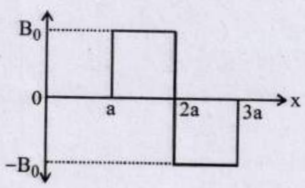
Chapter
Moving Charges and Magnetism

Topic-1: Motion of Charged Particle in Magnetic Field

1 MCQs with One Correct Answer

1. 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 **[2007]**



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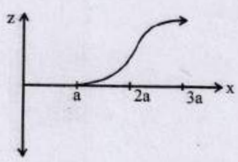

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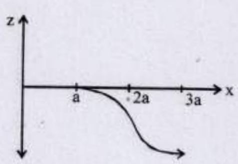

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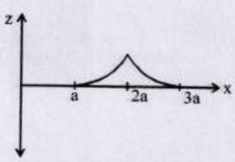

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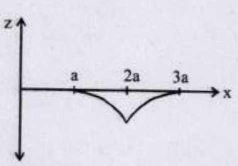


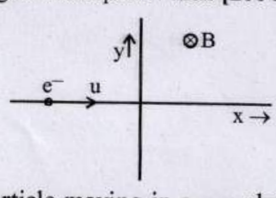
2. An electron travelling with a speed u along the positive x-axis enters into a region of magnetic field where $B = -B_0\hat{k}$ $(x > 0)$. It comes out of the region with speed v then **[2004S]**

(a) $v = u$ at $y > 0$

(b) $v = u$ at $y < 0$

(c) $v > u$ at $y > 0$

(d) $v > u$ at $y < 0$



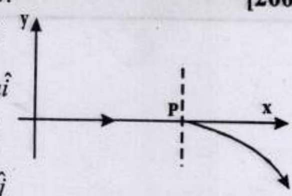
3. For a positively charged particle moving in a x-y plane initially along the x-axis, there is a sudden change in its path due to the presence of electric and/or magnetic fields beyond P. The curved path is shown in the x-y plane and is found to be non-circular. Which one of the following combinations is possible? **[2003S]**

(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) $\vec{E} = a\hat{i}; \vec{B} = c\hat{k} + b\hat{j}$



4. 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 **[2002S]**

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

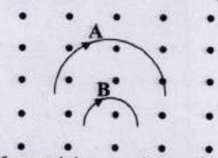
5. Two particles A and B of masses m_A and m_B respectively and having the same charge are moving in a plane. A uniform magnetic field exists perpendicular to this plane. The speeds of the particles are v_A and v_B respectively and the trajectories are as shown in the figure. Then **[2001S]**

(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 $v_A = v_B$



6. 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 **[2000S]**

(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.

7. 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 **[2000S]**
(a) ω and q (b) ω, q and m
(c) q and m (d) ω and m

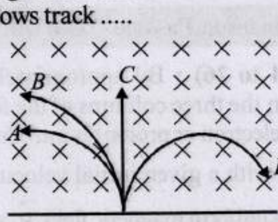
8. A charged particle is released from rest in a region of steady and uniform electric and magnetic fields which are parallel to each other. The particle will move in a **[1999S - 2 Marks]**
(a) straight line (b) circle
(c) helix (d) cycloid

9. 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 centre. The value of the magnetic induction at the centre due to the current in the ring is **[1995S]**
(a) proportional to $2(180° - \theta)$
(b) inversely proportional to r
(c) zero, only if $\theta = 180°$
(d) zero for all values of θ

10. 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 **[1988 - 2 Marks]**
(a) $(R_1/R_2)^{1/2}$ (b) R_2/R_1
(c) $(R_1/R_2)^2$ (d) R_1/R_2.

