charge is R_1 In contrast, if the currents I in the two wires have directions opposite to each other, the radius of curvature of the path is R_2. If $\frac{X_0}{X_1} = 3$, the value of $\frac{R_1}{R_2}$ is **(JEE Advanced 2014)**

Assertion-Reasoning Type

Mark your answer as

a. Statement 1 is true, Statement 2 is true; Statement 2 is the correct explantion for Statement 1.

b. Statement 1 is true, Statement 2 is true; Statement 2 is NOT the correct explantion for Statement 1.

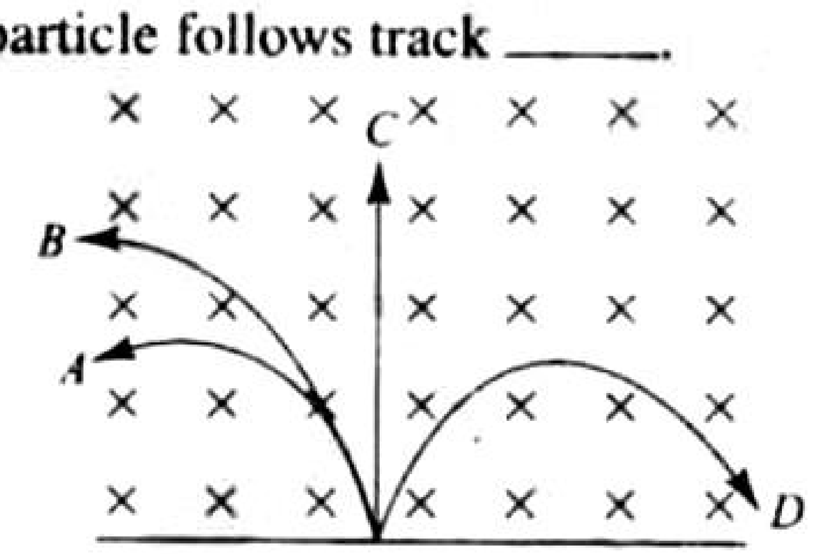
c. Statement 1 is true but Statement 2 is false.

d. Statement 1 is false but Statement 2 is true.

1. **Statement 1:** The sensitivity of a moving coil galvanometer is increased by placing a suitable magnetic material as a core inside the coil.
   Statement 2: Soft iron has a high magnetic permeability and cannot be easily magnetized or demagnetized. **(IIT-JEE 2008)**

Fill in the Blanks Type

1. A neutron, a proton, an electron and an alpha particle enter a region of constant magnetic field with equal velocities. The magnetic field is along the inward normal to the plane of the paper. The tracks of the particles are labelled in the figure. The electron follows track ______ and the alpha particle follows track ______.

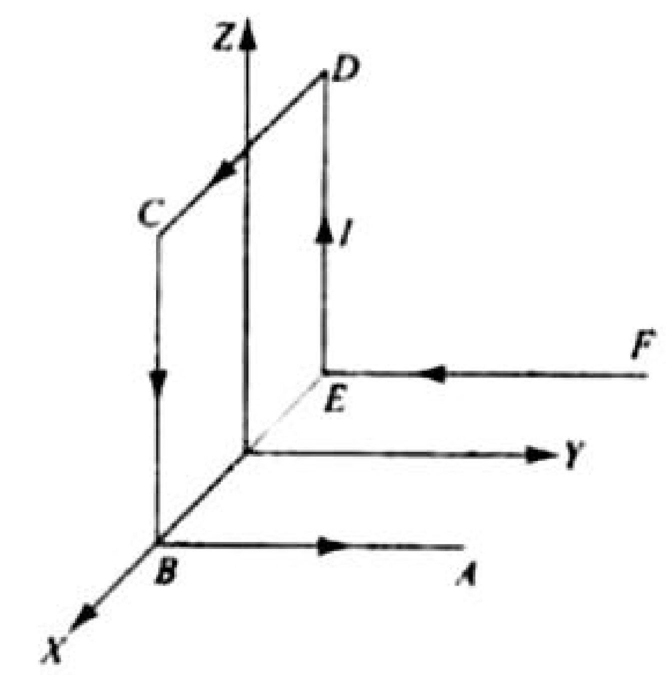


(IIT-JEE 1984)

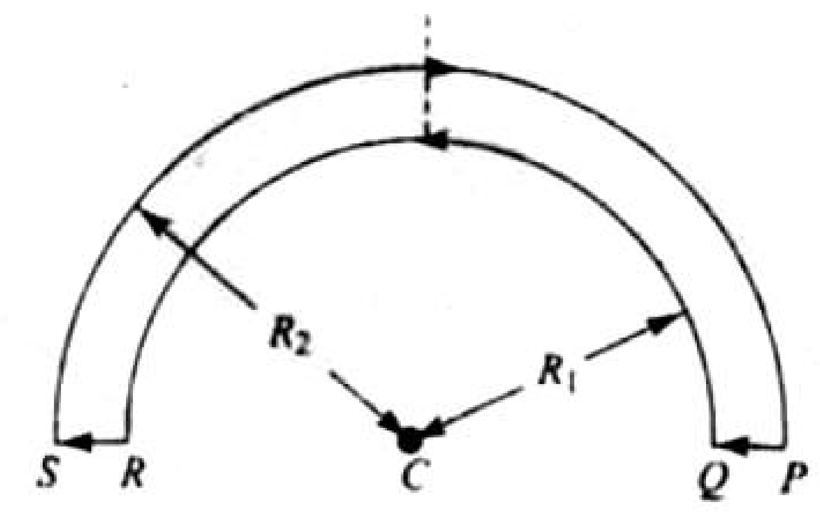
2. A wire of length L meters, carrying a current i amperes, is bent in the form of a circle. The magnitude of its magnetic moment is ______ in MKS units. **(IIT-JEE 1987)**

3. In a hydrogen atom, the electron moves in an orbit of radius 0.5 Å making 10^{16} revolutions per second. The magnetic moment associated with the orbital motion of the electron is ______. **(IIT-JEE 1988)**

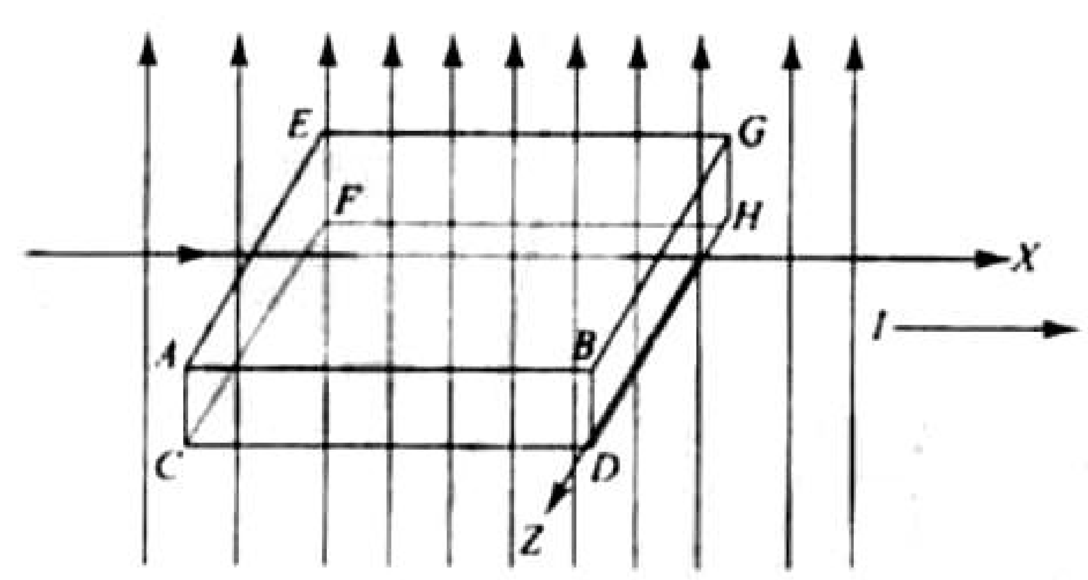
4. A wire $ABCDEF$ (with each side of length L) bent as shown in the figure and carrying a current I is placed in a uniform magnetic induction B parallel to the positive y-direction. The force experienced by the wire is ______ in the ______ direction. **(IIT-JEE 1990)**



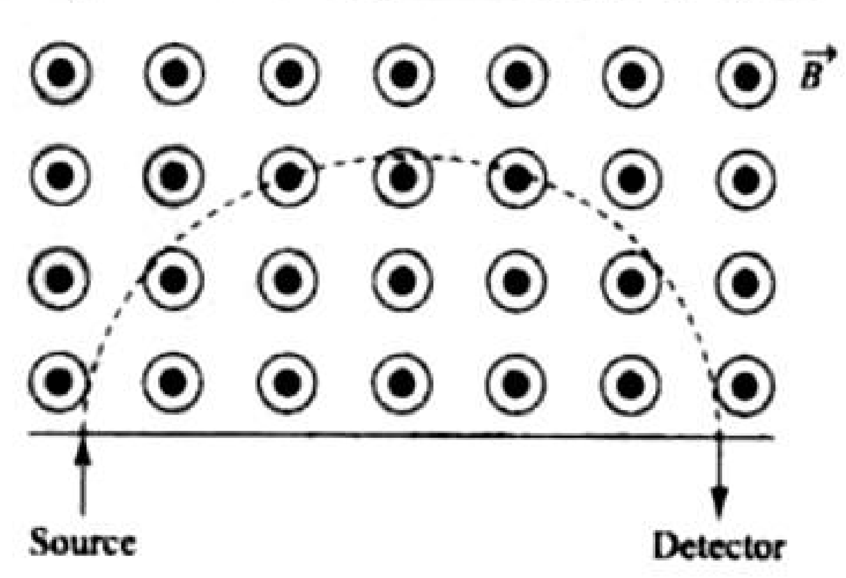
5. The wire loop $PQRSP$ formed by joining two semicircular wires of radii R_1 and R_2 carries a current I as shown in the figure. The magnitude of the magnetic induction at center C is ______. **(IIT-JEE 1990)**



6. A metallic block carrying current I is subjected to a uniform magnetic induction $\vec{B}$ shown in the figure. The moving charges experience a force $\vec{F}$ given by ______ which results in the lowering of the potential of the face ______. Assume the speed of the carriers to be v. **(IIT-JEE 1996)**



7. A uniform magnetic field with a slit system as shown in the figure is to be used as a momentum filter for high-energy charged particles. With a field B tesla, it is found that the filter transmits α particles each of energy 5.3 MeV. The magnetic field is increased to 2.3 tesla and deuterons are passed into the filter. The energy of each deuteron transmitted by the filter is ______ MeV. **(IIT-JEE 1997)**

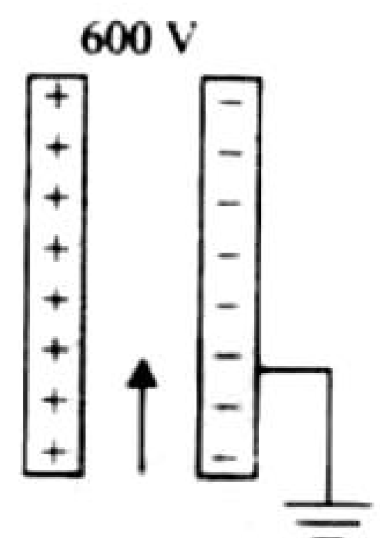


True/False Type

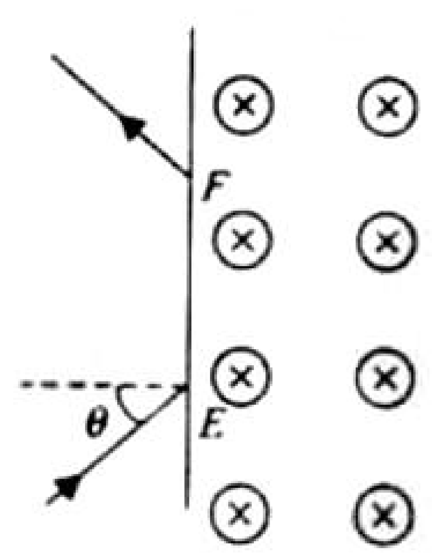
1. No net forces act on a rectangular coil carrying a steady current when suspended freely in a uniform magnetic field. **(IIT-JEE 1981)**
2. There is no change in the energy of a charged particle moving in a magnetic field although a magnetic force is acting on it. **(IIT-JEE 1983)**
3. A charged particle enters a region of uniform magnetic field at an angle to the magnetic line of force. The path of the particle is a circle. **(IIT-JEE 1983)**
4. An electron and a proton are moving with the same kinetic energy along the same direction. When they pass through a uniform magnetic field perpendicular to the direction of their motion, they describe circular paths of the same radius. **(IIT-JEE 1985)**

Subjective Type

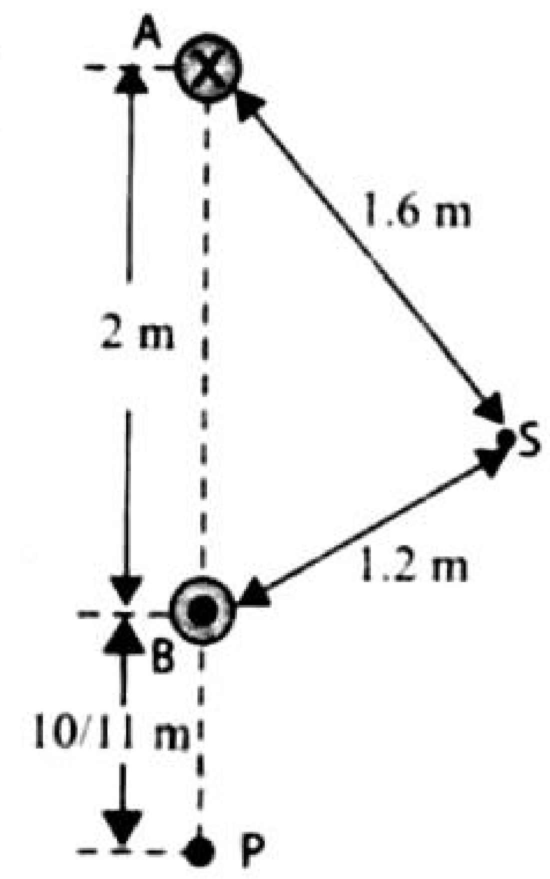
1. A potential difference of 600 V is applied across the plates of a parallel plate condenser. The separation between the plates is 3 mm. An electron projected vertically, parallel to the plates, with a velocity of 2×10^6 m s^{-1} moves undeflected between the plates. Find the magnitude and direction of the magnetic field in the region between the condenser plates. (Neglect the edge effects. Charge of the electron = -1.6×10^{-19} C.) **(IIT-JEE 1981)**



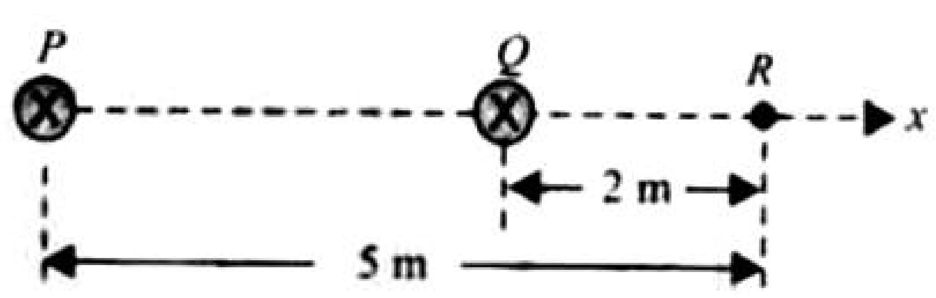
2. A particle of mass 1×10^{-26} kg and charge $+1.6 \times 10^{-19}$ C travelling with a velocity 1.28×10^6 m s^{-1} in the $+x$ direction enters a region in which uniform electric field E and a uniform magnetic field of induction B are present such that $E_x = E_y = 0$, $E_z = -102.4$ kV m^{-1}, and $B_x = B_z = 0$, $B_y = 8 \times 10^{-2}$. The particle enters this region at time $t = 0$. Determine the location (x, y, z coordinates) of the particle at $t = 5 \times 10^{-6}$ s. If the electric field is switched off at this instant (with the magnetic field present), what will be the position of the particle at $t = 7.45 \times 10^{-6}$ s? **(IIT-JEE 1982)**
3. A particle of mass m and charge $+q$ enters a region of magnetic field with a velocity v, as shown in the figure.



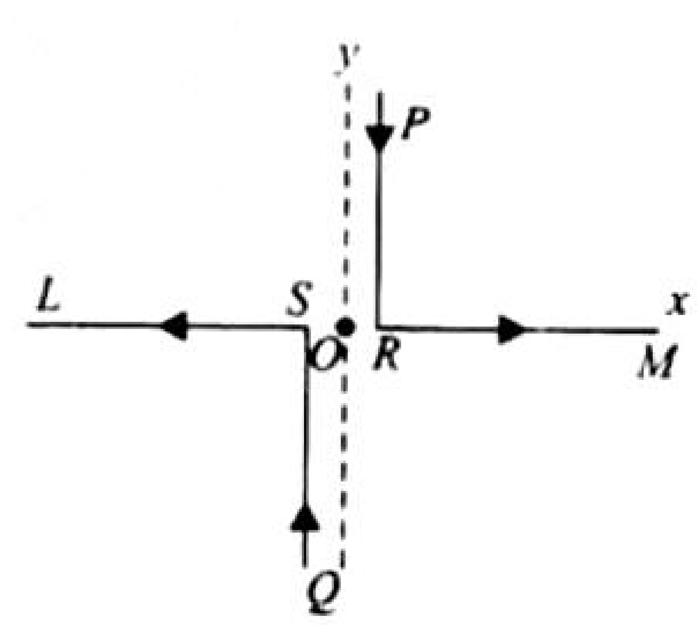
   a. Find the angle subtended by the circular arc described by it in the magnetic field.
   b. How long does the particle stay inside the magnetic field?
   c. If the particle enters at E, what is the intercept EF? **(IIT-JEE 1984)**
4. A beam of protons with a velocity 4.0×10^5 m s^{-1} enters a uniform magnetic field of 0.3 T at an angle of 60° to the magnetic field. Find the radius of the helical path taken by the proton beam. Also, find the pitch of the helix (which is the distance travelled by a proton in the beam parallel to the magnetic field during one period of rotation). **(IIT-JEE 1986)**
5. Two long straight parallel wires are 2 m apart, perpendicular to the plane of the paper. The wire A carries a current of 9.6 A, directed into the plane of the paper. The wire B carries a current such that the magnetic field of induction at point P, at a distance of 10/11 m from wire B is zero.



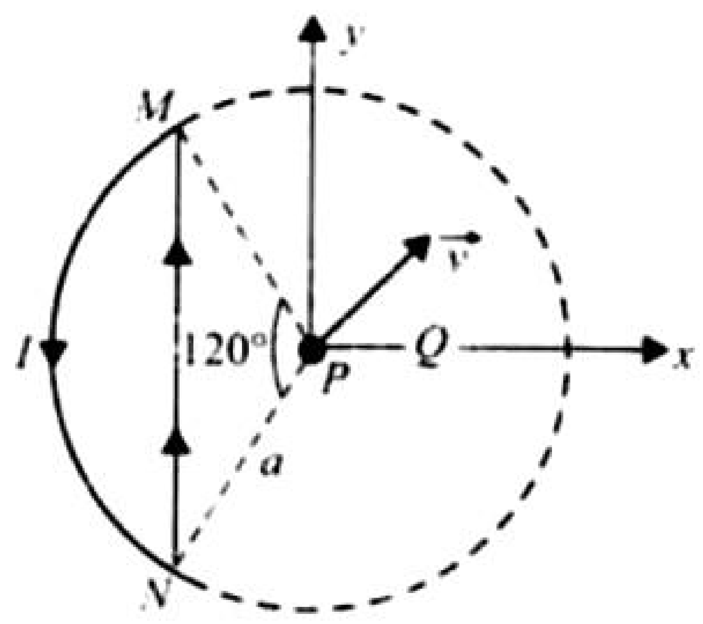
   Find:
   a. The magnitude and direction of the current in B.
   b. The magnitude of the magnetic field of induction at point S.
   c. The force per unit length on wire B. **(IIT-JEE 1987)**
6. Two long parallel wires carrying currents 2.5 A and I (ampere) in the same direction (directed into the plane of the paper) are held at P and Q, respectively, such that they are perpendicular to the plane of paper. Points P and Q are located at a distance of 5 m and 2 m, respectively from a collinear point R (see figure).



   a. An electron moving with a velocity of 4×10^5 m s^{-1} along the positive x direction experiences a force of magnitude 3.2×10^{-20} N at the point R, find the value of I.
   b. Find all the positions at which a third long parallel wire carrying a current of magnitude 2.5A may be placed, so that the magnetic induction at R is zero. **(IIT-JEE 1990)**
7. A pair of stationary and infinitely long bent wires is placed in the x–y plane as shown in the figure. Each wire carries current of 10 A. Segments L and M are along the x-axis. Segments P and Q are parallel to the y-axis such that $OS = OR = 0.02$ m. Find the magnitude and direction of the magnetic induction at origin O. **(IIT-JEE 1998)**

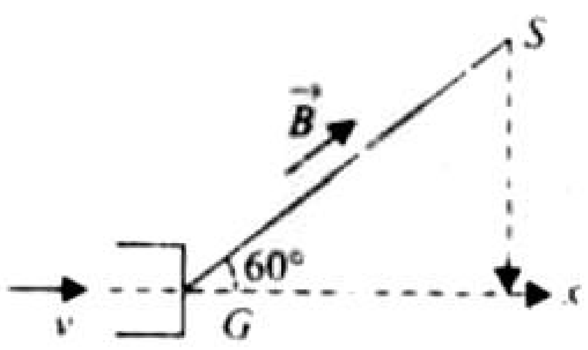


8. A wire loop carrying a current is placed in the x-y plane as shown in the figure. If a particle with charge $+Q$ and mass m is placed at the center P and given a velocity $\vec{v}$ along NP, find its instantaneous acceleration. (b) If an external uniform magnetic induction field $\vec{B} = B\hat{i}$ is applied, find the force and torque acting on the loop. **(IIT-JEE 1991)**

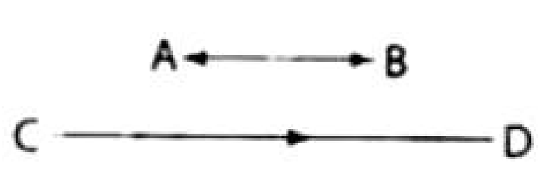


9. A straight segment OC (of length L metre) of a circuit carrying a current I amp is placed along the x-axis. Two infinitely long straight wires A and B, each extending from $z = -\infty$ to $+\infty$ are fixed at $y = -a$ metre and $y = +a$ metre, respectively, as shown in the figure. If wires A and B each carry a current I amp into the plane of the paper, obtain an expression for the force acting on segment OC. What will be the force on OC if the current in wire B is reversed? **(IIT-JEE 1992)**

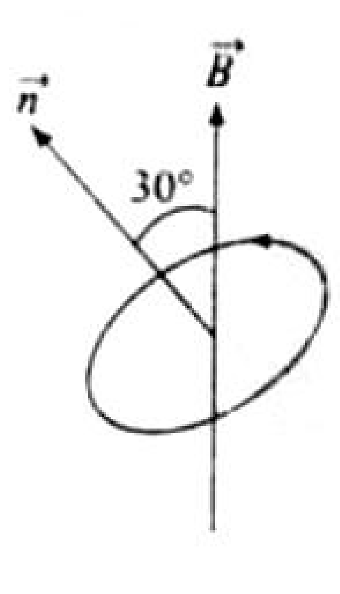
10. An electron gun G emits electrons of energy 2 keV travelling in the positive x-direction. The electrons are required to hit the spot S where $GS = 0.1$ m, and the line GS makes an angle of 60° with the x axis as shown in the figure. A uniform magnetic field $\vec{B}$ parallel to GS exists in the region outside the electron gun. Find the minimum value of B needed to make the electrons hit S. **(IIT-JEE 1993)**



11. A long horizontal wire AB, which is free to move in a vertical plane and carries a steady current of 20 A, is in equilibrium at a height of 0.01 m over another parallel long wire CD which is fixed in a horizontal plane and carries a steady current of 30 A, as shown in the figure. Show that when AB is slightly depressed, it executes simple harmonic motion. Find the period of oscillations. **(IIT-JEE 1994)**



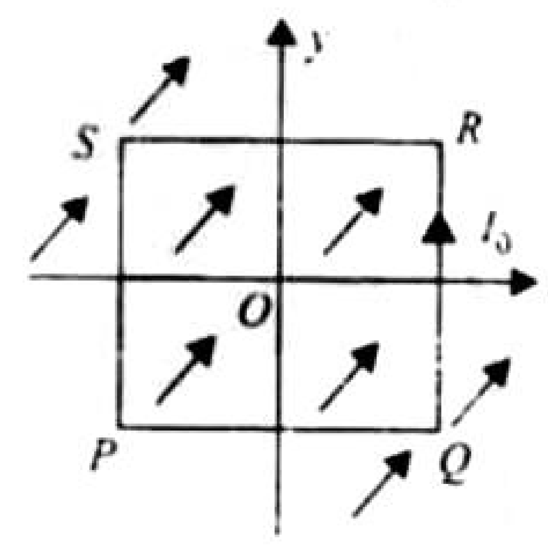
12. An electron in the ground state of hydrogen atom is revolving in anticlockwise direction in a circular orbit of radius R (see figure)
   a. Obtain an expression for the orbital mag-netic moment of the electron.
   b. The atom is placed in a uniform magnetic induction $\vec{B}$ such that the normal to the plane of electron's orbit makes an angle of 30° with the magnetic induction. Find the torque experienced by the orbiting electron. **(IIT-JEE 1996)**



13. Three infinitely long thin wires, each carrying current i in the same direction, are in the x–y plane of a gravity free space. The central wire is along the y–axis while the other two are along $x = \pm d$.
   a. Find the locus of the points for which the magnetic field B is zero.
   b. If the central wire is displaced along the z-direction by a small amount and released, show that it will execute simple harmonic motion. If the linear density of the wire is l, find the frequency of oscillation. **(IIT-JEE 1997)**

14. A particle of mass m and charge q is moving in a region where uniform, constant electric and magnetic fields $\vec{E}$ and $\vec{B}$ are present. $\vec{E}$ and $\vec{B}$ are parallel to each other. At time $t = 0$, the velocity $\vec{v}_0$ of the particle is perpendicular to $\vec{E}$ (Assume that its speed is always $<< c$, the speed of light in vacuum). Find the velocity $\vec{v}$ of the particle at time t. You must express your answer in terms of t, q, m, the vector $\vec{v}_0 . \vec{E}$ and $\vec{B}$ and their magnitudes $\vec{v}_0, \vec{E}$ and $\vec{B}$. **(IIT-JEE 1998)**

15. A uniform, constant magnetic field $\vec{B}$ directed at an angle of 45° to the x-axis in the x–y plane. $PQRS$ is a rigid, square wire frame carrying a steady current I_0, with its center at the origin O. At time $t = 0$, the frame is at rest in the position shown in the figure, with its sides parallel to the x- and y-axes. Each side of the frame is of mass M and length L.



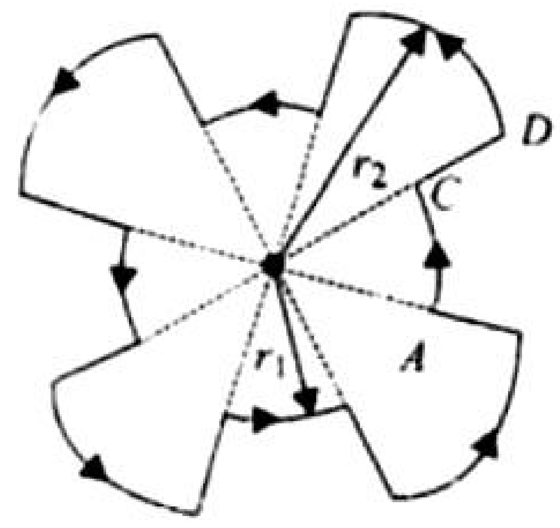
   a. What is the torque $\vec{\tau}$ about O acting on the frame due to the magnetic field?
   b. Find the angle by which the frame rotates under the action of this torque in a short interval of time Δt, and the axis about which this rotation occurs. (Δt is so short that any variation on the torque during this interval may be neglected). Given, moment of inertia of the frame about an axis through its center perpendicular to its plane is $(4/3) ML^2$. **(IIT-JEE 1998)**

16. The region between $x = 0$ and $x = L$ is filled with uniform, steady magnetic field $B_0\hat{k}$. A particle of mass m, positive charge q and velocity $v_0\hat{i}$ travels along x-axis and enters the region of magnetic field. Neglect gravity throughout the question.
   a. Find the value of L if the particle emerges from the region of magnetic field with its final velocity at an angle 30° to the initial velocity.
   b. Find the final velocity of the particle and the time spent by it in the magnetic field, if the field now extends up to $x = 2.1L$. **(IIT-JEE 1999)**

17. A current of 10 A flows around a closed path in a circuit which is in the horizontal plane as shown in the figure. The circuit consists of eight alternating arcs of radii r_1 = 0.08 m and r_2 = 0.12 m. Each arc subtends the same angle at the center.

a. Find the magnetic field produced by this circuit at the center.

b. An infinitely long straight wire carrying a current of 10 A is passing through the center of the above circuit vertically with the direction of the current being into the plane of the circuit. What is the force acting on the wire at the center due to the current in the circuit? What is the force acting on arc AC and the straight segment CD due to the current at the center?



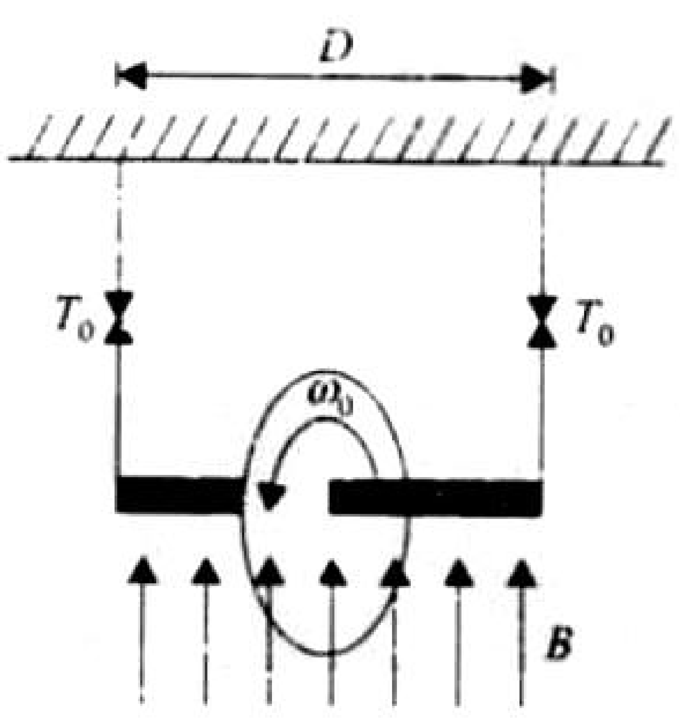
(IIT-JEE 2001)

18. A rectangular loop $PQRS$ made from a uniform wire has length a, width b and mass m. It is free to rotate about the arm PQ, which remains hinged along a horizontal line taken as the y-axis. Take the vertically upward direction as the z-axis. A uniform magnetic field $\vec{B} = (3\hat{i} + 4\hat{k})B_0$ exists in the region. The loop is held in the x–y plane and a current I is passed through it. The loop is now released and is found to stay in the horizontal position in equilibrium.

a. What is the direction of the current I in PQ?
b. Find the magnetic force on the arm RS.
c. Find the expression for I in terms of B_0, a, b and m.

(IIT-JEE 2002)

19. A ring of radius R having uniformly distributed charge Q is mounted on a rod suspended by two identical strings. The tension in strings in equilibrium is T_0. Now a vertical magnetic field is switched on and ring is rotated at constant angular velocity ω. Find the maximum ω with which the ring can be rotated if the strings can withstand a maximum tension of $3T_0/2$. **(IIT-JEE 2003)**



20. A proton and an α-particle are accelerated with same potential difference and they enter in the region of constant magnetic field B perpendicular to the velocity of particles. Find the ratio of radius of curvature of proton to the radius of curvature of α-particle.

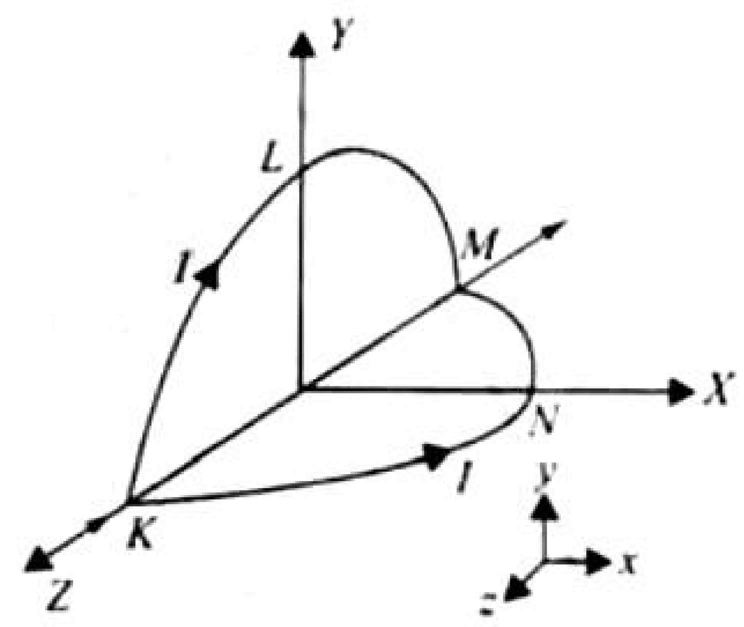
(IIT-JEE 2004)

21. A moving coil galvanometer has a coil of area A and number of turns N. A magnetic field B is applied on it. The torque acting on it is given by $\tau = ki$ where i is current through the coil. If moment of inertia of the coil is I about the axis of rotation

a. Find the value of k in terms of galvanometer parameters (N, B, A).
b. Find the value of torsional constant if current i_0 produces angular deflection of $\pi/2$ rad.
c. If a charge Q is passed almost instantaneously through coil, find the maximum angular deflection in it.

(IIT-JEE 2005)

22. A circular loop of radius R is bent along the diameter and given a shape as shown in the figure. One of the semicircles (KNM) lies in the x–z plane and the other one (KLM) in the y–z plane with their centers at the origin. Current I is flowing through each of the semicircles as shown in the figure.



a. A particle of charge q is released at the origin with a velocity $v = -v_0\hat{i}$. Find the instantaneous force $\vec{F}$ on the particle. Assume that space is gravity free.
b. If an external uniform magnetic field $B\hat{j}$ is applied, determine the forces $\vec{F}_1$ and $\vec{F}_2$ on the semicircles KLM and KNM due to this field and the net force $\vec{F}$ on the loop.

(IIT-JEE 2006)

23. A slightly divergent beam of charged particles accelerated by a Potential difference V propagates from a point A along the axis of a solenoid. The beam is brought into focus at a distance l from the point A at two successive values of magnetic induction B_1 and B_2. Find the specific charge q/m of the particles. **(IIT-JEE 2007)**

ANSWER KEY

JEE Advanced

Single Correct Answer Type

1. a.	**2.** c.	**3.** c.	**4.** b.	**5.** c.
6. b.	**7.** d.	**8.** a.	**9.** a.	**10.** d.

11. a.	**12.** c.	**13.** c.	**14.** b.	**15.** c.
16. b.	**17.** d.	**18.** c.	**19.** b.	**20.** a.
21. d.	**22.** b.	**23.** b.	**24.** c.	**25.** b.
26. a.	**27.** c.	**28.** c.	**29.** a.	**30.** b.
31. d.				

Multiple Correct Answers Type

1. a, b, d **2.** a, b, d **3.** a, c **4.** a, c
5. a, c, d **6.** b, d **7.** c, d **8.** a, c
9. a., d. **10.** a., b., c.

Linked Comprehension Type

1. a. **2.** b. **3.** c. **4.** b.
5. a., d. **6.** a., c.

Matching Column Type

1. i. → b., c. ii. → a., iii. → b., c. iv. → b.
2. i. → a., c., d. ii. → c., d. iii. → a., b., e. iv. → c., d.

Integer Answer Type

1. (5) **2.** (3)

Assertion–Reasoning Type

1. c.

Fill in the Blanks Type

1. D, B **2.** $\frac{iL^2}{4\pi}$ **3.** $ILB \sin\theta$ **7.** 0158 eV

True/False Type

1. True **2.** True **3.** False **4.** False

Subjective Type

1. 0.1 T (perpendicular to paper inwards)
2. (6.4 m, 0, 0), (6.4 m, 0, 2m)
3. **a.** 0.14 m, 45° **b.** 4.712×10^{-8} s
4. 1.2×10^{-2} m, 4.37×10^{-2} m
5. **a.** 3 A, perpendicular to paper outwards
b. 13×10^{-7} T **c.** 2.88×10^{-6} N/m
6. **a.** 4 A
b. At distance 1m from R to the left or right of it, current is outwards if placed to the left and inwards if placed to the right of R.
7. 10^{-4} T, perpendicular to paper outwards
8. **a.** $\frac{0.11\mu_0 IQv}{2am}(\hat{j} - \sqrt{3}\hat{i})$ **b.** zero, $(0.61 Ia^2 B)\hat{j}$
9. $\vec{F} = \frac{-\mu_0 I^2}{2\pi} \ln\left(\frac{L^2 + a^2}{a^2}\right)\hat{k}$, zero **10.** 4.73×10^{-3} T
11. 0.2 s
12. **a.** $M = \frac{eh}{4\pi m}$ **b.** $\tau = \frac{ehB}{8\pi m}$, perpendicular to both $\vec{M}$ and $\vec{B}$
13. **a.** $x = 0 = z$ and $z = 0$, $x = \pm\frac{d}{\sqrt{3}}$ **b.** $f = \frac{i}{2\pi d}\sqrt{\frac{\mu_0}{\pi\lambda}}$
14. $\vec{v} = \cos\left(\frac{qB}{m}t\right)(\vec{v_0}) + \left(\frac{q}{m}t\right)(\vec{E}) + \sin\left(\frac{qB}{m}t\right)\left(\frac{\vec{v_0} \times \vec{B}}{B}\right)$
15. **a.** $|\vec{\tau}| = I_0 L^2 B$ **b.** $\theta = \frac{3}{4}\frac{I_0 B}{M}(\Delta t)^2$
16. **a.** $L = \frac{mv_0}{2B_0 q}$ **b.** $\vec{v_f} = -v_0\hat{i}$, $t = \frac{\pi m}{B_0 q}$
17. **a.** 6.54×10^{-5} T (Vertically upward or outward normal to the paper)
b. zero, zero, 8.1×10^{-6} N (inwards)
18. **a.** P to Q **b.** $IbB_0(3\hat{k} - 4\hat{i})$ **c.** $\frac{mg}{6bB_0}$
19. $\omega_{max} = \frac{DT_0}{BQR^2}$ **20.** $\frac{1}{\sqrt{2}}$
21. **a.** $k = BNA$ **b.** $K = \frac{2BiNA}{\pi}$ **c.** $Q\sqrt{\frac{BNA\pi}{2I}}$
22. **a.** $\vec{F} = -\frac{\mu_0 q V_0 I}{4R}\hat{k}$ **b.** $\vec{F_1} = \vec{F_2} = 2BIR\hat{i}$, $\vec{F} = 4BIR\hat{i}$
23. $\frac{q}{m} = \frac{8\pi^2 V}{l^2(B_2 - B_1)^2}$

HINTS AND SOLUTIONS

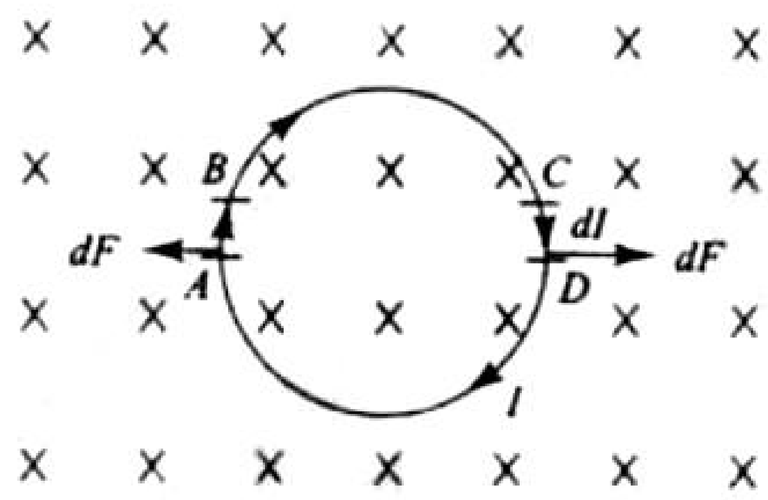
JEE Advanced

Single Correct Answer Type

1. a. In a non-uniform magnetic field, the needle will experience both a force and a torque.