4 Fill in the Blanks

11. A neutron, a proton, and 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 fig. The electron follows track ...... and the alpha particle follows track ..... **[1984- 2 Marks]**



5 True / False

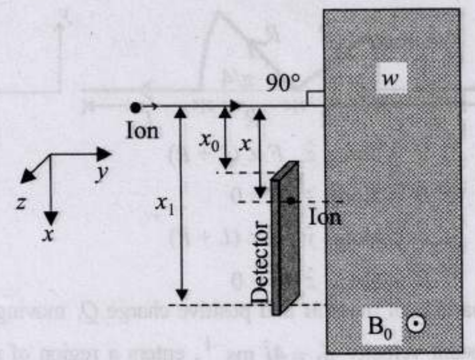
12. An electron and a proton are moving with the same kinetic energy along the same direction. When they pass through a uniform magnetic field perpendicular to the direction of their motion, they describe circular paths of the same radius. **[1985 - 3 Marks]**

13. A charged particle enters a region of uniform magnetic field at an angle of 85° to the magnetic line of force. The path of the particle is a circle. **[1983 - 2 Marks]**

14. There is no change in the energy of a charged particle moving in a magnetic field although a magnetic force is acting on it. **[1983 - 2 Marks]**

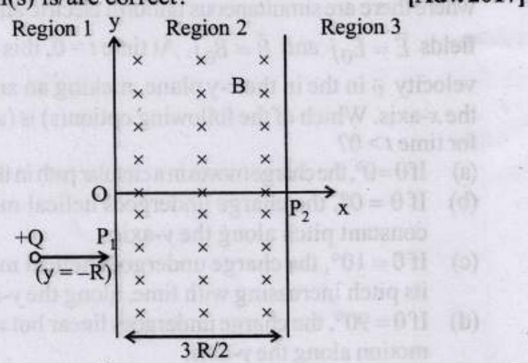
6 MCQs with One or More than One Correct Answer

15. A positive, singly ionized atom of mass number A_M is accelerated from rest by the voltage 192 V. Thereafter, it enters a rectangular region of width w with magnetic field $\vec{B}_0 = 0.1\hat{k}$ Tesla, as shown in the figure. The ion finally hits a detector at the distance x below its starting trajectory.
[Given: Mass of neutron/proton $= \left(\frac{5}{3}\right) \times 10^{-27}$ kg, charge of the electron $= 1.6 \times 10^{-19}$ C.] **[Adv. 2024]**



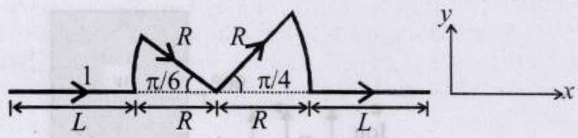
Which of the following option(s) is(are) correct?
(a) The value of x for H^+ ion is 4 cm.
(b) The value of x for an ion with $A_M = 144$ is 48 cm.
(c) For detecting ions with $1 \le A_M \le 196$, the minimum height $(x_1 - x_0)$ of the detector is 55 cm.
(d) The minimum width w of the region of the magnetic field for detecting ions with $A_M = 196$ is 56 cm.

16. A uniform magnetic field B exists in the region between $x = 0$ and $x = \frac{3R}{2}$ (region 2 in the figure) pointing normally into the plane of the paper. A particle with charge $+Q$ and momentum p directed along x–axis enters region 2 from region 1 at point P_1 $(y = -R)$. Which of the following option(s) is/are correct? **[Adv. 2017]**



(a) For $B > \frac{2}{3}\frac{p}{QR}$, the particle will re–enter region 1
(b) For $B = \frac{8}{13}\frac{p}{QR}$, the particle will enter region 3 through the point P_2 on x–axis
(c) When the particle re–enters region 1 through the longest possible path in region 2, the magnitude of the change in its linear momentum between point P_1 and the farthest point from y–axis is $p/\sqrt{2}$
(d) For a fixed B, particles of same charge Q and same velocity v, the distance between the point P_1 and the point of re–entry into region 1 is inversely proportional to the mass of the particle

17. 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) **[Adv. 2015]**



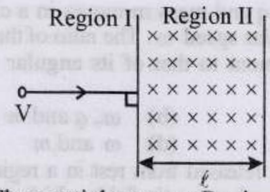
(a) If $\vec{B}$ is along $\hat{z}$, $F \propto (L+R)$
(b) If $\vec{B}$ is along $\hat{x}$, $F = 0$
(c) If $\vec{B}$ is along $\hat{y}$, $F \propto (L+R)$
(d) If $\vec{B}$ is along $\hat{z}$, $F = 0$

18. A particle of mass M and positive charge Q, moving with a constant velocity $\vec{u}_1 = 4\hat{i}\ \text{ms}^{-1}$, 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 $\vec{u}_2 = 2(\sqrt{3}\hat{i} + \hat{j})\ \text{ms}^{-1}$. The correct statement(s) is (are) **[Adv. 2013]**
(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

19. Consider the motion of a positive point charge in a region where there are simultaneous uniform electric and magnetic fields $\vec{E} = E_0\hat{j}$ and $\vec{B} = B_0\hat{j}$. At time $t = 0$, this charge has velocity $\vec{v}$ in the in the x-y plane, making an angle θ with the x-axis. Which of the following option(s) is (are) correct for time $t > 0$? **[2012]**
(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.

20. 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? **[2011]**
(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.

21. 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). **[2008]**



(a) The particle enters Region III only if its velocity $v > \dfrac{q\ell B}{m}$
(b) The particle enters Region III only if its velocity $v < \dfrac{q\ell B}{m}$
(c) Path length of the particle in Region II is maximum when velocity $v = \dfrac{q\ell B}{m}$
(d) Time spent in Region II is same for any velocity v as long as the particle returns to Region I

22. H^+, He^+ and O^{++} all having the same kinetic energy pass through a region in which there is a uniform magnetic field perpendicular to their velocity. The masses of H^+, He^+ and O^{2+} are 1 amu, 4 amu and 16 amu respectively. Then **[1994 - 2 Marks]**
(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

23. 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 : **[1985 - 2 Marks]**
(a) $E = 0, B = 0$ (b) $E = 0, B \neq 0$
(c) $E \neq 0, B = 0$ (d) $E \neq 0, B \neq 0$

8 Comprehension/Passage Based Questions

Directions (Qs. 24 to 26) : By appropriately matching the information given in the three columns of the following table. A charged particle (electron or proton) is introduced at the origin (x = 0, y = 0, z = 0) with a given initial velocity $\vec{v}$. A uniform electric field $\vec{E}$ and a uniform magnetic field $\vec{B}$ exist everywhere. The velocity $\vec{v}$, electric field $\vec{E}$ and magnetic field $\vec{B}$ are given in columns 1, 2 and 3, respectively. The quantities E_0, B_0 are positive in magnitude.

Column 1	Column 2	Column 3
(I) Electron with $\vec{v} = 2\dfrac{E_0}{B_0}\hat{x}$	(i) $\vec{E} = E_0\hat{z}$	(P) $\vec{B} = -B_0\hat{x}$
(II) Electron with $\vec{v} = \dfrac{E_0}{B_0}\hat{y}$	(ii) $\vec{E} = -E_0\hat{y}$	(Q) $\vec{B} = B_0\hat{x}$
(III) Proton with $\vec{v} = 0$	(iii) $\vec{E} = -E_0\hat{x}$	(R) $\vec{B} = B_0\hat{y}$
(IV) Proton with $\vec{v} = 2\dfrac{E_0}{B_0}\hat{x}$	(iv) $\vec{E} = E_0\hat{x}$	(S) $\vec{B} = B_0\hat{z}$

24. In which case will the particle move in a straight line with constant velocity?
(a) (III) (ii) (R) (b) (IV) (i) (S)
(c) (III) (iii) (P) (d) (II) (iii) (S)

25. In which case will the particle describe a helical path with axis along the positive z direction?
(a) (IV) (i) (S) (b) (II) (ii) (R)
(c) (III) (iii) (P) (d) (IV) (ii) (R)

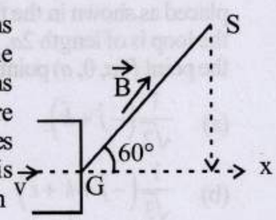
26. In which case would the particle move in a straight line along the negative direction of y-axis (i.e., move along $-\hat{y}$)?
(a) (II) (iii) (Q) (b) (III) (ii) (R)
(c) (IV) (ii) (S) (d) (III) (ii) (P)