2. c. The magnetic field is perpendicular to the plane of the paper. Let us consider two diametrically opposite elements. By Fleming's left hand rule on element AB, the direction of force will be leftward and the magnitude will be

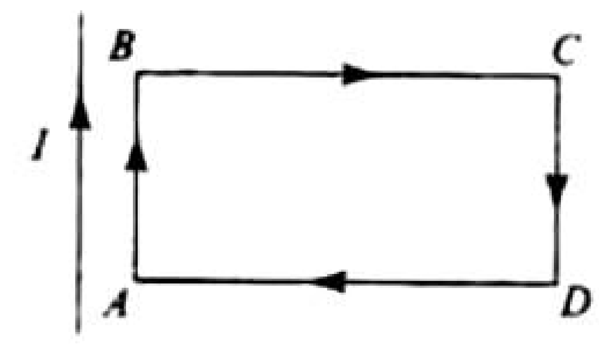
$$dF = Idl\, B \sin 90^\circ = IdlB$$



On element CD, the direction of force will be toward right on the plane of the paper and the magnitude will be $dF = IdlB$. These two forces will cancel out.

Similarly, all forces acting on the diametrically opposite elements will cancel out in pair. The net force on the loop will be zero.

3. c. is the correct option. Part AB of the rectangular loop will get attracted to the long straight wire as the currents are parallel and in the same direction whereas part CD will be repelled. But since this force $F \propto (1/r)$, where r is the distance between the wires. Therefore, there will be a net attractive force on the rectangular loop.



4. b. Force per unit length between two wires carrying currents i_1 and i_2 at distance r is given by

$$\frac{F}{\ell} = \frac{\mu_0}{2\pi}\frac{i_1 i_2}{r}$$

Here, $i_1 = i_2 = i$ and $r = b$

$$\frac{F}{\ell} = \frac{\mu_0 i^2}{2\pi b}$$

5. c. $R = \dfrac{\sqrt{2qVm}}{Bq}$ or $R \propto \sqrt{m}$

$$\frac{R_1}{R_2} = \sqrt{\frac{m_X}{m_Y}} \quad \text{or} \quad \frac{m_X}{m_Y} = \left(\frac{R_1}{R_2}\right)^2$$

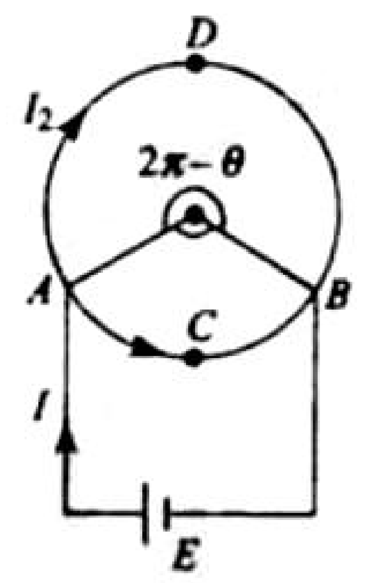
6. b. Using Ampere's circuital law over a circular loop of any radius less than the radius of the pipe, we can see that net current inside the loop is zero. Hence, magnetic field at every point inside the loop will be zero.

7. d. Magnetic field at the centre due to current in arc ACB is

$$B_1 = \frac{\mu_0}{4\pi}\frac{2\pi I_1}{r}\frac{\theta}{2\pi} \text{ (directed upwards)}$$

Magnetic field at the centre due to current in arc ADB is

$$B_2 = \frac{\mu_0}{4\pi}\frac{2\pi I_2}{r}\frac{2\pi-\theta}{2\pi} \text{ (directed downwards)}$$



Therefore, net magnetic field at the centre

$$B = \frac{\mu_0}{4\pi}\frac{2\pi I_1}{r}\frac{\theta}{2\pi} - \frac{\mu_0}{4\pi}\frac{2\pi I_2}{r}\frac{(2\pi-\theta)}{2\pi}$$

Also, $I_1 = \frac{E}{R_1} = \frac{E}{\rho l_1/A} = \frac{EA}{\rho r\theta}$

And $I_2 = \frac{E}{R_2} = \frac{E}{\rho l_2/A} = \frac{EA}{\rho r(2\pi-\theta)}$

$$\therefore \quad B = \frac{\mu_0}{4\pi}\left[\frac{EA}{\rho r\theta}\times\frac{\theta}{r} - \frac{EA}{\rho r(2\pi-\theta)}\times\frac{(2\pi-\theta)}{r}\right] = 0$$

(d) is the correct option.

8. a. The centripetal force is provided by the magnetic force

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

$$\Rightarrow \quad r = \frac{mv}{qB} = \frac{p}{qB} \quad [\because p = mv]$$

But $\quad KE = \frac{p^2}{2m} \Rightarrow p = \sqrt{2m\text{KE}}$

Here, KE and B are same for the three particles

$$\therefore \quad r \propto \frac{\sqrt{m}}{q}$$

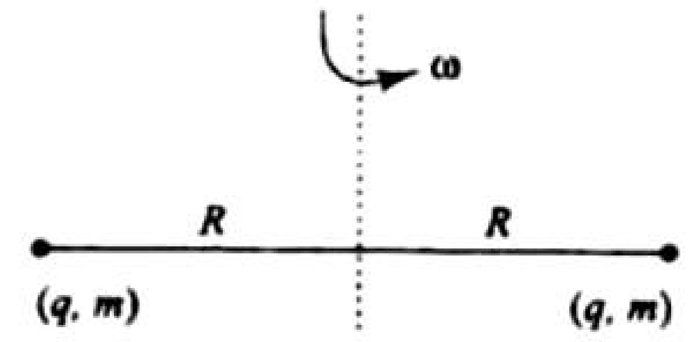
$$\therefore \quad r_p : r_d : r_\alpha = \frac{\sqrt{1}}{1} : \frac{\sqrt{2}}{1} : \frac{\sqrt{4}}{2} = 1 : \sqrt{2} : 1$$

$$\Rightarrow \quad r_\alpha = r_p < r_d$$

$\therefore$ (a) is the correct option.

9. a. Current, i = (frequency) (charge)

$$= \left(\frac{\omega}{2\pi}\right)(2q) = \frac{q\omega}{\pi}$$



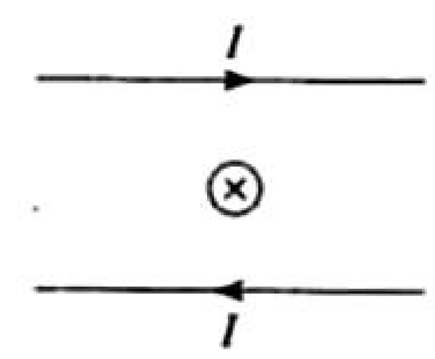
Magnetic moment,

$$M = (I)(A) = \left(\frac{q\omega}{\pi}\right)(\pi R^2) = (q\omega R^2)$$

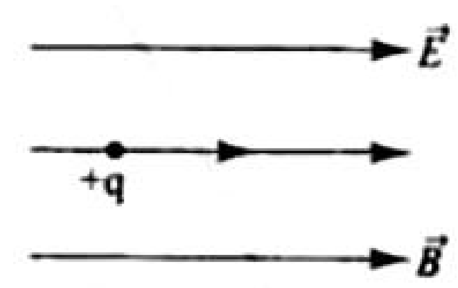
Angular momentum, $L = 2I\omega = 2(mR^2)\omega$

$$\frac{M}{L} = \frac{q\omega R^2}{2(mR^2)\omega} = \frac{q}{2m}$$

10. d. Net magnetic field due to the wires will be downward as shown below in the figure. Since angle between $\vec{v}$ and $\vec{B}$ is 180°, therefore magnetic force $\vec{F}_m = q(\vec{v}\times\vec{B}) = 0$



11. a. $F_E = qE$ (Force due to electric field)
$F_B = qvB\sin\theta = qvB\sin 0 = 0$ (Force due to magnetic field)
Force due to electric field will make the charged particle released from rest to move in the straight line (that of electric field). Since the force due to magnetic field is zero, therefore the charged particle will move in a straight line.



$\therefore$ (a) is the correct option.

12. c. The angular momentum L of the particle is given by $L = mr^2\omega$
$\rightarrow$ where $\omega = 2\pi n$

$$\therefore \quad \text{Frequency } n = \frac{\omega}{2\pi}$$

Further $i = q\times n = \frac{\omega q}{2\pi}$

Magnetic moment, $M = iA = \frac{\omega q}{2\pi}\times\pi r^2$

$$\therefore \quad M = \frac{\omega q r^2}{2} \Rightarrow \frac{M}{L} = \frac{\omega q r^2}{2mr^2\omega} = \frac{q}{2m}$$

13. c. **Case of positively charged particle:** Two forces are acting on the positively charged particle (i) force due to electric field in the positive x direction, and (ii) force due to magnetic field.

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

$$\Rightarrow \quad \vec{F} = q[V\hat{i}\times B\hat{k}] \Rightarrow \vec{F} = qVB(\hat{i}\times\hat{k})$$

$$\Rightarrow \quad \vec{F} = qvB(-\hat{j})$$

This force will deflect the positively charged particle toward $-y$ axis.

Case of negatively charged particle:
Two forces are acting on the negatively charged particle
(i) due to electric field in the negative X direction, and
(ii) due to magnetic field

$$\Rightarrow \quad \vec{F} = -q(\vec{v}\times\vec{B}) \Rightarrow \vec{F} = -q[v(-\hat{i})\times B(\hat{k})]$$

$$\Rightarrow \quad \vec{F} = qvB[\hat{i}\times\hat{k}] \Rightarrow \vec{F} = qvB(-\hat{j})$$

Same direction as that of positive charge. (c) is the correct answer.

14. b. The wires are at A and B perpendicular to the plane of paper and current is toward the reader. Let us consider certain points.

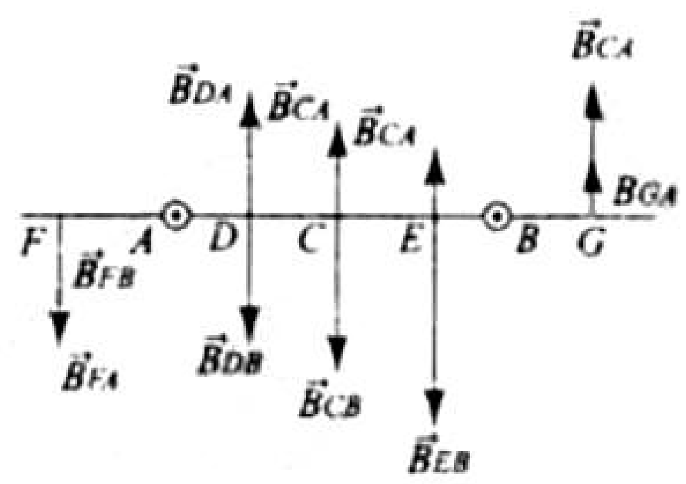
Point C: The magnetic field at C due to A $(\vec{B}_{CA})$ is in upward direction but magnetic field at C due to B is in downward direction. Net field is zero.

Point E: Magnetic field due to A is upward and magnetic field due to B is downward but $|\vec{B}_{EA}| < |\vec{B}_{EB}|$

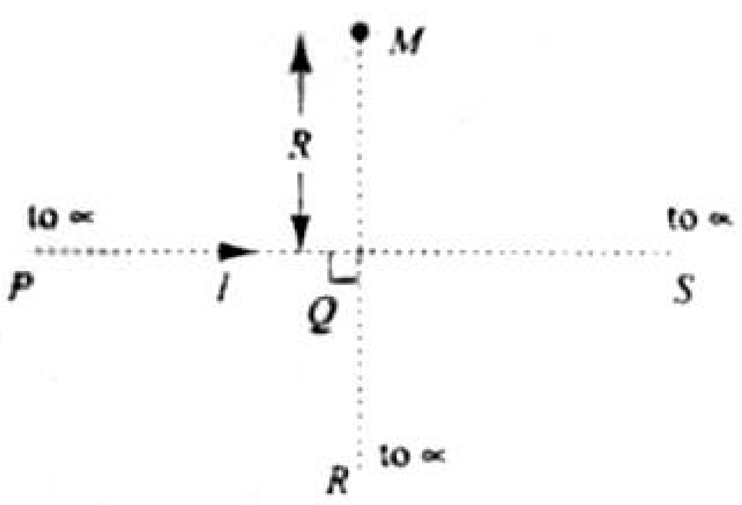
$\therefore$ Net magnetic field is in downward direction.

Point D: $|\vec{B}_{DA}| > |\vec{B}_{DB}| \Rightarrow$ Net field upward.

Similarly, other points can be considered.



15. c. **Case 1:** Magnetic field at M due to PQ and QR is



$$H_1 = \frac{1}{2}\left[\frac{\mu_0 I}{2\pi R}\right] + 0 = \frac{\mu_0 I}{4\pi R}$$

Case 2: When wire Q is joined

H_2 = (Magnetic field at M due to PQ)

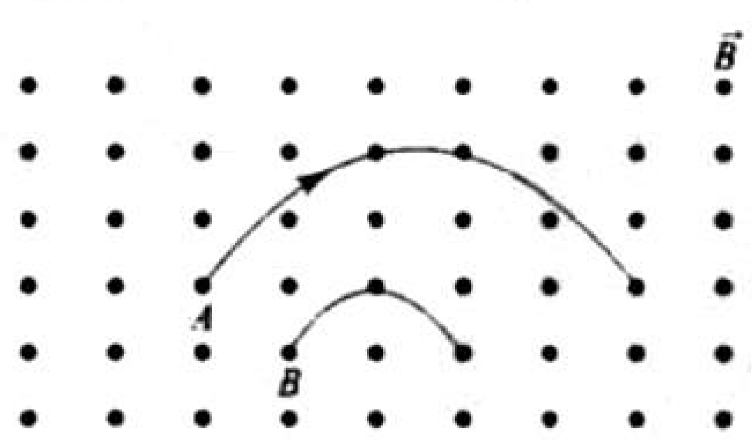
+ (Magnetic field at M due to QR)

+ (Magnetic field at M due to QS)

$$= \frac{1}{2}\left[\frac{\mu_0 I}{2\pi R}\right] + 0 + \frac{1}{2}\left[\frac{\mu_0 I/2}{2\pi R}\right] = \frac{3\mu_0 I}{8\pi R}$$

$$\therefore \quad \frac{H_1}{H_2} = \frac{2}{3}$$

16. b. When a charged particle is moving at right angle to the magnetic field, then a force acts on it which behaves as a centripetal force and moves the particle in circular path.



$$\therefore \quad \frac{m_A v_A^2}{2r} = q v_A B \quad \therefore \quad \frac{m_A v_A}{2r} = qB$$

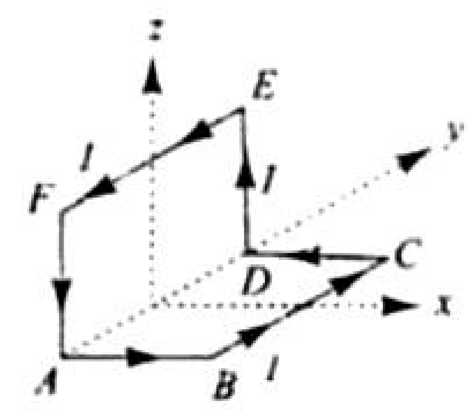
Similarly, for second particle moving with half radius as compared to the first one, we have

$$\frac{m_B v_B}{r} = qB \Rightarrow \frac{m_A v_A}{2r} = \frac{m_B v_B}{r} \Rightarrow m_A v_A = 2 m_B v_B$$

$$\Rightarrow \quad m_A v_A > m_B v_B$$

$\therefore$ Correct option is (b).

17. d. If we take individual length for the purpose of calculating the magnetic field in a 3-dimensional figure, then it will be difficult.



Here, a smart choice is to divide the loop into two loops. One loop is $ADEFA$ in y–z plane and the other loop will be $ABCDA$ in the x–y plane.

We actually do not have any current in the segment AD. By choosing the loops, we find that in one loop we have to take current from A to D and in the other one from D to A. Hence, these two cancel out the effect of each other as far as creating magnetic field at the concerned point is considered.

The point $(a, 0, a)$ is in the X–Z plane.

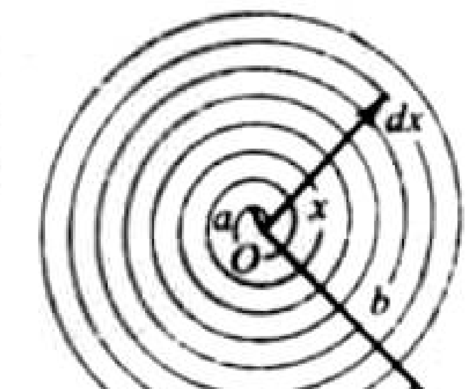
The magnetic field due to current in $ABCDA$ will be in positive z direction. Due to symmetry, the y-components and x-components will cancel out each other.

Similarly, the magnetic field due to current in $ADEFA$ will be in x direction.

$\therefore$ The resultant magnetic field will be $\vec{B} = \frac{1}{\sqrt{2}}(\hat{i} + \hat{k})$

Correct option is (d).

18. c. Let us consider a thickness dx of wire. Let it be at a distance x from the centre O.



Number of turns per unit length $= \frac{N}{b-a}$

Number of turns in thickness

$$dx = \frac{N}{b-a}dx$$

Small amount of magnetic field produced at O due to thickness dx of the wire

$$dB = \frac{\mu_0}{2}\frac{NI}{(b-a)}\frac{dx}{x}$$

On integrating, we get

$$B = \int_a^b \frac{\mu_0}{2}\frac{NI}{(b-a)}\frac{dx}{x} = \frac{\mu_0}{2}\frac{NI}{(b-a)}\int_a^b \frac{dx}{x}$$

$$= \frac{\mu_0}{2}\frac{NI}{(b-a)}\left[\log_e x\right]_a^b = \frac{\mu_0}{2}\frac{NI}{(b-a)}\log_e\frac{b}{a}$$

Correct option is (c).

19. b. Width of the magnetic field region $(b-a) \le R$; where 'R' is its radius of curvature inside magnetic field.

$$\therefore \quad R = \frac{mv}{qB} = (b-a) \Rightarrow v_{min} = \frac{(b-a)qB}{m}$$

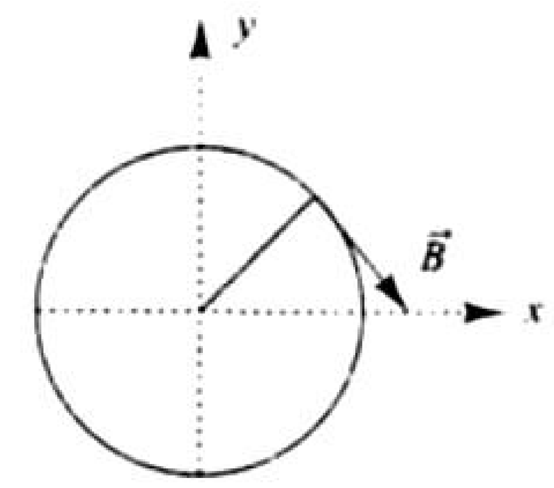
(b) is the correct option.

20. a. Magnetic field $|\vec{B}| = \frac{\mu_0 I}{2\pi\sqrt{x^2+y^2}}$; Unit vector perpendicular to the position vector is $\frac{(y\hat{i} - x\hat{j})}{\sqrt{x^2+y^2}}$.

$$\therefore \quad \vec{B} = \frac{\mu_0 I}{2\pi(x^2+y^2)}(y\hat{i} - x\hat{j})$$

(a) is the correct option.

21. d. Option (d) is the correct option. Magnetic lines of force form closed loops. Inside magnet, these are directed from south to north pole.



22. b. The velocity at P is in the x direction (given). Let $\vec{V} = m\hat{i}$.

After P, the positively charged particle gets deflected in the x–y plane toward $-y$ direction and the path is non-circular.

$$\text{Now, } \vec{F} = q(\vec{V} \times \vec{B})$$

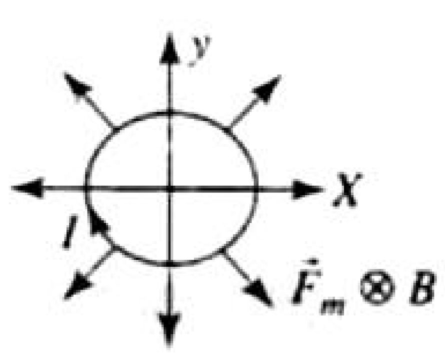
$$= q[m\hat{i} \times (c\hat{k} + a\hat{i})] \text{ [for option (b)]}$$

$$= q[mc\hat{i} \times \hat{k} + ma\hat{i} \times \hat{i}] = mcq(-\hat{j})$$

Since in option (b) electric field is also present, i.e., $\vec{E} = a\hat{i}$, therefore, it will also exert a force in the $+x$-direction. The net result of the two forces will be a non-circular path.

Only option (b) fits for the above logic. For other options, we get some other results.

23. b. According to Fleming's left hand rule, it is clear that a force acts radially outwards. The magnetic field is imposed at right angles to loop. The loop will have a tendency to expand under the force acting along outward drawn normal.