10 Subjective Problems

27. 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. **[2004 - 2 Marks]**

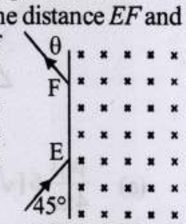
28. The region between $x = 0$ and $x = L$ is filled with uniform, steady magnetic field $B_0\hat{k}$. A particle of mass m, positive charge q and velocity $v_0\hat{i}$ travels along x-axis and enters the region of the magnetic field. Neglect gravity throughout the question. **[1999 - 10 Marks]**
(a) Find the value of L if the particle emerges from the region of magnetic field with its final velocity at angle 30° to its initial velocity.
(b) Find the final velocity of the particle and the time spent by it in the magnetic field, if the magnetic field now extends up to $2.1L$.

29. An electron gun G emits electrons of energy 2keV 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 fig. A uniform magnetic field $\vec{B}$ parallel to GS exists. Find $\vec{B}$ parallel to GS exists in the region outside the electron gun. Find the minimum value of B needed to make the electrons hit S. **[1993-7 Marks]**

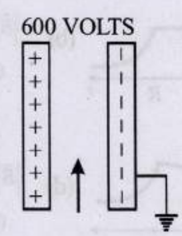


30. A beam of protons with a velocity 4×10^5 m/sec enters a uniform magnetic field of 0.3 tesla at an angle of 60° to the magnetic field. Find the radius of the helical path taken by the proton beam. Also find the pitch of the helix (which is the distance travelled by a proton in the beam parallel to the magnetic field during one period of rotation). **[1986 - 6 Marks]**

31. A particle of mass $m = 1.6 \times 10^{-27}$ kg and charge $q = 1.6 \times 10^{-19}$ C enters a region of uniform magnetic field of strength 1 tesla along the direction shown in fig. The speed of the particle is 10^7 m/s. (i) The magnetic field is directed along the inward normal to the plane of the paper. The particle leaves the region of the field at the point F. Find the distance EF and the angle θ. (ii) If the direction of the field is along the outward normal to the plane of the paper, find the time spent by the particle in the region of the magnetic field after entering it at E. **(1984- 8 Marks)**



32. A potential difference of 600 volts 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/sec 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 $= -1.6 \times 10^{-19}$ coulomb) **[1981- 3 Marks]**



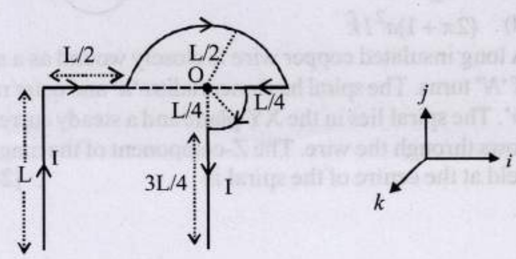
Topic-2: Magnetic Field Lines, Biot-Savart's Law and Ampere's Circuital Law

1 MCQs with One Correct Answer

1. An infinitely long wire, located on the z-axis, carries a current I along the $+z$-direction and produces the magnetic field $\vec{B}$. The magnitude of the line integral $\int \vec{B} \cdot \vec{dl}$ along a straight line from the point $(\sqrt{3}a, a, 0)$ to $(a, a, 0)$ is given by [μ_0 is the magnetic permeability of free space.] **[Adv. 2024]**

(a) $\frac{7\mu_0 I}{24}$ (b) $\frac{7\mu_0 I}{12}$ (c) $\frac{\mu_0 I}{8}$ (d) $\frac{\mu_0 I}{6}$

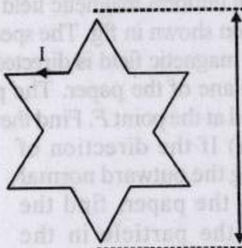
2. Which one of the following options represents the magnetic field $\vec{B}$ at O due to the current flowing in the given wire segments lying on the xy plane? **[Adv. 2022]**



(a) $\vec{B}=\frac{-\mu_0 I}{L}\left(\frac{3}{2}+\frac{1}{\sqrt[4]{2\pi}}\right)\hat{K}$ (b) $\vec{B}=\frac{-\mu_0 I}{L}\left(\frac{3}{2}+\frac{1}{2\sqrt{2\pi}}\right)\hat{K}$