24. c. $U = -\vec{M} \cdot \vec{B} = -MB\cos\theta$

In case I: $\theta = 180°$, $U = +MB$

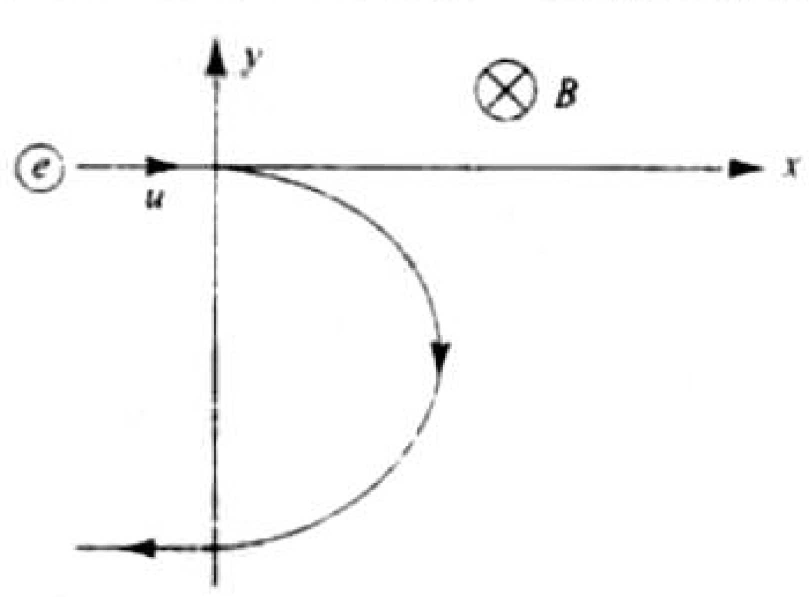
In case II: $\theta = 90°$, $U = 0$

In case III: θ is acute, $U = -\text{ve}$

In case IV: θ is obtuse, $U = +\text{ve}$

$\therefore \quad$ I > IV > II > III

25. b. The force acting on the electron will be perpendicular to the direction of velocity till the electron remains in the magnetic field. So, the electron will follow the path as given.



26. a. Using $\vec{F} = q\vec{v} \times \vec{B}$, the force on the charge in the region $a < x < 2a$ must be in the direction $\hat{i} \times \hat{j}$, that is, in $+z$ direction, which is vertically upward. And in the region $2a < x < 3a$, the force on the charge will be in $-z$ direction, which is vertically downward.

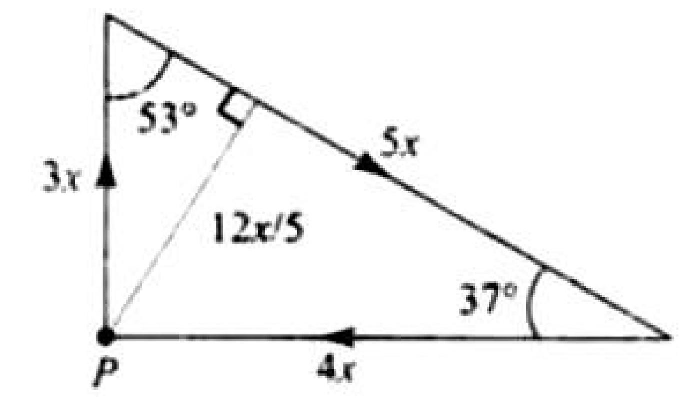
For $a < x < 2a$, path will be concave upward.

For $2a < x < 3a$, path will be concave downward.

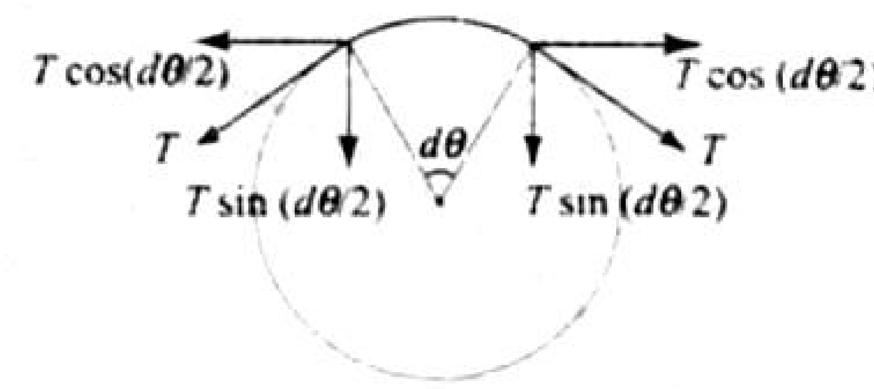
Moreover, there must not be any link in the path at $x = 2a$.

27. c. $B = \frac{\mu_0 I}{4\pi \frac{12x}{5}}[\cos 53° + \cos 37°] = 7\left(\frac{\mu_0 I}{48\pi x}\right)$

$\therefore \quad k = 7$



28. c. $2T\sin\frac{d\theta}{2} = BIRd\theta$



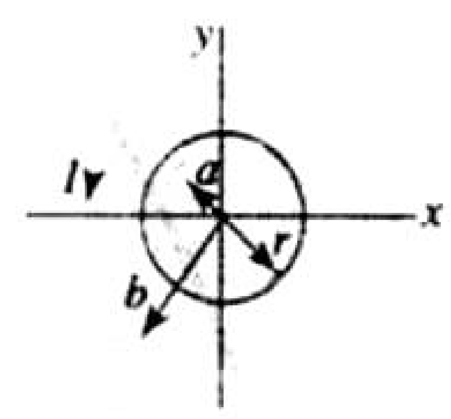
$Td\theta = BIRd\theta$ (for θ small)

$T = BIR = \frac{BIL}{2\pi}$

29. a. Take an element of thickness dr at a distance r from the center of spiral coil.

Number of turns in spiral = N

Number of turns per unit thickness $= \frac{N}{b-a}$



Number of turns in element dr is, $dN = \frac{Ndr}{b-a}$

Magnetic field at the center of the spiral due to current in element dr is

$$dB = \frac{\mu_0}{4\pi}\frac{2\pi dNI}{r} = \frac{\mu_0 I}{2r}dN = \frac{\mu_0 I}{2r}\left(\frac{Ndr}{b-a}\right)$$

$$= \frac{\mu_0 I}{2}\frac{N}{(b-a)} \times \frac{dr}{r}$$

Total magnetic field at the center of the spiral due to current through the wire is

$$B = \int_a^b \frac{\mu_0 INdr}{2(b-a)r} = \frac{\mu_0 IN}{2(b-a)}\int_a^b \frac{dr}{r} = \frac{\mu_0 IN}{2(b-a)}\ln\left(\frac{b}{a}\right)$$

30. b. Area of the loop $\hat{k}$

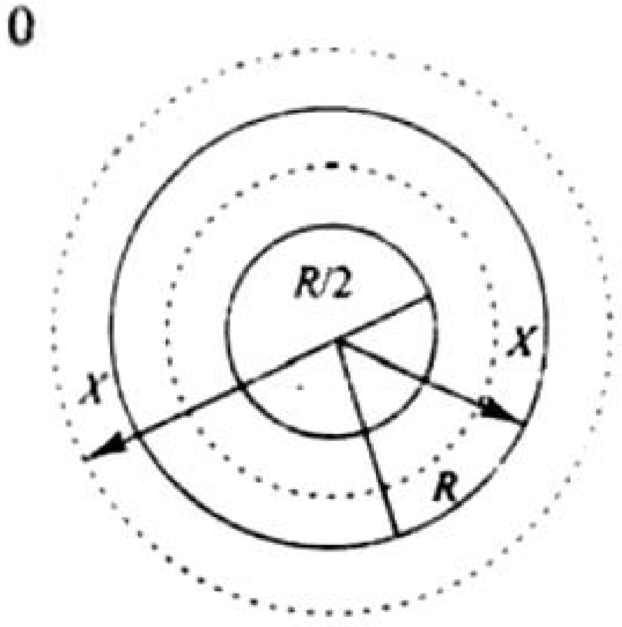
$$A = \left[a^2 + 4 \times \frac{\pi\left(\frac{a}{2}\right)^2}{2}\right]\hat{k} = \left[a^2 + \frac{\pi a^2}{2}\right]\hat{k}$$

Therefore, the magnetic moment of the current loop is

$$M = I \times A = I\left[a^2 + \frac{\pi a^2}{2}\right]\hat{k} = \left[1 + \frac{\pi}{2}\right]Ia^2\hat{k}$$

31. d. Case I: $x < \frac{R}{2}$

$|B| = 0$



Case II: $\frac{R}{2} \le x < R$

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

$$|B| 2\pi x = \mu_0 \left[\pi x^2 - \pi \left(\frac{R}{2}\right)^2\right] J$$

$$|B| = \frac{\mu_0 J}{2x}\left(x^2 - \frac{R^2}{4}\right)$$

Case III: $x \ge R$

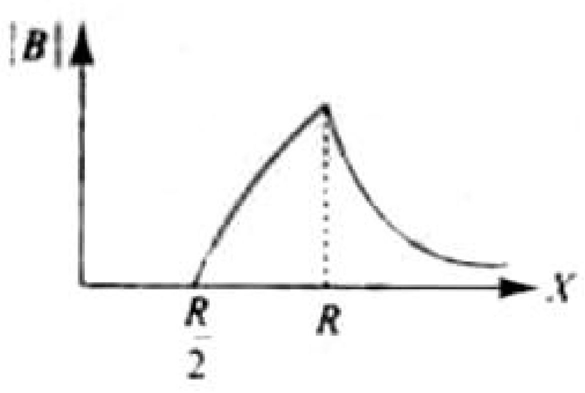
$$\int \vec{B} \cdot d\vec{l} = \mu_0 I$$

$$|B| 2\pi x = \mu_0 \left[\pi R^2 - \pi \left(\frac{R}{2}\right)^2\right] J$$

$$|B| = \frac{\mu_0 J}{2x} \frac{3}{4} R^2$$

$$|B| = \frac{3\mu_0 J R^2}{8x}$$

so



Multiple Correct Answers Type

1. **a, b, d.**
   a. When $E = 0$, $B = 0$ no force acts on proton. Velocity therefore does not change.
   b. When $E = 0$, electrical force is zero. When $B \ne 0$ but it acts in the direction of motion of proton, magnetic force is zero. Velocity, therefore, does not change.
   c. When $E = 0$ but $B = 0$, the proton will be accelerated or retarded under electrical force. Velocity will therefore change.
   d. When $E \ne 0$, the velocity of proton will change. When $B \ne 0$, the magnetic force may counteract the electrical force. The magnitudes may be equal. Velocity of proton does not change.

2. a, b, d: In going from P to Q, increase in kinetic energy

$$= \frac{1}{2}m(2v)^2 - \frac{1}{2}mv^2 = \frac{1}{2}m(3v^2)$$

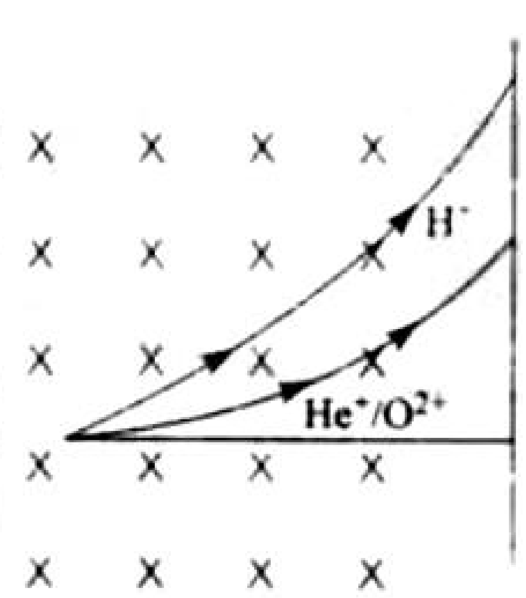
= work done by the electric field

$$\frac{3}{2}mv^2 = Eq \times 2a \quad \text{or} \quad E = \frac{3}{4}\left(\frac{mv^2}{qa}\right)$$

The rate of work done by E at P = force due to E × velocity

$$= (qE)v = qv\left[\frac{3}{4}\left(\frac{mv^2}{qa}\right)\right] = \frac{3}{4}\left(\frac{mv^3}{a}\right)$$

At Q, $\vec{v}$ is perpendicular to $\vec{E}$ hence no power or rate of work done by electric field. Rate of work done by magnetic field is always zero.



3. a, c: When the charged particles enter a magnetic field, then a force acts on the particle which will acts as a centripetal force.

$$qvB = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{qB} \qquad \text{(i)}$$

Now, $E = \frac{1}{2}mv^2 \Rightarrow v = \frac{\sqrt{2E}}{m}$ (ii)

$$\therefore \quad r = \frac{m}{qB}\sqrt{\frac{2E}{m}} = \frac{\sqrt{2Em}}{qB} = \frac{\sqrt{2E}}{B} \times \frac{\sqrt{m}}{q}$$

$$\Rightarrow \quad r \propto \frac{\sqrt{m}}{q}$$

$$\therefore r_{H^+} \propto \frac{\sqrt{1}}{1};\ pr_{He^+} \propto \frac{\sqrt{4}}{1};\ r_{O^+} \propto \frac{\sqrt{16}}{2}$$

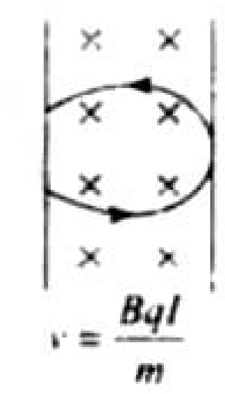
$$\Rightarrow \quad r_{H^+} \propto 1;\ r_{He^+} \propto 2;\ r_{O^+} \propto 2$$

⇒ He^+ and O^+ will be deflected equally.
H^+ will be deflected the most since its radius is smallest.
∴ **(a), (c)** are correct options.

4. a, c: Net force on AB and CD will be zero because magnetic field due to I_1 is along these parts. Force on BC due to I_1 will be outwards and on AD will be inwards. This will provide clockwise torque as seen from O.

5. a, c, d: $\vec{v} \perp \vec{B}$ in region II. Therefore, path of particle is circle in region II. Particle enters in region III, if radius of circular path, $r > l$

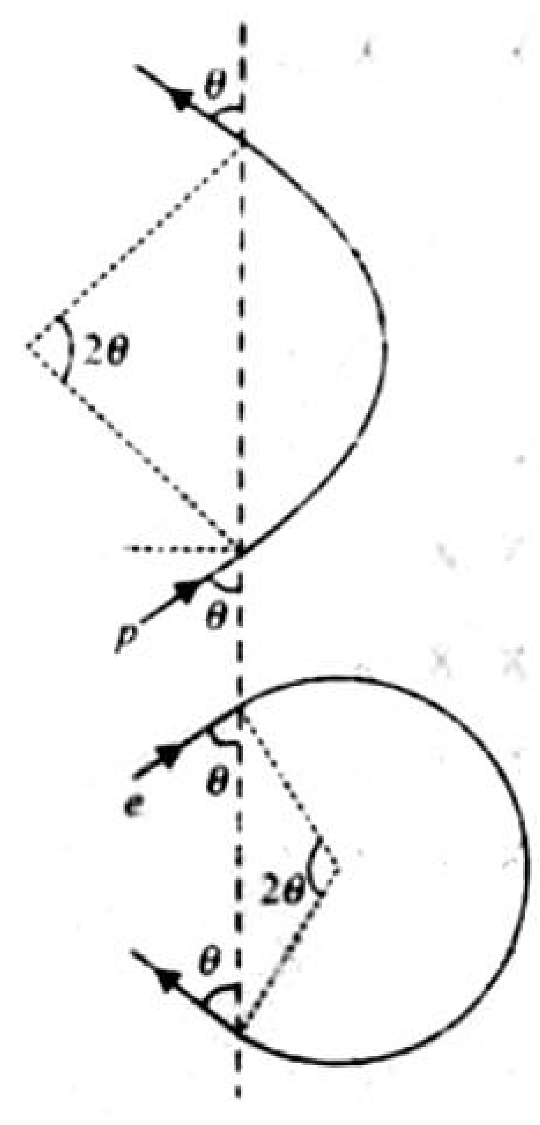
or $\frac{mv}{Bq} > l$ or $v > \frac{Bql}{m}$



If $v = \frac{Bql}{m}$, $r = \frac{mv}{Bq} = l$, particle will turn back and path length will be maximum. If particle returns to region I, time spent in region II will be

$$t = \frac{T}{2} = \frac{\pi m}{Bq}, \text{ which is independent of } v$$

6. b, d: $t_p = \frac{2\theta \times R_p}{v} = \frac{2\theta \times m_p v}{eBv} = \frac{2\theta m_p}{eB}$

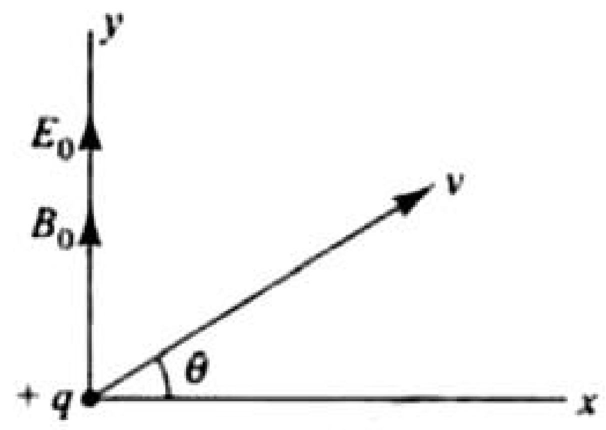


$$t_e = \frac{(2\pi - 2\theta) \times R_e}{v} = \frac{(2\pi - 2\theta)m_e v}{eBv} = \frac{(2\pi - 2\theta)m_e}{eB}$$

$t_e \ne t_p$

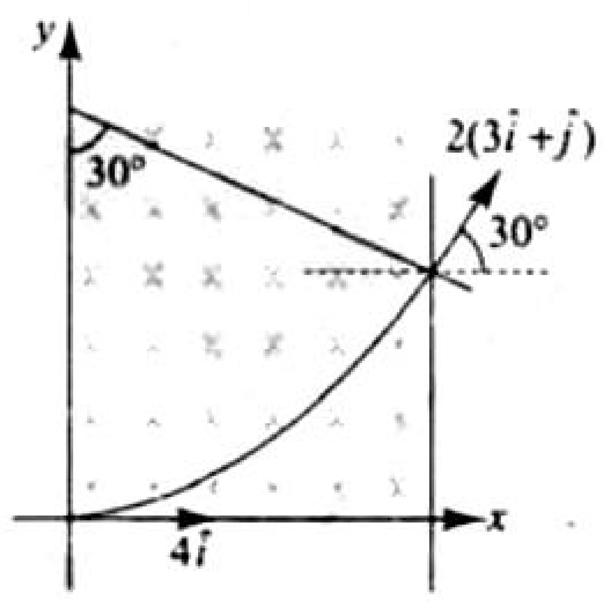
7. c, d: If $\theta = 0°$ then due to magnetic force path is circular but due to force qE_0 (↑) q will have accelerated motion along y-axis. So combined path of q will be a helical path with variable pitch so (a) and (b) are wrong.

If $\theta = 10°$, then due to $v \cos \theta$, path is circular and due to qE_0 and $v \sin \theta$, q has accelerated motion along y-axis so combined path is a helical path with variable pitch (C) is correct.



If $\theta = 90°$ then $F_B = 0$ and due to qE_0 motion is accelerated along y-axis. (d)

8. a, c: So magnetic field is along –ve, z-direction.



Time taken in the magnetic field $= 10 \times 10^{-3} = \dfrac{\pi M}{6QB}$

$$B = \frac{\pi M}{6 \times 10^{-3} Q} = \frac{1000\pi M}{60Q} = \frac{50\pi M}{3Q}$$

9. a., d. Due to field of solenoid is non zero in region $0 < r < R$ and non zero in region $r > 2R$ due to conductor.

10. a., b., c. As $\vec{B}$ is uniform

⇒ Wire can be replaced by a straight current carrying conductor.

$$\Rightarrow \quad \vec{F} = i(\vec{l} \times \vec{B})$$

$$= \left(2(L+R)\hat{i} \times \vec{B}\right)$$

if $\vec{B}$ is along x-axis ⇒ $\vec{F} = 0$

otherwise $F \propto (L + R)$

Linked Comprehension Type

1. a. Larger the magnetic field, smaller the critical temperature.