(c) $\vec{B}=\frac{-\mu_0 I}{L}\left(1+\frac{1}{4\sqrt{2\pi}}\right)\hat{K}$ (d) $\vec{B}=\frac{-\mu_0 I}{L}\left(1+\frac{1}{4\pi}\right)\hat{K}$

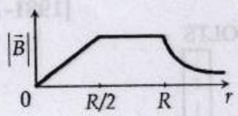
3. A symmetric star shaped conducting wire loop is carrying a steady state current I as shown in the figure. The distance between the diametrically opposite vertices of the star is 4a. The magnitude of the magnetic field at the center of the loop is **[Adv. 2017]**

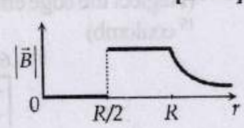


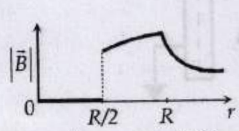
(a) $\frac{\mu_0 I}{4\pi a}6[\sqrt{3}-1]$ (b) $\frac{\mu_0 I}{4\pi a}6[\sqrt{3}+1]$

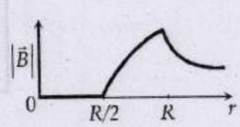
(c) $\frac{\mu_0 I}{4\pi a}3[\sqrt{3}-1]$ (d) $\frac{\mu_0 I}{4\pi a}3[2-\sqrt{3}]$

4. An infinitely long hollow conducting cylinder with inner radius $R/2$ and outer radius R carries a uniform current density along its length. The magnitude of the magnetic field, $|\vec{B}|$ as a function of the radial distance r from the axis is best represented by **[2012]**

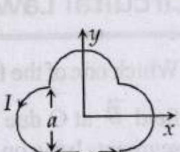
(a) 

(b) 

(c) 

(d) 

5. A loop carrying current I lies in the x-y plane as shown in the figure. The unit vector $\hat{k}$ is coming out of the plane of the paper. The magnetic moment of the current loop is **[2012]**



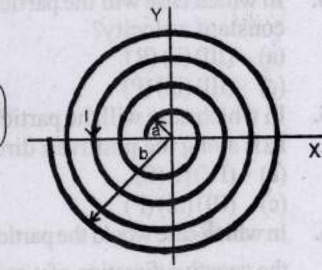
(a) $a^2 I\hat{k}$

(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) $(2\pi+1)a^2 I\hat{k}$

6. 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 XY plane and a steady current 'I' flows through the wire. The Z-component of the magnetic field at the centre of the spiral is **[2011]**



(a) $\frac{\mu_0 NI}{2(b-a)}\ell n\left(\frac{b}{a}\right)$

(b) $\frac{\mu_0 NI}{2(b-a)}\ell n\left(\frac{b+a}{b-a}\right)$

(c) $\frac{\mu_0 NI}{2b}\ell n\left(\frac{b}{a}\right)$

(d) $\frac{\mu_0 NI}{2b}\ell n\left(\frac{b+a}{b-a}\right)$

7. 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 **[2002S]**

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

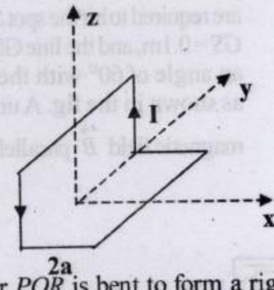
(c) $\frac{\mu_0 I(x\hat{j}-y\hat{i})}{2\pi(x^2+y^2)}$ (d) $\frac{\mu_0 I(x\hat{i}-y\hat{j})}{2\pi(x^2+y^2)}$

8. 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 **[2001S]**

(a) $\frac{\mu_o NI}{b}$ (b) $\frac{2\mu_o NI}{a}$

(c) $\frac{2\mu_o NI}{2(b-a)}\ln\frac{b}{a}$ (d) $\frac{2\mu_o NI}{2(b-a)}\ln\frac{a}{b}$