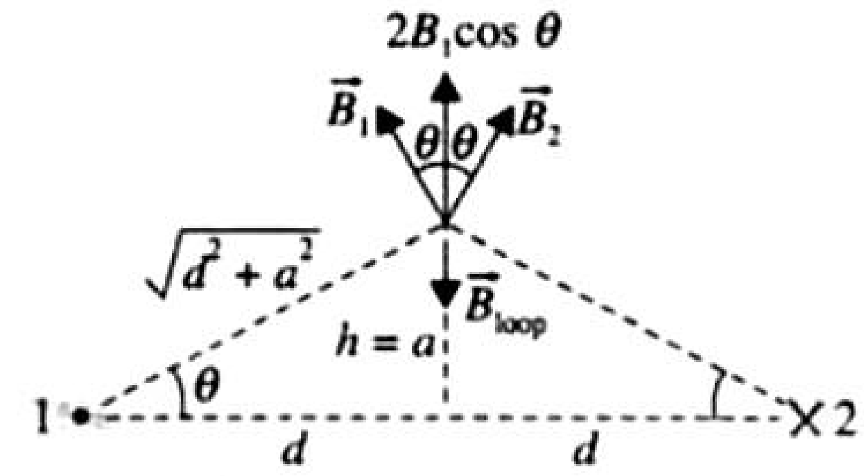
2. b. If 0 < B < 7.5 T, then 75 K < Tc(B) < 100 K

3. c. The net magnetic field at the given point will be zero if. $\left|\vec{B}_{\text{wires}}\right| = \left|\vec{B}_{\text{loops}}\right|$

The direction of magnetic field at the given point due to the loop is normally out of the plane. Therefore, the net magnetic field due the both wires should be into the plane. For this current in wire I should be along PQ and that in wire RS should be along SR.

$$B_{\text{loop}} = \frac{\mu_0}{2} \frac{ia^2}{(h^2 + a^2)^{3/2}}$$

$$B_{\text{wires}} = 2 \times \frac{\mu_0 i}{2\pi\sqrt{d^2 + h^2}} \cos\theta$$



$$\therefore \quad \frac{\mu_0}{2} \cdot \frac{ia^2}{(h^2 + a^2)^{3/2}} = \frac{2\mu_0 i}{2\pi} \frac{d}{d^2 + h^2}$$

$$\Rightarrow \quad \frac{a^2}{2(h^2 + a^2)^{3/2}} = \frac{a}{\pi(a^2 + h^2)} \Rightarrow \pi a = 2\sqrt{h^2 + a^2}$$

$$\Rightarrow \quad a = \frac{2h}{\sqrt{(\pi^2 - 4)}} \Rightarrow h \approx 1.2a$$

4. b. $B = 2\left(\dfrac{\mu_0 i}{2\pi d}\right)$

$$\therefore \quad \tau = i\pi a^2 \frac{\mu_0}{\pi d} \sin(30°) = \frac{\mu_0 I^2 a}{2d}$$

5. a., d. $qVB = Eq$

$$E = VB \qquad i = n_0 eAVd$$

$$E = \frac{i}{n_0 eA} \cdot B$$

$$E = \frac{iB}{n_0 e(Wd)}$$

Potential difference : $V_{KM} = W.E.$

$$\therefore \quad V_1 = \frac{iB}{n_0 e}\left(\frac{1}{d_1}\right)$$

$$V_2 = \frac{iB}{n_0 e}\left(\frac{1}{d_2}\right)$$

$$\therefore \quad \frac{V_1}{V_2} = \frac{d_2}{d_1}$$

Hence, (a) and (d).

6. a., c. As done in the above question

$$V_1 = \frac{iB}{n_1 e}\left(\frac{1}{d_1}\right) \text{ and } V_2 = \frac{iB}{n_2 e}\left(\frac{1}{d_2}\right)$$

In this case, $\dfrac{V_1}{V_2} = \dfrac{n_2 B_1}{n_1 B_2}$

Hence (a) and (c).

Matching Column Type

1. **i. → b., c. ii. → a., iii. → b., c. iv. → b**
   a. According to right hand rule the magnetic field at P due to upper wire is into the plane of paper while due to lower wire the magnetic field is away from plane of paper or opposite to each other. As the magnitude of current in both wires is same hence net magnetic field at P should be zero.
   Hence i. → b., c.
   b. Point P is zero at axial position of both the rings. The direction of magnetic field at P can be find by again right hand rule. By right hand rule it is clear the direction of magnetic field due to both the rings is in right direction.
   Hence ii. → a.,
   c. The magnetic field at P due to both the rings is equal and opposite hence net magnetic field at P is zero.
   Hence iii. → b., c.
   d. The direction of magnetic field at P will be opposite direction as the direction of current are opposite. **Hence iv. →** b
2. **i. → a., c., d. ii. → c., d. iii. → a., b., e. iv. → c., d.**
   When the charges are distributed symmetrically about a point, $E = 0$. If they are symmetrically distributed and the distances of the positive and negative charges are also the same, only then $V = 0$.
   a. $E = 0$ for p, r and s only because all positive charges and negative charges should separately be symmetric about the given point. For q, this is not true.
   c. When opposite charges are moving in opposite directions, with the same radii, there will be no resultant B. This is the case when p, q and r. For r and s, the resultant flux is not zero.
   d. The magnetic moment $\mu \neq 0$, only in the case of r and s. One can confirm that if there is no resultant B, there can be no resultant magnetic moment also.

Integer Answer Type

1.(5) $B_1 = \dfrac{\mu_0 J\pi a^2}{2\pi a} = \dfrac{\mu_0 Ja}{2}$, $B_2 = \dfrac{\mu_0 J\pi(a/2)^2}{2\pi(3a/2)} = \dfrac{\mu_0 Ja}{12}$

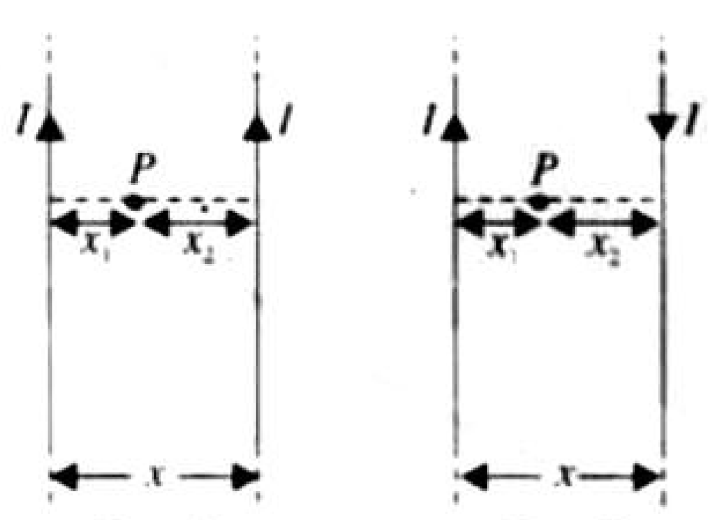
$$B_1 - B_2 = \frac{\mu_0 Ja}{2} - \frac{\mu_0 Ja}{12}$$

$$= \left(\frac{\mu_0 Ja}{2}\right)\left(1 - \frac{1}{6}\right) = \frac{5}{6}\left(\frac{\mu_0 Ja}{2}\right) = \frac{5\mu_0 aJ}{12}$$

$$\Rightarrow \frac{N}{12}\mu_0 aJ$$

$\therefore \quad N = 5$

2. (3) $X_1 = \dfrac{X_0}{3}$ and $X_2 = \dfrac{2X_0}{3}$



Case I   Case II

$$r = \frac{mu}{qB}$$

Hence ratio of radian

$$\frac{R_1}{R_2} = \frac{B_2}{B_1}$$

Case I

$$B_1 = \frac{\mu_0 I}{2\pi}\left(\frac{1}{x_1} - \frac{1}{x_2}\right) = \frac{\mu_0 I}{2\pi}\left(\frac{3}{x_0} - \frac{3}{2x_2}\right) = \frac{3\mu_0 I}{4\pi x_0}$$

Case II

$$B_2 = \frac{\mu_0 I}{2\pi}\left(\frac{1}{x_1} + \frac{1}{x_2}\right) = \frac{9\mu_0 I}{4\pi x_0} \Rightarrow \frac{R_1}{R_2} = \frac{B_2}{B_1} = 3$$

Assertion-Reasoning Type

1. **c.** $c\phi = BINA$

$$\phi = \left(\frac{BNA}{c}\right)I$$

Using iron core, value of magnetic field increases. So, deflection increases for the same current. Hence, sensitivity increases.
Soft iron can be easily magnetized or demagnetized.
∴ correct option is (c).

Fill in the Blanks Type

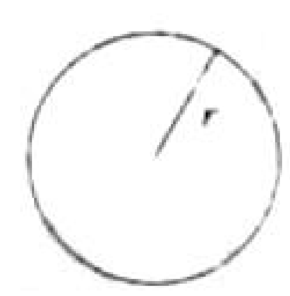
1. **D, B:** According to Fleming's left hand rule, the force on electrons will be toward right (D).
   Also, by the same rule we find that the force on proton and α-particle is toward left.
   Now, since the magnetic force will behave as centripetal force

$$\therefore \quad \frac{mv^2}{r} = qvB \Rightarrow \frac{mv}{qB} = r \quad \text{or} \quad r \propto \frac{m}{q}$$

For proton $r \propto \dfrac{1}{1} = 1$. For α-particle $r \propto \dfrac{4}{2} = 2$

∴ Radius will be greater for α-particle
∴ α-particle will take path B.

2. $2\pi r = L \Rightarrow r = \dfrac{L}{2\pi}$



∴ Area of the circle $= \pi r^2 = \dfrac{\pi L^2}{4\pi^2} = \dfrac{L^2}{4\pi}$

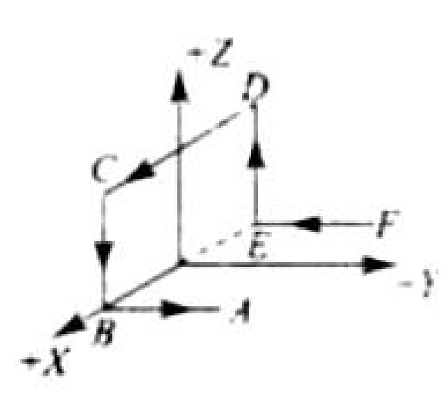
Magnetic moment of a loop in which current i flows is given by

$$M = iA = \frac{iL^2}{4\pi}$$

3. $i = \dfrac{q}{t} = \dfrac{ne}{t} = \dfrac{10^{16}}{1} \times 1.6 \times 10^{-19} = 1.6 \times 10^{-3}$ A

$$M = i \times A = i\pi r^2 = 1.6 \times 10^{-3} \times 3.14 \times (0.5 \times 10^{-10})^2$$
$$= 1.25 \times 10^{-23} \text{ Am}^2$$

4. We use the formula $\vec{F} = I(\vec{l} \times \vec{B}) \Rightarrow F = ILB \sin\theta$
   For sides FE and BA, the angle will be 180° and 0°, respectively.
   ∴ $F = 0$
   For sides DE and CB, the forces will be ILB but opposite in directions, in $+X$ and $-X$ directions, respectively.
   The net force due to these two sides will be zero.

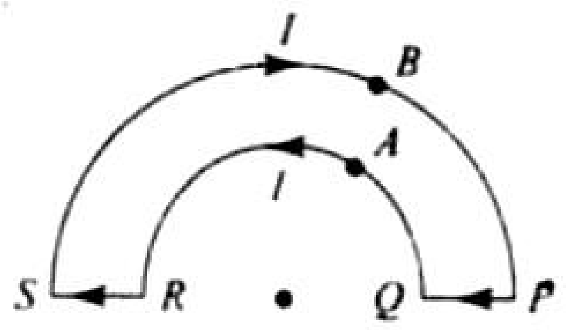


The force due to current inside DC will be $ILB \sin 90° = ILB$ in $+Z$ direction (according to Fleming's left hand rule).

So net force on the wire is ILB in positive z direction.

5. The effect of current in PQ and RS for producing magnetic field at centre is zero.

Magnetic field due to current in semicircular arc QAR



$= \frac{1}{2}\left[\frac{\mu_0}{2}\frac{I}{R_1}\right]$ directed towards the reader perpendicular to the plane of paper.

Magnetic field due to current in semicircular arc SBP

$= \frac{1}{2}\left[\frac{\mu_0}{2}\frac{I}{R_2}\right]$ directed away from the reader perpendicular to the plane of paper.

$\therefore$ Net magnetic field $= \frac{1}{2}\left[\frac{\mu_0}{2}\frac{I}{R_1}\right] - \frac{1}{2}\left[\frac{\mu_0}{2}\frac{I}{R_2}\right]$

(directed towards the reader perpendicular to plane of paper).

$$= \frac{\mu_0 I}{4}\left[\frac{I}{R_1} - \frac{I}{R_2}\right]$$

6. $\vec{F} = q(\vec{v} \times \vec{B}) \Rightarrow qvB \sin\theta = F$

$\Rightarrow$ $F = evB \sin 90° = evB$

Since current is in positive x-direction, so electrons will be moving in negative x-direction. Due to this, force on electrons will act towards the face $ABDC$. Hence this surface $ABDC$ will have lower potential.

7. The positively charged particle enters the uniform magnetic field at right angle. Therefore, the force acting on the charged particle in the magnetic field acts as centripetal force.

$$\frac{mv^2}{r} = qvB \Rightarrow mv = qrB$$

$$\Rightarrow m^2v^2 = q^2r^2B^2 \Rightarrow p^2 = q^2r^2B^2$$

But $KE = \frac{p^2}{2m}$

$\therefore$ $(KE)2m = q^2r^2B^2$

r is same for both particles.

$$\Rightarrow \frac{(KE)_\alpha 2m_\alpha}{(KE)_d 2m_d} = \frac{q_\alpha^2 r^2 B^2}{q_d^2 r^2 (2.3B)^2}$$

$$\therefore \frac{5.3}{(KE)_d} \times \frac{4}{2} = \frac{4}{1} \times \frac{1}{2.3 \times 2.3}$$

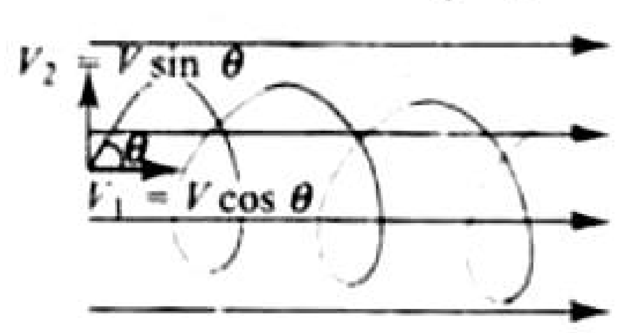
$$\Rightarrow (KE)_d = 14.0185 \text{ eV}$$

True/False Type

1. True: Net force on a current carrying closed loop in a uniform magnetic field is zero.

2. True: The magnetic force acts in a direction perpendicular to the direction of velocity and hence it cannot change the speed of the charged particle. Therefore, the kinetic energy $\left(= \frac{1}{2}mv^2\right)$ does not change.

3. False: The velocity component v_2 will be responsible in moving the charged particle in a circle.



The velocity component v_1 will be responsible in moving the charged particle in horizontal direction. Therefore, the charged particle will travel in a helical path.

4. False: $r = \frac{\sqrt{2mKE}}{qB}$ $\therefore$ $r \propto \frac{\sqrt{m}}{q}$ [for constant KE and B]

Here, q is the same for electron and proton

Therefore, radius of proton will be more.

Subjective Type

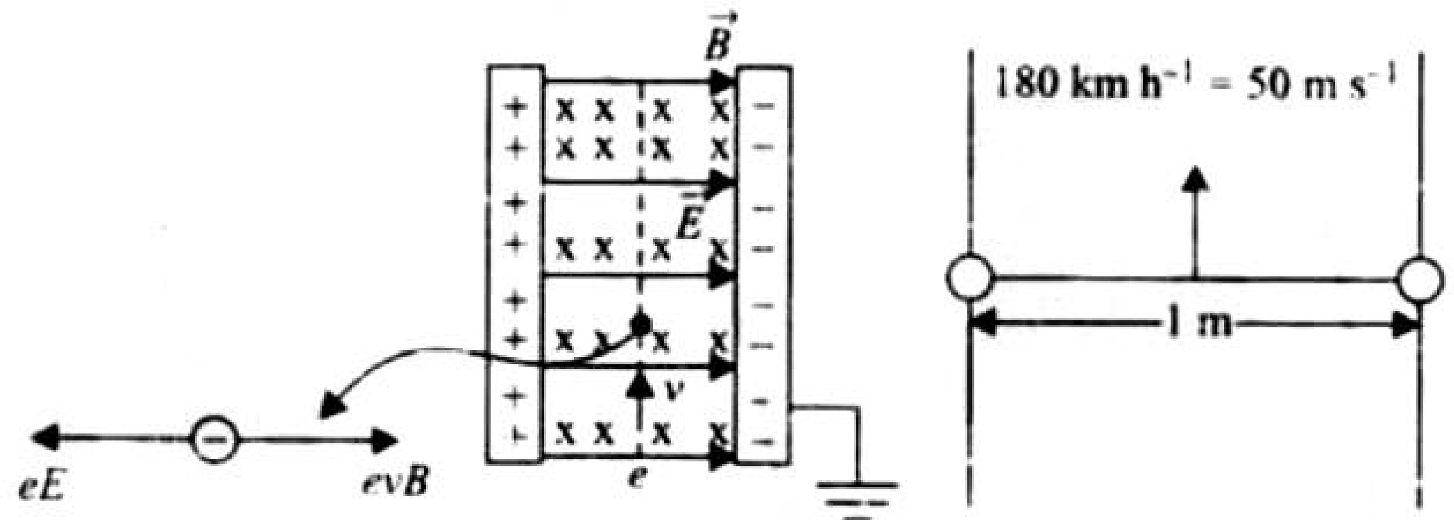
1. The force on electron will be toward the left plane due to electric field and will be equal to $F_e = eE$.

For the electron to move undeflected between the plates, there should be a force (magnetic) which is equal to the electric force and opposite in direction to electric force. So the force should be directed toward the right as the electric force is toward the left. On applying Fleming's left hand rule, we get that the magnetic field should be directed perpendicular to the plane of paper and inwards. Therefore,

Force due to electric field = Force due to magnetic field

$$eE = evB \qquad \left[\because E = \frac{V}{d}\right]$$

$$B = \frac{E}{v} = \frac{V/d}{v}$$



where V = potential difference between the plates, and

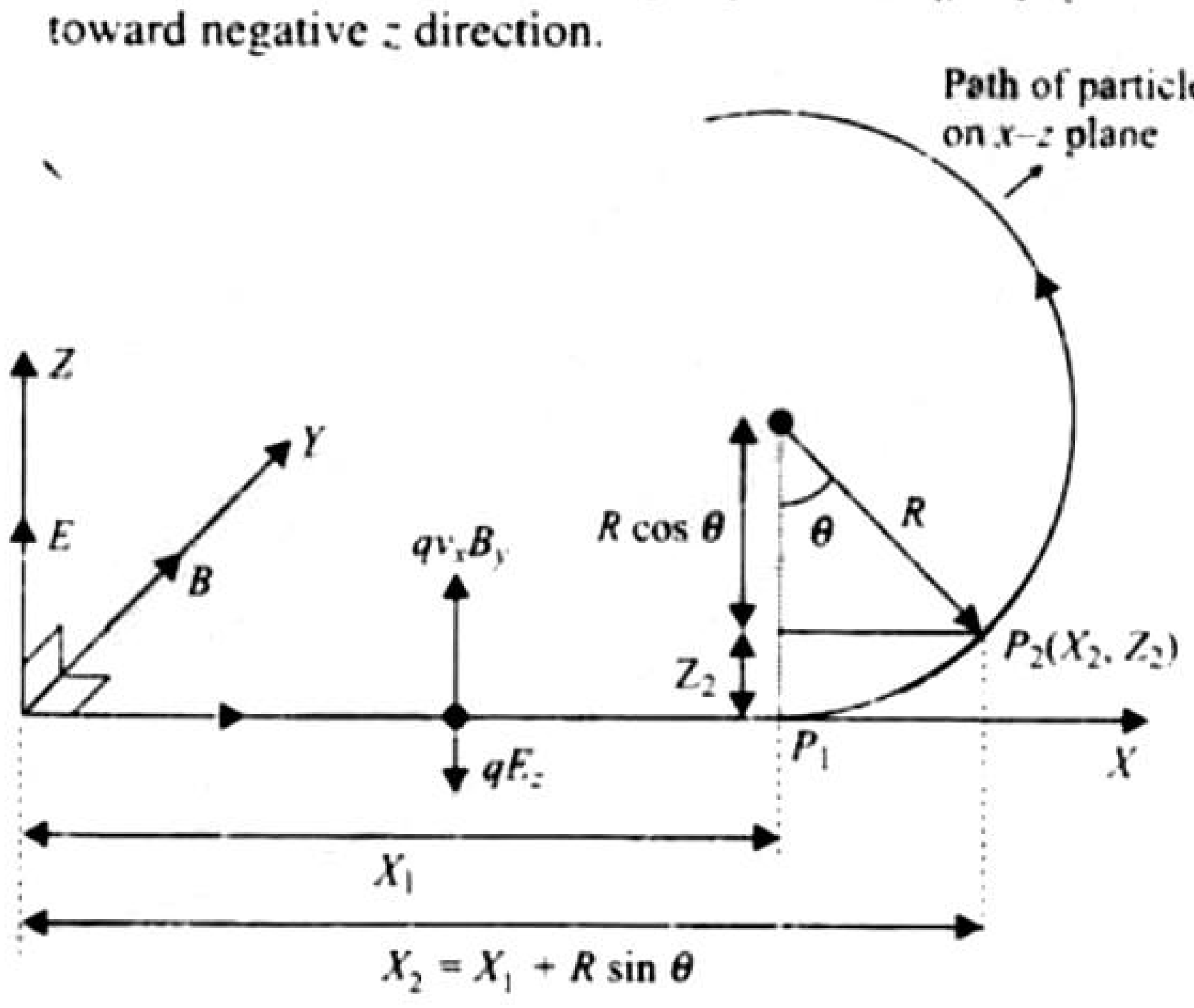
d = distance between the plates

$$B = \frac{600/3 \times 10^{-3}}{2 \times 10^6} = \frac{600}{3 \times 10^{-3} \times 2 \times 10^6} \Rightarrow B = 0.1 \text{ T}$$

2. The Lorentz force on the charged particle is

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

The electric force on the charged particle, $F_E = qE_z$ which acts toward negative z direction.



The magnetic force on the charged particle, $F_B = qv_xB_y$.

As velocity of charge is in +x direction and magnetic field is along +y direction, from right hand rule the magnetic force acts along +z direction. The resultant force,

$$F = F_E + F_B = q\,(E_z + v_x B_y)$$
$$= q\,[-102.4 \times 10^3 + 1.28 \times 10^6 \times 8 \times 10^{-2}] = 0$$

During time $t = 0$ to $t_1 = 5 \times 10^{-6}$, the resultant force on the particle is zero, it moves with uniform velocity v_x. The position of the particle (X_1, Y_1, Z_1) after time t_1 is

$$X_1 = v_x t_1 = (1.28 \times 10^6) \times (5 \times 10^{-6}) = 6.4 \text{ m}$$

When electric field is switched off, the particle circulates in xz-plane under the influence of magnetic field.

Radius R of circulation is

$$R = \frac{mv_x}{qB_y} = \frac{10^{-26} \times 1.28 \times 10^6}{1.6 \times 10^{-19} \times 8 \times 10^{-2}} = 1 \text{ m}$$

$$\theta = \frac{P_1P_2}{R} = \frac{v_x(t_2 - t_1)}{R} = \frac{(1.28 \times 10^6) \times (2.45 \times 10^{-6})}{1}$$
$$= 3.136 \simeq \pi \text{ radian}$$

The coordinates of the particle are

$$X_2 = X_1 + R \sin \theta = X_1 + R \sin \pi = X_1 = 6.4 \text{ m}$$

and $Z_2 = R - R \cos \theta = R - R \cos \pi = 2R = 2$ m

Note that $\theta = \pi$ implies that $t_2 = T/2$, where T is time period of circulation. We could have written the result directly.

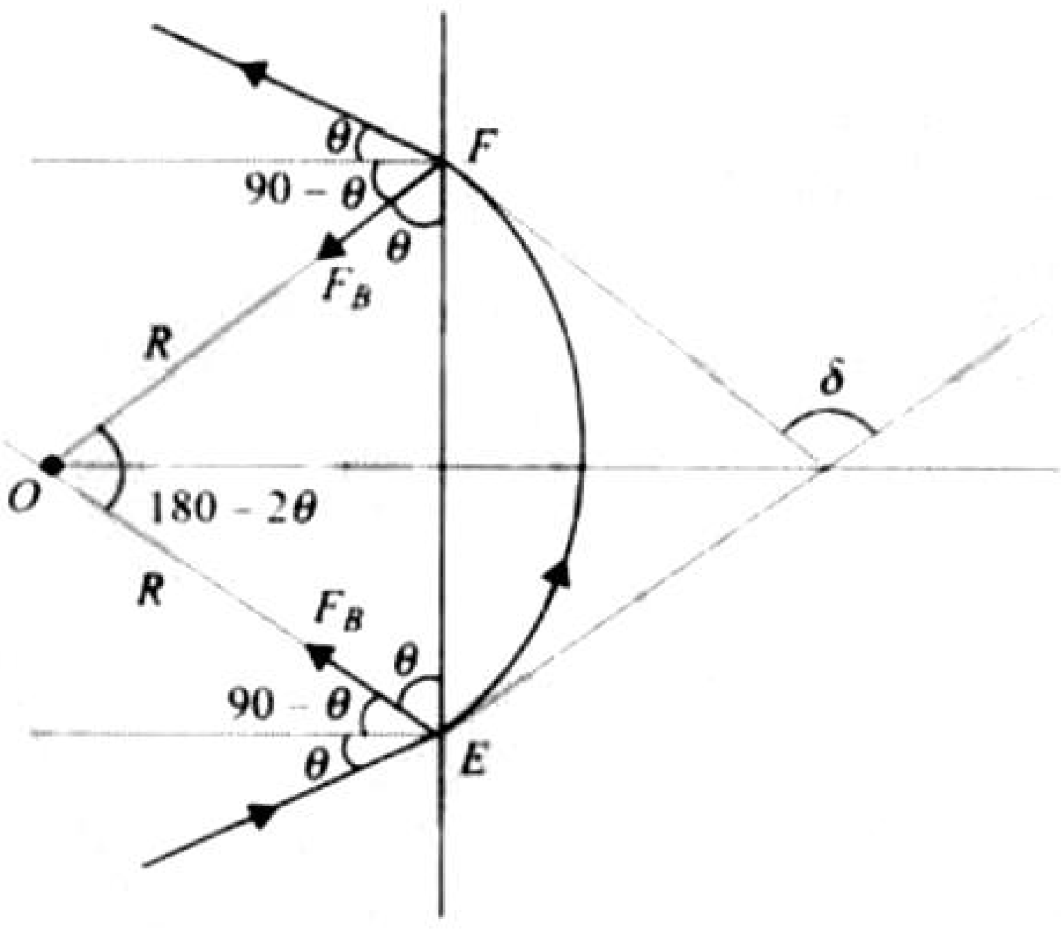
3. a. The particle circulates under the influence of magnetic field. As the magnetic field is uniform, the charge comes out symmetrically. The angle subtended at the center is $(180 - 2\theta)$.

b. The length of the arc traced by the particle, $l = R(\pi - 2\theta)$

Time spent in the field, $t = \frac{l}{v} = \frac{R(\pi - 2\theta)}{v}$ and $R = \frac{mv}{Bq}$

which gives $t = \frac{m}{Bq}(\pi - 2\theta)$

As time period: $T = \frac{2\pi m}{Bq}$, hence $t = \frac{T}{2\pi}(\pi - 2\theta)$



We can generalize this result. If ϕ is the angle subtended by the arc traced by the charged particle in the magnetic field, the time spent is $t = T\left(\frac{\phi}{2\pi}\right)$

c. Intercept $EF = 2R \cos \theta$

4. The radius of helical path $r = \frac{mv_\perp}{Bq}$

$$r = \frac{mv \sin\theta}{Bq} = \frac{(1.67 \times 10^{-27})(4 \times 10^5)(\sin 60°)}{(0.3)(1.6 \times 10^{-19})}$$
$$= 1.2 \times 10^{-2} \text{ m}$$

Pitch of helical path $p = v_{\parallel} \times T$

$$p = \left(\frac{2\pi m}{Bq}\right)(v \cos \theta)$$
$$= \frac{(2\pi)(1.67 \times 10^{-27})(4 \times 10^5)(\cos 60°)}{(0.3)(1.6 \times 10^{-19})} = 4.37 \times 10^{-2} \text{ m}$$

5. a. Direction of current at B should be perpendicular to paper outwards. Let current in this wire be i_B. Then

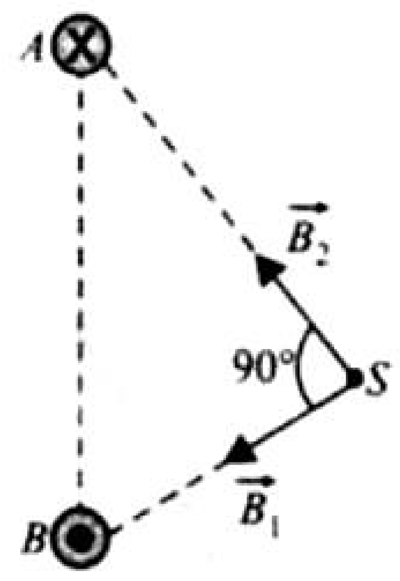
$$\frac{\mu_0}{2\pi}\frac{i_A}{\left(2 + \frac{10}{11}\right)} = \frac{\mu_0}{2\pi}\frac{i_B}{(10/11)}$$

or $\frac{i_B}{i_A} = \frac{10}{32}$

or $i_B = \frac{10}{32} \times i_A = \frac{10}{32} \times 9.6 = 3\text{A}$

b. Since $AS^2 + BS^2 = AB^2$

$\therefore$ $\angle ASB = 90°$



At S: B_1 = Magnetic field due to i_A

$$= \frac{\mu_0}{2\pi}\frac{i_A}{1.6} = \frac{(2 \times 10^{-7})(9.6)}{1.6}$$
$$= 12 \times 10^{-7} \text{ T}$$

B_2 = Magnetic field due to $i_B = \frac{\mu_0}{2\pi}\frac{i_B}{1.2} = \frac{(2 \times 10^{-7})(3)}{1.2}$

$$= 5 \times 10^{-7} \text{ T}$$

Since B_1 and B_2 are mutually perpendicular, net magnetic field at S would be:

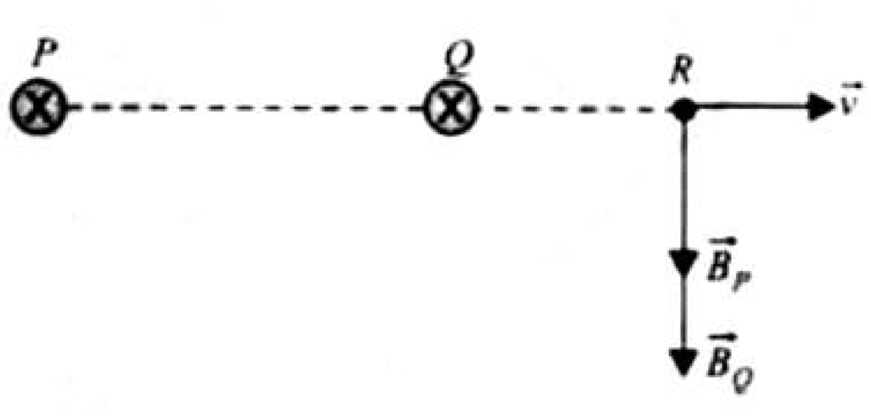
$$B = \sqrt{B_1^2 + B_2^2} = \sqrt{(12 \times 10^{-7})^2 + (5 \times 10^{-7})^2}$$
$$= 13 \times 10^{-7} \text{ T}$$

c. Force per unit length on wire B:

$$\frac{F}{l} = \frac{\mu_0}{2\pi}\frac{i_A i_B}{r} \quad (r = AB = 2 \text{ m})$$
$$= \frac{(2 \times 10^{-7})(9.6 \times 3)}{2} = 2.88 \times 10^{-6} \text{ N m}^{-1}$$

6. a. Magnetic field at R due to both wires P and Q will be downward as shown in the figure. Therefore, net field at R will be sum of these two.

$$B = B_P + B_Q = \frac{\mu_0}{2\pi}\frac{I_P}{5} + \frac{\mu_0}{2\pi}\frac{I_Q}{2} = \frac{\mu_0}{2\pi}\left(\frac{2.5}{5} + \frac{I}{2}\right)$$
$$= \frac{\mu_0}{4\pi}(I + 1) = 10^{-7}(I + 1)$$



Net force on the electron $F = Bqv \sin 90°$

or $(3.2 \times 10^{-20}) = (10^{-7})(I + 1)(1.6 \times 10^{-19})(4 \times 10^5)$

or $I + 1 = 5$ $\therefore$ $I = 4$ A

b. Net field at R due to wires P and Q is

$$B = 10^{-7}(I + 1)\,T = 5 \times 10^{-7}\,\text{T}$$

Magnetic field due to third wire carrying a current of 2.5 A should be 5×10^{-7} T in upward direction so that net field at R becomes zero. Let distance of this wire from R be r. Then,

$$\frac{\mu_0}{2\pi}\frac{2.5}{r} = 5\times10^{-7} \quad \text{or} \quad \frac{(2\times10^{-7})(2.5)}{r} = 5\times10^{-7}\,\text{m}$$

or $\quad r = 1$ m

So, the third wire can be put at M or N as shown in the figure. If it is placed at M, then current in it should be outwards and if placed at N, then current will be inward.

7. As point O is along the length of segments L and M, so the field at O due to these segments will be zero. Also, point O is near one end of a long wire.

The resultant field at O, $B_R = B_P + B_Q$, this field will be into the plane of paper.

$$\Rightarrow \quad B_R = \frac{\mu_0}{4\pi}\frac{I}{RO} + \frac{\mu_0}{4\pi}\frac{I}{SO}$$

But $\quad RO = SO = 0.02$ m

Hence, $B_R = 2 \times \frac{\mu_0}{4\pi} \times \frac{10}{0.02} = 2\times10^{-7}\,\frac{10}{0.02} = 10^{-4}$ Wb m^{-2}

8. a. As in case of current-carrying straight conductor and arc, the magnitude of B is given by

$$B_1 = \frac{\mu_0 I}{4\pi d}(\sin\alpha + \sin\beta) \text{ and } B_2 = \frac{\mu_0 I\phi}{4\pi r}$$

So in accordance with right hand screw rule,

$$\left(\vec{B}_w\right) = \frac{\mu}{4\pi}\frac{I}{(a\cos 60^o)} \times 2\sin 60°(-\hat{k}) \text{ and}$$

$$\left(\vec{B}\right)_{MN} = \frac{\mu_0 I}{2a}\left[\frac{2\pi/3}{2\pi}\right](\hat{k})a$$

and hence net $\vec{B}$ at P due to the given loop

$$\vec{B} = \vec{B}_w + \vec{B}_A \quad \Rightarrow \quad \vec{B} = \frac{\mu_o}{4\pi}\frac{2I}{a}\left[\sqrt{3} - \frac{\pi}{3}\right]\left(-\hat{k}\right) \qquad \text{(i)}$$

Now as force on charged particle in a magnetic field is given by $\vec{F} = q\left(\vec{v} \times \vec{B}\right)$

so here, $\vec{F} = qvB\sin 90°$ along PF

i.e. $\quad \vec{F} = \frac{\mu_0}{4\pi}\frac{2QvI}{a}\left[\sqrt{3} - \frac{\pi}{3}\right]$ along PF

and so $\vec{a} = \frac{\vec{F}}{m} = 10^{-7}\frac{2QvI}{ma}\left[\sqrt{3} - \frac{\pi}{3}\right]$ along PF

b. As $d\vec{F} = Id\vec{L} \times \vec{B}$, so $\vec{F} = \int Id\vec{L} \times \vec{B}$

As here I and $\vec{B}$ are constant

$$\vec{F} = \left[\oint d\vec{L}\right] \times \vec{B} = 0 \qquad \left[as \oint d\vec{L} = 0\right]$$

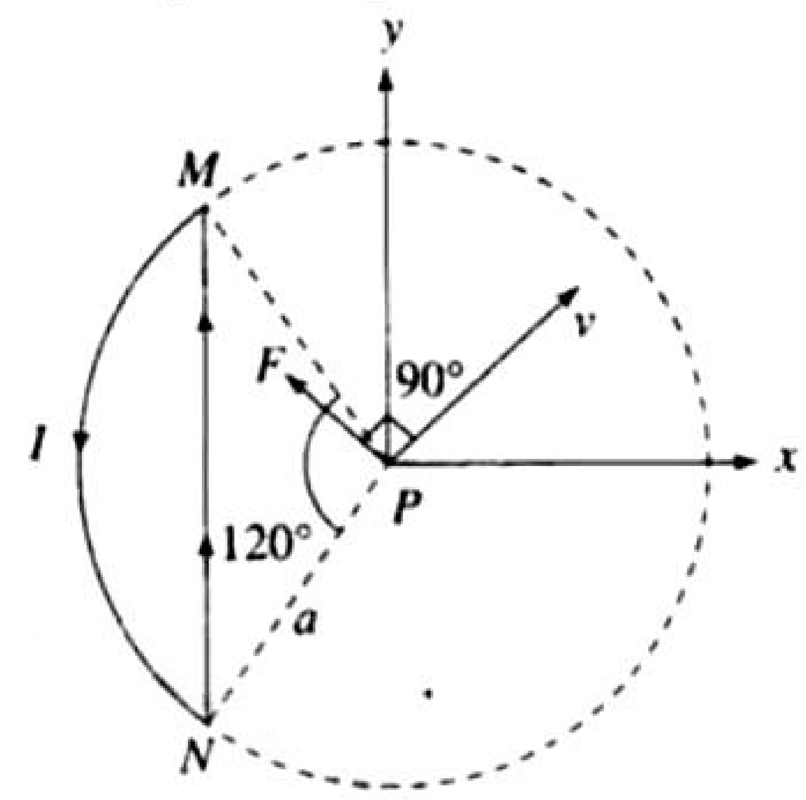
Further as area of coil,

$$\vec{S} = \left[\frac{1}{3}\pi a^2 - \frac{1}{2}.2a\sin 60° \times a\cos 60°\right]\hat{k} = a^2\left[\frac{\pi}{3} - \frac{\sqrt{3}}{4}\right]\hat{k}$$

so $\quad \vec{M} = I\vec{S} = Ia^2\left[\frac{\pi}{3} - \frac{\sqrt{3}}{4}\right]\hat{k}$

and hence $\vec{\tau} = \vec{M} \times \vec{B} = Ia^2 B\left[\frac{\pi}{3} - \frac{\sqrt{3}}{4}\right]\left(\hat{k} \times \hat{i}\right)$

$$\Rightarrow \quad \vec{\tau} = Ia^2 B\left[\frac{\pi}{3} - \frac{\sqrt{3}}{4}\right]\hat{j}\ \text{Nm}$$



9. Let us take an element of thickness dx at a distance x from origin on the wire OC. Magnetic field B_A produced at P $(x,0,0)$ due to wires placed at A and B are

$$B_A = \mu_0 I/2\pi R, \quad B_B = \mu_0 I/2\pi R$$

Components of B_A and B_B along x-axis cancel, while those along y-axis add up to give total field,

$$B = 2\left(\frac{\mu_0 I}{2\pi R}\right)\cos\theta = \frac{2\mu_0 I}{2\pi R}\frac{x}{R} = \frac{\mu_0 I}{\pi}\frac{x}{(a^2 + x^2)}$$

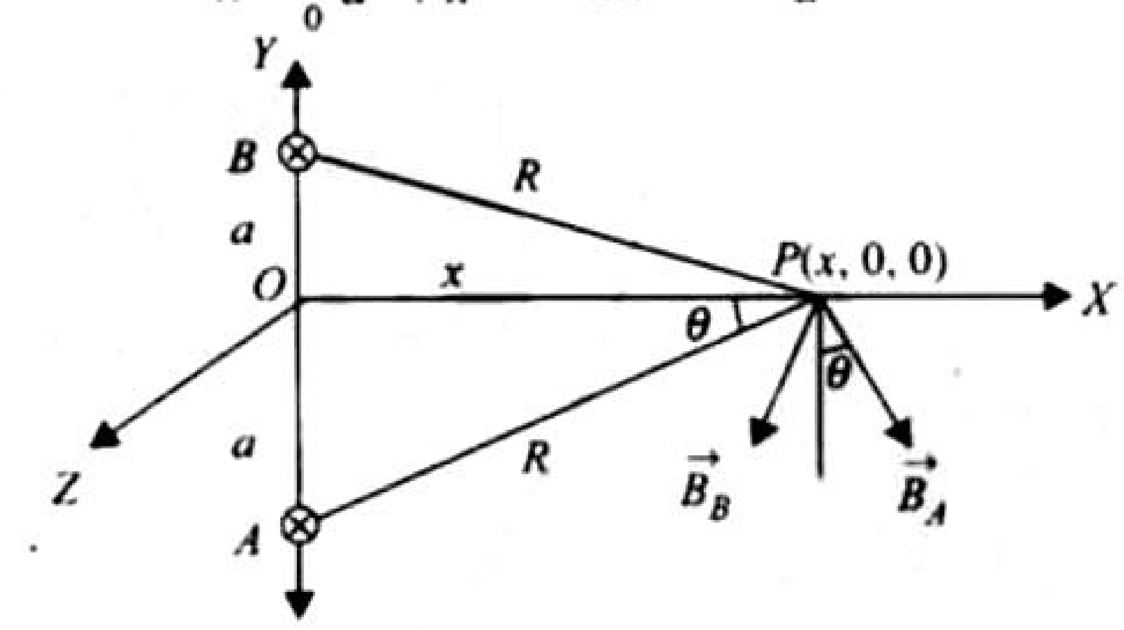
The force dF acting on the current element is

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

$$dF = \frac{\mu_0 I^2}{\pi}\frac{xdx}{a^2 + x^2} \qquad [\because \sin 90° = 1]$$

Hence, net force on wire OC, $F = \int dF$

i.e., $F = \frac{\mu_0 I^2}{\pi}\int_0^L \frac{xdx}{a^2 + x^2} = \frac{\mu_0 I^2}{2\pi}\ln\frac{a^2 + L^2}{a^2}$ along $-z$ direction.



If the current in B is reversed, the magnetic field due to the two wires would be only along x-direction and the force on the current carrying wire along x-direction will be zero.

10. Kinetic energy of electron, $K = \frac{1}{2}mv^2 = 2$ keV

$$\therefore \text{Speed of electron, } v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2\times2\times1.6\times10^{-16}}{9.1\times10^{-31}}}\ \text{m s}^{-1}$$

$= 2.65 \times 10^7$ m s^{-1}

Since the velocity $(\vec{v})$ of the electron makes an angle of $\theta = 60°$ with the magnetic field $\vec{B}$, the path will be a helix. So, the particle will hit S if $GS = np$; Here, $n = 1, 2, 3, \ldots$

$$p = \text{pitch of helix} = \frac{2\pi m}{qB}v\cos\theta$$

$$\Rightarrow \quad GS = \frac{n\, 2\pi\, mv\cos\theta}{qB}$$

$$\Rightarrow \quad B = \frac{n\, 2\pi\, mv\cos\theta}{q(GS)}$$

But for B to be minimum, $n = 1$

$$B_{min} = \frac{2\pi mv\cos\theta}{q(GS)}$$

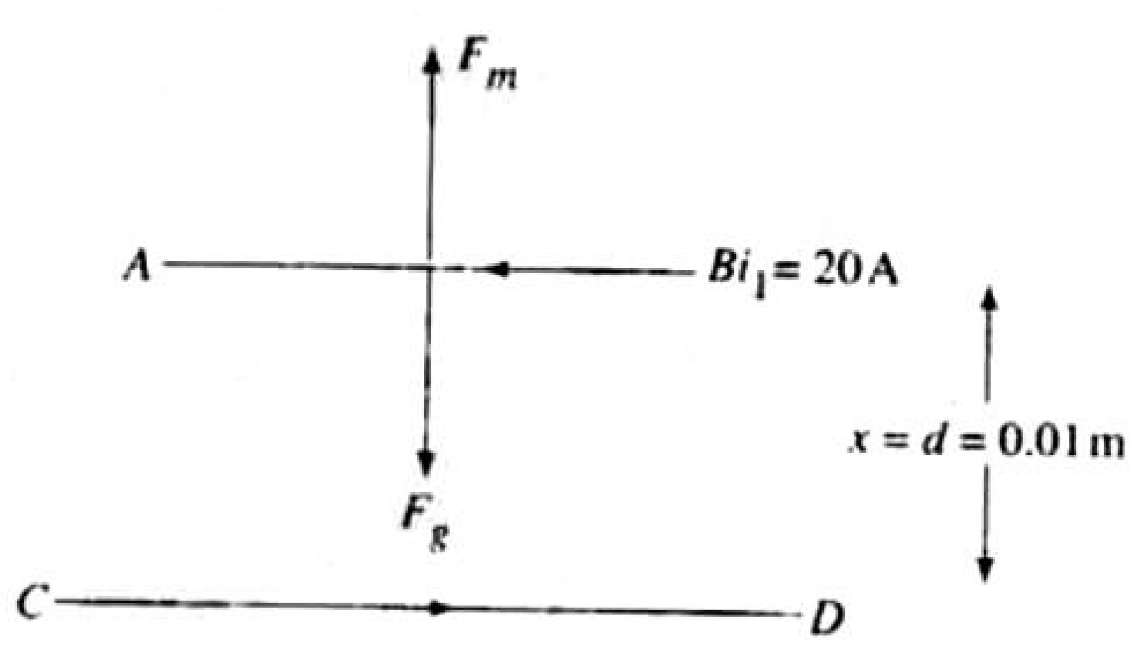
Substituting the values, we have

$$B_{min} = \frac{(2\pi)(9.1\times10^{-31})(2.65\times10^{7})\left(\frac{1}{2}\right)}{(1.6\times10^{-19})(0.1)}$$

or $\quad B_{min} = 4.73\times10^{-3}$ T

11. Let m be the mass per unit length of wire AB. At a height x above the wire CD, magnetic force per unit length on wire AB will be given by

$$F_m = \frac{\mu_0}{2\pi}\frac{i_1 i_2}{x} \quad \text{(upward)} \qquad \text{(i)}$$



Weight per unit length of wire AB is

$$F_g = mg \quad \text{(downwards)}$$

Here, m = mass per unit length of wire AB

At $x = d$, wire is in equilibrium, i.e.,

$$F_m = F_g; \text{ or } \frac{\mu_0}{2\pi}\frac{i_1 i_2}{d} = mg$$

When AB is depressed, x decreases therefore, F_m will increase, while F_g remains the same. Let AB be displaced by dx downwards. Differentiating Eq. (i) w.r.t. x, we get

$$\frac{dF_m}{dx} = -\frac{\mu_0}{2\pi}\frac{i_1 i_2}{x^2}dx = \frac{-\mu_0}{2\pi}\frac{i_1 i_2}{d^2}dx$$

$$\Rightarrow \quad dF_m = -\left(\frac{mg}{d}\right)dx \qquad \text{(ii)}$$

i.e., restoring force, $dF_m \propto -dx$

Hence, the motion of wire is simple harmonic.

$\therefore$ Acceleration of wire $a = \frac{dF_m}{m} = -\left(\frac{g}{d}\right)\cdot dx$

Hence, period of oscillation

$$T = 2\pi\sqrt{\left|\frac{dx}{a}\right|} = 2\pi\sqrt{\frac{|\text{displacement}|}{|\text{acceleration}|}}$$

or $\quad T = 2\pi\sqrt{\frac{d}{g}} = 2\pi\sqrt{\frac{0.01}{9.8}}$ or $T = 0.2$ s

12. a. In ground state ($n = 1$) according to Bohr's theory:

$$mvR = \frac{h}{2\pi} \text{ or } v = \frac{h}{2\pi mR}$$

Now time period, $T = \frac{2\pi R}{v} = \frac{2\pi R}{h/2\pi mR} = \frac{4\pi^2 mR^2}{h}$

Magnetic moment $M = iA$

where $I = \frac{\text{charge}}{\text{time period}} = \frac{e}{\frac{4\pi^2 mR^2}{h}} = \frac{eh}{4\pi^2 mR^2}$

and $\quad A = \pi R^2$

$\therefore \quad M = (\pi R^2)\left(\frac{eh}{4\pi^2 mR^2}\right)$ or $M = \frac{eh}{4\pi m}$

Direction of magnetic moment $\vec{M}$ is perpendicular to the plane of orbit.

b. $\quad \vec{\tau} = \vec{M}\times\vec{B}$

$|\vec{\tau}| = MB\sin\theta$

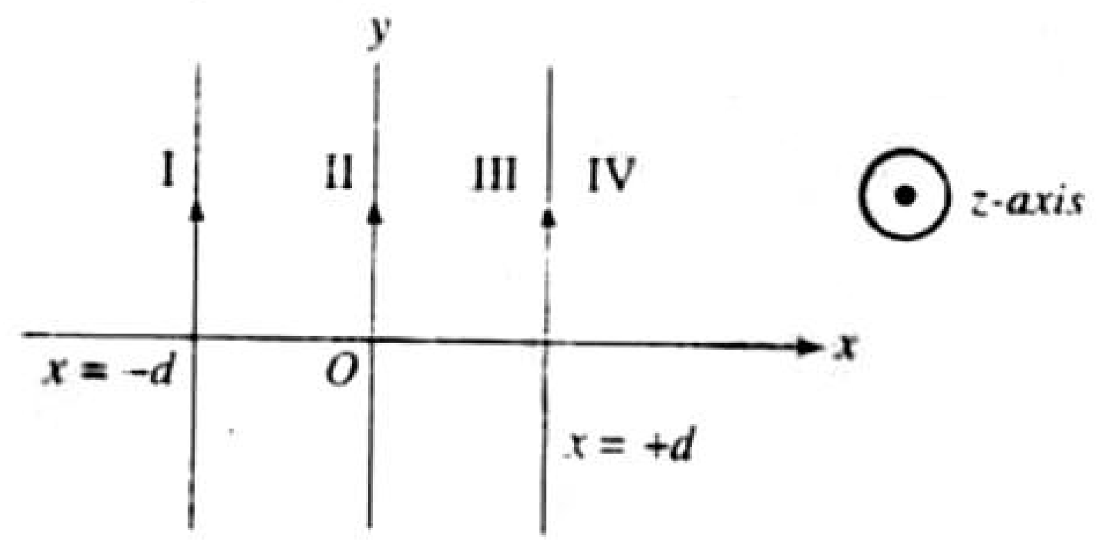
where θ is the angle between $\vec{M}$ and $\vec{B}$ $\theta = 30°$

$\therefore \quad \tau = \left(\frac{eh}{4\pi m}\right)(B)\sin 30° = \frac{ehB}{8\pi m}$

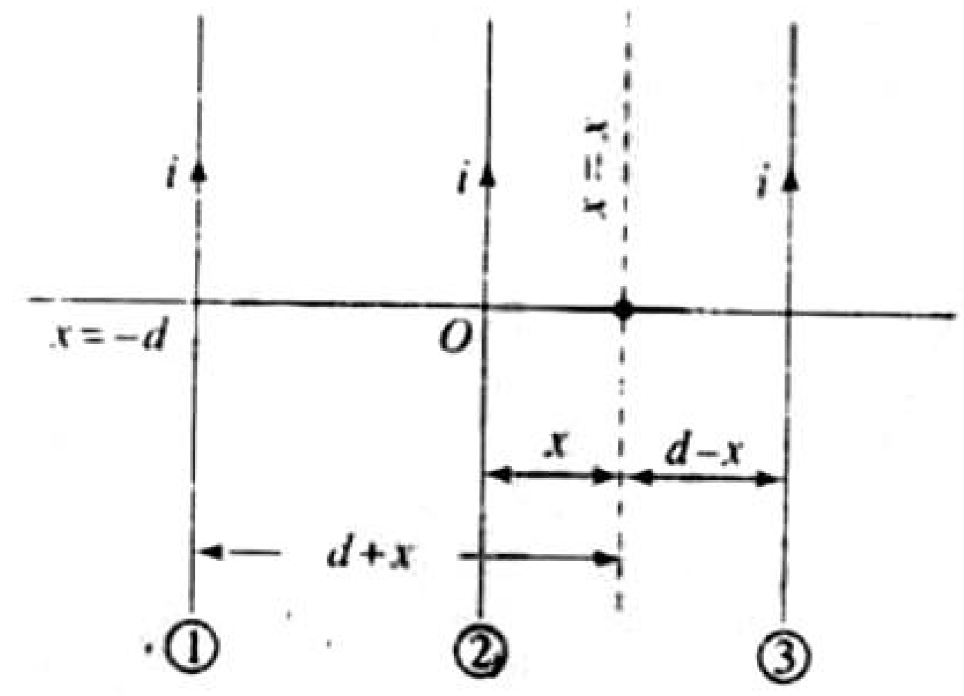
The direction of $\vec{\tau}$ is perpendicular to both $\vec{M}$ and $\vec{B}$.

13. a. Magnetic field will be zero on the y-axis i.e.,

$$x = 0 = z$$



magnetic field cannot be zero in region I and region IV because in region I magnetic field is along positive z-direction due to all the three wires, while in region IV magnetic field is along negative z-axis due to all the three wires. It can be zero only in region II and III.



Let magnetic field be zero on line ($z = 0$) and $x = x$. Then magnetic field on this line due to wires (1) and (2) will be along negative z-axis and due to wire (3) along positive z-axis. Thus,

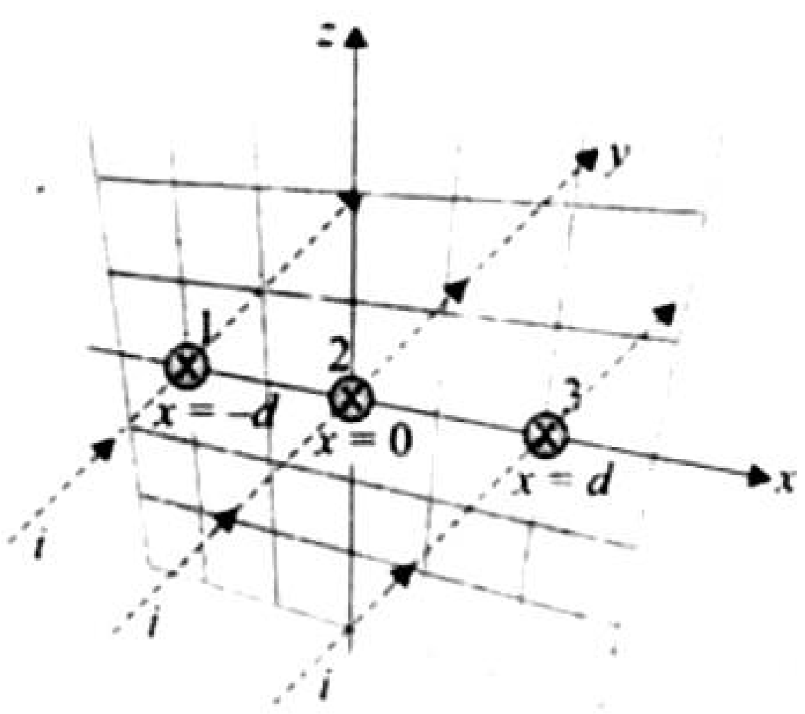
$$B_1 + B_2 = B_3$$

or $\quad \frac{\mu_0}{2\pi}\frac{i}{d+x} + \frac{\mu_0}{2\pi}\frac{i}{x} = \frac{\mu_0}{2\pi}\frac{i}{d-x}$

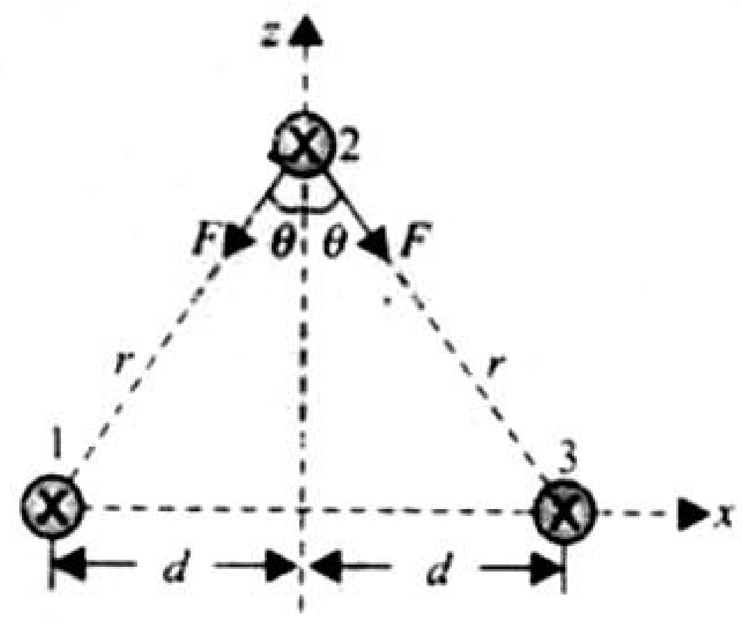
or $\quad \frac{1}{d+x} + \frac{1}{x} = \frac{1}{d-x}$

This equation gives $x = \pm\frac{d}{\sqrt{3}}$ where magnetic field is zero.

b. In this part we change our coordinate axes system just for better understanding.



There are three wires (1), (2) and (3) as shown in the above figure. If we displace wire (2) toward the z-axis, then force of attraction per unit length between wires (1 and 2) and (2 and 3) will be given by



$$F = \frac{\mu_0}{2\pi}\frac{i^2}{r}$$

The components of F along x-axis will be cancelled out. Net resultant force will be towards negative z-axis (or mean position) and will be given by

$$F_{net} = \frac{\mu_0}{2\pi}\frac{i^2}{r}(2\cos\theta) = 2\left\{\frac{\mu_0}{2\pi}\frac{i^2}{r}\right\}\frac{z}{r} = \frac{\mu_0}{\pi}\frac{i^2}{(z^2+d^2)}z$$

If $z << d$, then $Z^2 + d^2 = d^2$ and $F_{net} = -\left(\frac{\mu_0}{\pi}\frac{i^2}{d^2}\right)z$

Negative sign implies that F_{net} is restoring in nature

Therefore, $F_{net} \propto -z$

i.e., the wire will oscillate simple harmonically.

Let a be the acceleration of wire in this position and λ is the mass per unit length of this wire then

$$F_{net} = \lambda.a = -\left(\frac{\mu_0}{\pi}\frac{i^2}{d^2}\right)z \quad \text{or} \quad a = -\left(\frac{\mu_0 i^2}{\pi\lambda d^2}\right)z a$$

Therefore, frequency of oscillation

$$f = \frac{1}{2\pi}\sqrt{\frac{a}{z}} = \frac{1}{2\pi}\frac{i}{d}\sqrt{\frac{\mu_0}{\pi\lambda}} = f = \frac{i}{2\pi d}\sqrt{\frac{\mu_0}{\pi\lambda}}$$

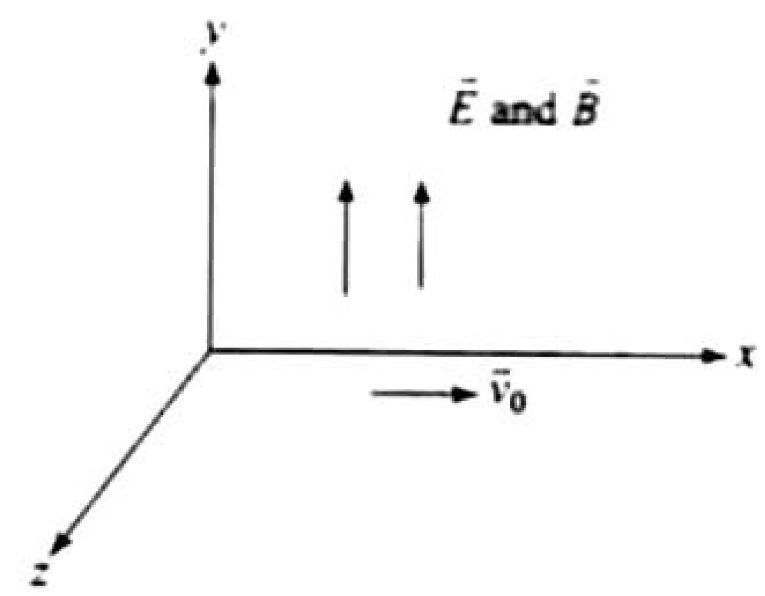
14. $\hat{j} = \frac{\vec{E}}{E}$ or $\frac{\vec{B}}{B}$; $\hat{i} = \frac{\vec{v}_0}{v_0}$; $\hat{k} = \frac{\vec{v}_0 \times \vec{B}_0}{v_0 B}$

Force due to electric field will be along y-axis. Magnetic force will not affect the motion of charged particle in the direction of electric field (or y-axis) so.

$$a_y = \frac{F_e}{m} = \frac{qE}{m},$$

$$v_y = a_y t$$

$$= \frac{qE}{m}T \qquad \text{(i)}$$



The charged particle under the action of magnetic field describes a circle in x–z plane (perpendicular to $\vec{B}$) with $T = \frac{2\pi m}{Bq}$ or

$$\omega = \frac{2\pi}{T} = \frac{qB}{m}$$

Initially ($t = 0$) velocity was along x-axis. Therefore, magnetic force $(\vec{F}_m)$ will be along positive z-axis $\left[\vec{F}_m = q(\vec{v}_0 \times \vec{B})\right]$. Let it this force makes an angle θ with x - axis at time t, then

$$\theta = \omega t$$

$$\therefore \quad v_x = v_0 \cos\omega t = v_0 \cos\left(\frac{qB}{m}t\right) \qquad \text{(ii)}$$

$$v_z = v_0 \sin\omega t = v_0 \sin\left(\frac{qB}{m}t\right) \qquad \text{(iii)}$$

From Eqs (i), (ii), and (iii)

$$\vec{v} = v_x\hat{i} + v_y\hat{j} + v_z\hat{k}$$

$$\therefore \vec{v} = v_0\cos\left(\frac{qB}{m}t\right)\left(\frac{\vec{v}_0}{v_0}\right) + \frac{qE}{m}t\left(\frac{\vec{E}}{E}\right) + v_0\sin\left(\frac{qB}{m}t\right)\left(\frac{\vec{v}_0 \times \vec{B}}{v_0 B}\right)$$

Or $$\vec{v} = \cos\left(\frac{qB}{m}t\right)(\vec{v}_0) + \left(\frac{q}{m}t\right)(\vec{E}) + \sin\left(\frac{qB}{m}t\right)\left(\frac{\vec{v}_0 \times \vec{B}}{B}\right)$$

Note: The path of the particle will be a helix of increasing pitch. The axis of the helix will be along y-axis.

15.a. As magnetic field is in x–y plane and subtends an angle of 45° with x-axis,

$$B_x = B\cos 45° = B/\sqrt{2}$$

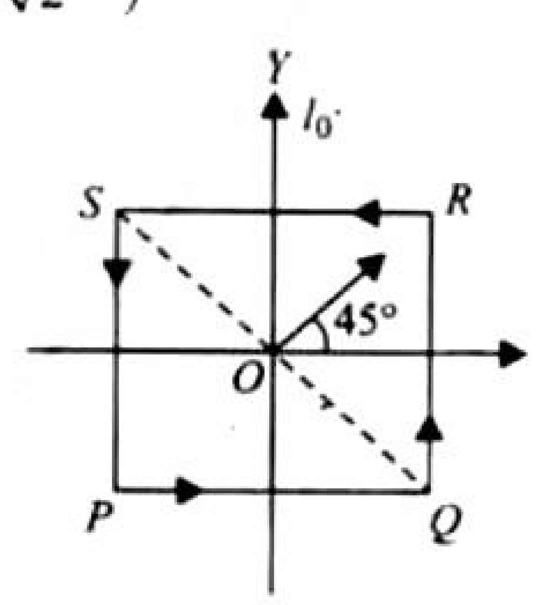
and $$B_y = B\sin 45° = B/\sqrt{2}$$

so, in vector form $\vec{B} = \hat{i}(B/\sqrt{2}) + \hat{j}(B/\sqrt{2})$

and $\vec{M} = I_0 S\hat{k} = I_0 L^2\hat{k}$

$$\Rightarrow \quad \vec{\tau} = \vec{M} \times \vec{B} = I_0 L^2\hat{k} \times \left(\frac{B}{\sqrt{2}}\hat{i} + \frac{B}{\sqrt{2}}\hat{j}\right)$$

$$\Rightarrow \quad \vec{\tau} = \frac{I_0 L^2 B}{\sqrt{2}} \times (-\hat{i} + \hat{j})$$



i.e., torque has magnitude $I_0 L^2 B$ and is directed along the line QS from Q to S.

b. By the theorem of perpendicular axis, moment of inertia of the frame about QS,

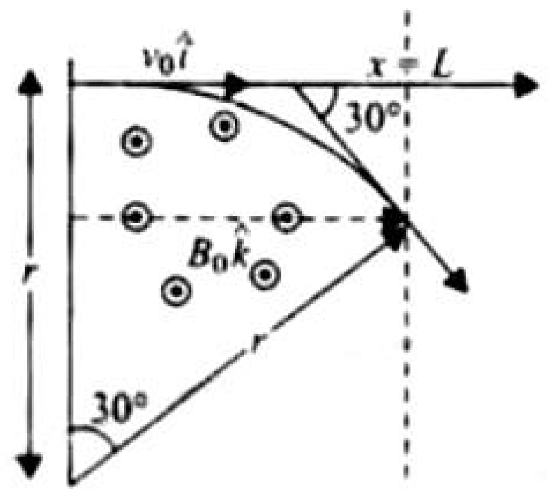
$$I_{QS} = \frac{1}{2}I_z = \frac{1}{2}\left(\frac{4}{3}ML^2\right) = \frac{2}{3}ML^2$$

as $\tau = I\alpha \Rightarrow \alpha = \frac{\tau}{I} = \frac{I_0 L^2 B \times 3}{2L^2 M} = \frac{3}{2}\frac{I_0 B}{M}$

As here α is constant, equations of circular motion are valid. Hence, from $\theta = \omega_0 t + \frac{1}{2}\alpha t^2$, with $\omega_0 = 0$, we have

$$\theta = \frac{1}{2}\alpha t^2 = \frac{1}{2}\left(\frac{3}{2}\frac{I_0 B}{M}\right)(\Delta t)^2 = \frac{3}{4}\frac{I_0 B}{M}\Delta t^2$$

16. a. As the initial velocity of the particle is perpendicular to the field, the particle will move along the arc of a circle as shown in the figure. If r is the radius of the circle, then



$$\frac{mv_0^2}{r} = qv_0B_0 \Rightarrow r = \frac{mv_0}{qB_0}$$

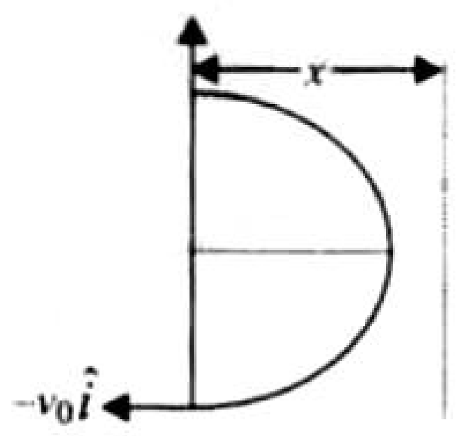
Also, from geometry, $L = r\sin 30°$

$\Rightarrow \quad r = 2L$

or $\quad L = \frac{r}{2} = \frac{mv_0}{2qB_0}$

b. In this case, $x = \frac{2.1mv_0}{2qB_0} > r$

Hence, the particle will complete semi-circular path and emerge from the field with velocity $-v_0\hat{i}$ as shown in the figure. Time spent by the particle in the magnetic field



$$T = \frac{\pi r}{v_0} = \frac{\pi m}{qB_0}$$

The speed of the particle does not change due to magnetic field.

17. a. Magnetic field at the center due to the straight parts is zero.

Magnetic field due to the arcs of radius r_1:

$= 4(\mu_0 i / 2r_1)(1/8) = (\mu_0 i / 4r_1)$

Similarly, the magnetic field due to the arcs of radius r_2:

$= (\mu_0 i / 4r_2)$

$\Rightarrow$ Net magnetic field

$= (\mu_0 i/4)\{1/r_1 + 1/r_2\} = 6.54 \times 10^{-5}$ T

b. **i.** As the current in the wire at the center is antiparallel to the direction of magnetic field, the force on the wire everywhere will be zero.

ii. Further due to the current at the center, the magnetic field at AC will be tangential and hence the force on AC will be zero.

iii. Force on $CD = \int_{r_1}^{r_2}\frac{\mu_0 i}{2\pi x}i\,dx = \frac{\mu_0 i^2}{2\pi}\ln\left(\frac{r_2}{r_1}\right)$

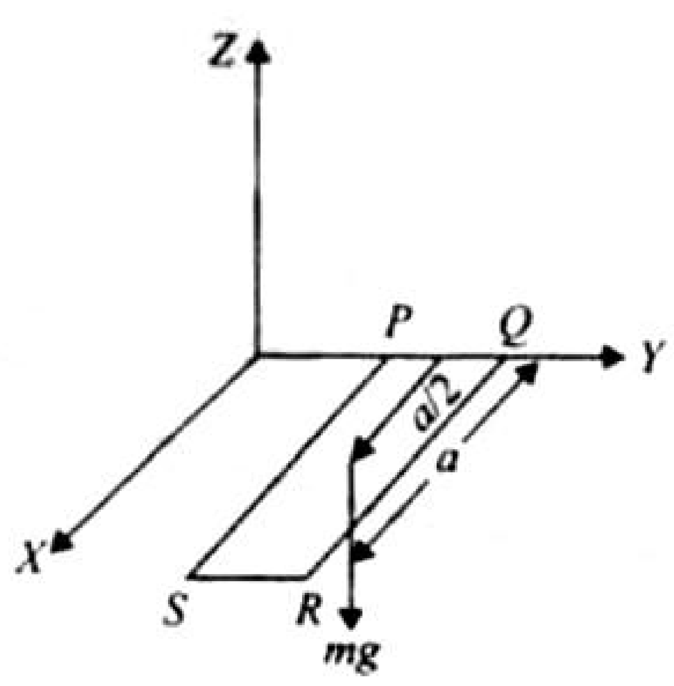
$= 8.11 \times 10^{-6}$ N

(Vertically downward)

18. a. Torque due to weight of coil,

$$\vec{\tau} = \left(\frac{a}{2}\hat{i}\right) \times (-mg\hat{k}) = mg\frac{a}{2}(\hat{j})$$

For the equilibrium of loop, torque on it must be along negative y-axis. Let the magnetic moment of loop be $\mu\hat{k}$. As the loop lies in x–y plane, its magnetic moment vector (from right hand thumb rule) either points up or down.



Torque due to magnetic force,

$$\vec{\tau}_B = \vec{\mu} \times \vec{B} = \mu\hat{k} \times (3\hat{i} + 4\hat{k})B_0 = 3\mu B_0\hat{j}$$

If it is in negative direction, $\vec{\mu}$ must point downward. So, the current in the coil must be from P to Q.

b. Force acting on arm

$$RS = I(\vec{l} \times \vec{B}) = I[(-b\hat{j}) \times (3\hat{i} + 4\hat{k})B_0]$$

$$= IB_0 b(3\hat{k} - 4\hat{i})$$

c. In equilibrium $\vec{\tau}_{gravity} + \vec{\tau}_B = 0$

Hence, $3(abI)B_0 = \frac{mga}{2}$ or $I = \frac{mg}{6B_0 b}$

19. In equilibrium,

$2T_0 = mg$

or $\quad T_0 = \frac{mg}{2}$ (i)

Magnetic moment, $M = iA = \left(\frac{\omega}{2\pi}Q\right)(\pi R^2)$

$$\tau = MB\sin 90° = \frac{\omega BQR^2}{2}$$

Let T_1 and T_2 be the tensions in the two strings when magnetic field is switched on ($T_1 > T_2$)

For translational equilibrium,

$T_1 + T_2 = mg$ (ii)

For rotational equilibrium

$$(T_1 - T_2)\frac{D}{2} = \tau = \frac{\omega BQR^2}{2}$$

or $\quad T_1 - T_2 = \frac{\omega BQR^2}{D}$ (iii)

Solving Eqs. (ii) and (iii) we have

$$T_1 = \frac{mg}{2} + \frac{\omega BQR^2}{2D}$$

As $T_1 > T_2$ and maximum values of T_1 can be $3T_0/2$, we have

$$\frac{3T_0}{2} = T_0 + \frac{\omega_{max}BQR^2}{2D} \qquad \left(\frac{mg}{2} = T_0\right)$$

$$\therefore \quad \omega_{max} = \frac{DT_0}{BQR^2}$$

20. $eV = \frac{1}{2}mv_P^2 \Rightarrow V_P = \sqrt{\frac{2eV}{m}}$

$$\therefore \quad r_P = \frac{mv_P}{eB} = \frac{1}{B}\sqrt{\frac{2mV}{e}}$$

Similarly $r_\alpha = \frac{1}{B}\sqrt{\frac{4mV}{e}} \therefore \frac{r_P}{r_\alpha} = \frac{1}{\sqrt{2}}$

21. a. The torque acting on the coil of moving coil galvanometer is

$\tau = NiAB$

Given $\tau = ki$

$ki = NiAB \Rightarrow k = NBA$

b. If C is torsional constant of the spring of galvanometer, then

$\tau = C\theta$

$$Ni_0AB = C\left(\frac{\pi}{2}\right) \Rightarrow C = \frac{2NBAi_0}{\pi}$$

c. If q_m is the maximum deflection, then from conservation of energy

$$\frac{1}{2}C\theta_m^2 = \frac{1}{2}I\omega^2 \Rightarrow \theta_m = \sqrt{\frac{I}{C}}\,\omega \qquad \text{(i)}$$

We have $\tau = NiAB$

Put $\tau = \dfrac{dL}{dt}$ where L is angular momentum.

$$\frac{dL}{dt} = N\left(\frac{dQ}{dt}\right)AB \quad \text{or} \quad dL = NAB\,dQ$$

Integrating $\int_0^L dL = NAB\int_0^Q dQ \Rightarrow L = NABQ$

If ω is angular velocity,

put $L = I\omega$

$I\omega = NABQ$

$$\omega = \frac{NABQ}{I} \qquad \text{(ii)}$$

Substituting this value in Eq. (i), we get

$$\theta = \sqrt{\frac{I}{C}}\cdot\frac{NABQ}{I} = \frac{NABQ}{\sqrt{\left\{\dfrac{2NAB\,i_0 l}{\pi}\right\}}} = Q\sqrt{\frac{\pi\,NAB}{2li_0}}$$

22. R = Radius of circular loop. Given that semicircle KNM lies in the x–z plane while the semicircle KLM lies in the y–z plane. Both the semicircles have their centers located at the origin.

a. Charge on the particle released at the origin = q

Velocity of the particle, $\vec{v} = -v_0\hat{i}$

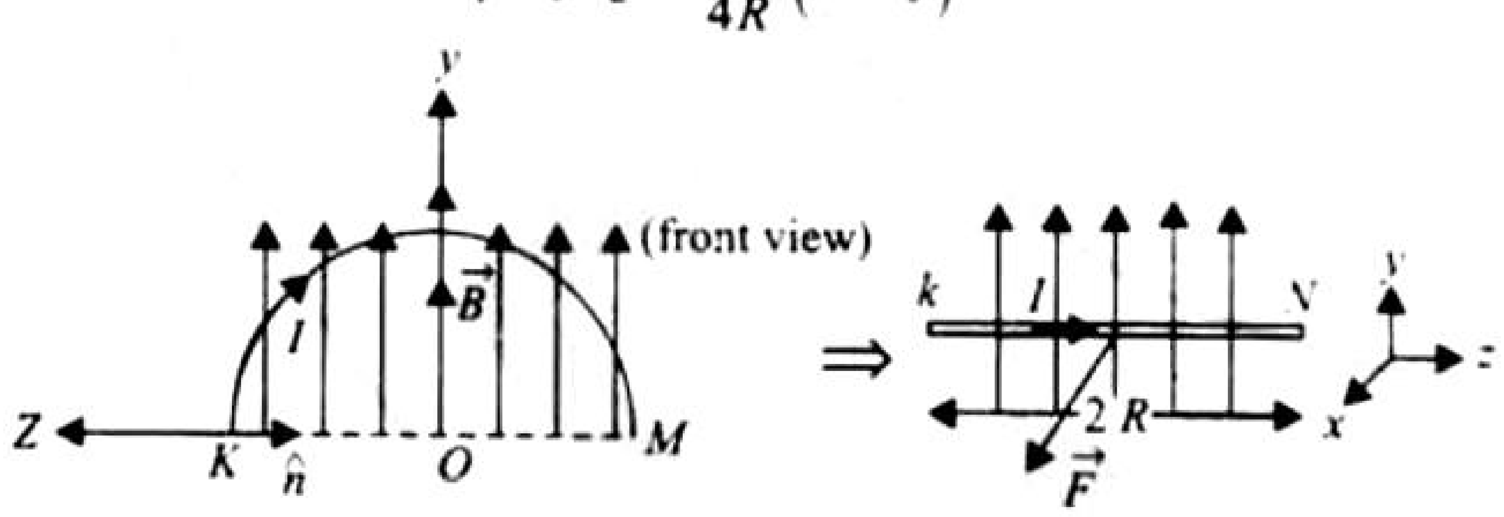
Magnetic field at center O due to current carrying loop KLM lying in y–z plane.

$\vec{B}_1 = \dfrac{\mu_0 I}{4R}(-\hat{i})$. The direction of $\vec{B}_1$ will be along –ve x-axis.

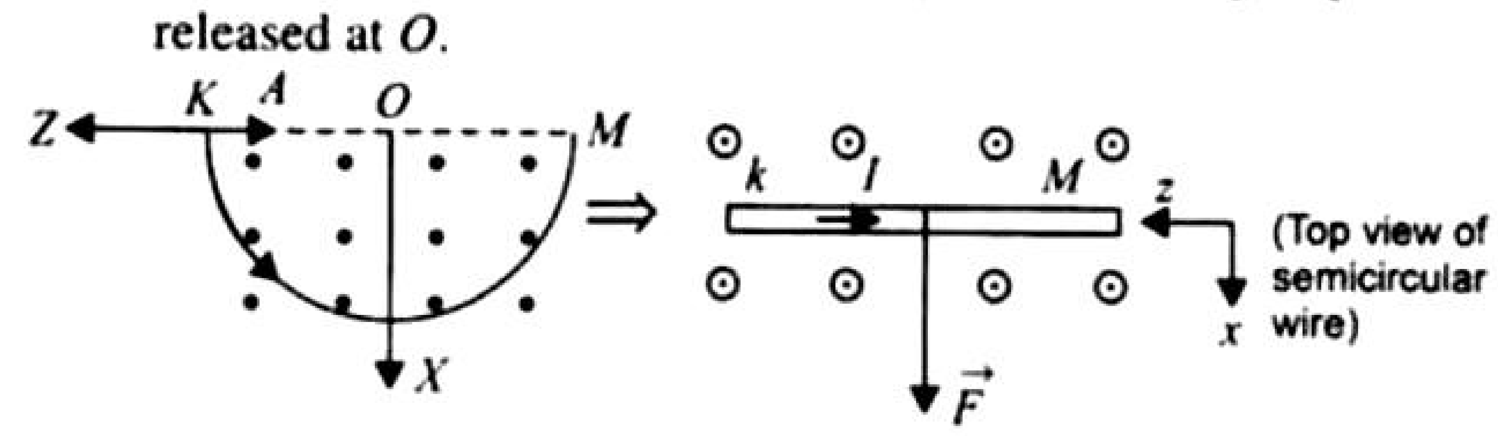
Similarly, magnetic field at center O due to current carrying loop KNM lying in x–z plane, $\vec{B}_2 = \dfrac{\mu_0 I}{4R}(\hat{j})$.

Thus, the two fields at O are mutually perpendicular in vector form. Total field at O can be expressed as

$$\vec{B} = -\hat{i}B_1 + \hat{j}B_2 = \frac{\mu_0 I}{4R}\left(-\hat{i}+\hat{j}\right)$$



Hence, instantaneous force acting on the charged particle, released at O.



$$\vec{F} = q\left(\vec{v}\times\vec{B}\right) = q\left[-v_0\hat{i}\times\left(-\hat{i}+\hat{j}\right)\frac{\mu_0 I}{4R}\right]$$

$$= \frac{q\mu_0 I v_0}{4R}\left[\hat{i}\times\left(\hat{i}-\hat{j}\right)\right] = -\frac{q\mu_0 I v_0}{4R}\hat{k}.$$

b. External uniform magnetic field $\vec{B}_{\text{ext}} = B\hat{j}$

As semicircular wires are placed in uniform magnetic field, these loops can be reduced to straight wires each of length $2R$ placed along z-axis (by joining initial point K and final point M).

$$\vec{F}_{KLM} = \vec{F}_{KMN} = \vec{F}_{KM} = BI2R\hat{i}$$

Net force due to both the wires :

$$\vec{F} = \vec{F}_{KLM} + \vec{F}_{KMN} = 4BIR\hat{i}$$

23. Let us first calculate the velocity of the particles from the energy equation,

$$\frac{1}{2}mv^2 = Vq \Rightarrow v = \sqrt{\frac{2Vq}{m}}$$

Since the charged particles are slightly divergent, they will follow a helical path. Let θ be the small angle made by a particle with B cos $\theta \simeq 1$

$\therefore$ p (pitch of the particle) = $v_{\parallel} \times T$

$$= v\cos\theta \times \frac{2\pi m}{qB} = \frac{2\pi vm}{qB}$$

Particles are focussed if l contains integral number of pitches.

$l = np \Rightarrow p = l/n = l, l/2, l/3, \ldots$

$\therefore$ For two consecutive focussings (as B increases, p decreases)

$$l = \frac{2\pi mv}{qB_1} \quad \text{and} \quad \frac{l}{2} = \frac{2\pi mv}{qB_2}$$

$$\text{or} \quad B_1 = \frac{2\pi mv}{ql} \quad \text{and} \quad B_2 = \frac{4\pi mv}{ql},$$

$$\text{or} \quad B_2 - B_1 = \frac{2\pi mv}{q\ell} \quad \text{or} \quad B_2 - B_1 = \frac{2\pi m}{ql}\sqrt{\frac{2Vq}{m}}.$$

$$\text{or} \quad \frac{q}{m} = \frac{8\pi^2 V}{l^2(B_2 - B_1)^2}$$