9. 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 **[2001S]**



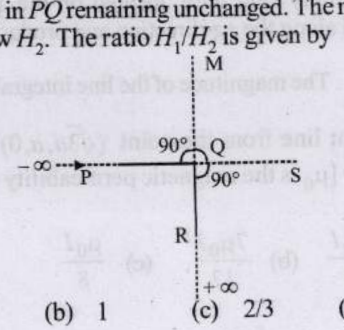
(a) $\frac{1}{\sqrt{2}}(-\hat{j}+\hat{k})$

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

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

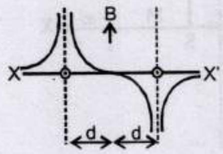
(d) $\frac{1}{\sqrt{2}}(\hat{i}+\hat{k})$

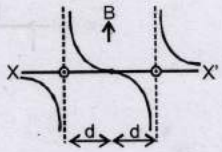
10. An infinitely long conductor PQR is bent to form a right angle as shown in Figure. A current I flows through PQR. The magnetic field due to this current at the point M is H_1. Now, another infinitely long straight conductor QS is connected at Q so that current is $I/2$ in QR as well as in QS, the current in PQ remaining unchanged. The magnetic field at M is now H_2. The ratio H_1/H_2 is given by **[2000S]**

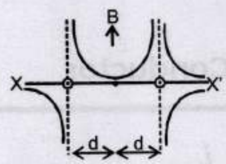


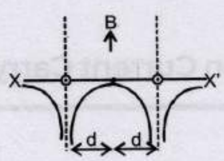
(a) 1/2 (b) 1 (c) 2/3 (d) 2

11. 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. The variation of the magnetic field B along the line XX' is given by **[2000S]**

(a) 

(b) 

(c) 

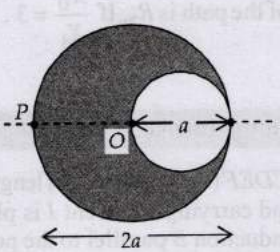
(d) 

12. 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 q at the centre. The value of the magnetic induction at the centre due to the current in the ring is **[1995S]**

(a) proportional to 2 (180° – q)
(b) inversely proportional to r
(c) zero, only if q = 180°
(d) zero for all values of q

2 Integer Value Answer

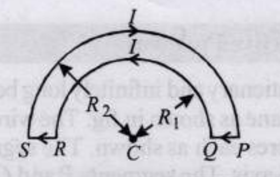
13. A cylindrical cavity of diameter a exists inside a cylinder of diameter $2a$ as shown in the figure. Both the cylinder and the cavity are infinity long. A uniform current density J flows along the length. If the magnitude of the magnetic field at the point P is given by $\frac{N}{12}\mu_0 aJ$, then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



14. 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 $k\left(\frac{\mu_0 I}{48\pi x}\right)$, find the value of k. **[2009]**

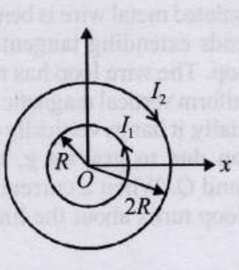
4 Fill in the Blanks

15. The wire loop $PQRSP$ formed by joining two semicircular wires of radii R_1 and R_2 carries a current I as shown. The magnitude of the magnetic induction at the centre C is.................. **[1988 - 2 Marks]**



6 MCQs with One or More than One Correct Answer

16. Two concentric circular loops, one of radius R and the other of radius $2R$, lie in the xy-plane with the origin as their common center, as shown in the figure. The smaller loop carries current I_1 in the anti-clockwise direction and the larger loop carries current I_2 in the clockwise direction, with $I_2 > 2I_1$. $\vec{B}(x, y)$ denotes the magnetic field at a point (x, y) in the xy-plane. Which of the following statement(s) is(are) correct? **[Adv. 2021]**



(a) $\vec{B}(x, y)$ is perpendicular to the xy-plane at any point in the plane
(b) $|\vec{B}(x, y)|$ depends on x and y only through the radial distance $r - \sqrt{x^2 + y^2}$
(c) $|\vec{B}(x, y)|$ is non-zero at all point for $r < R$
(d) $\vec{B}(x, y)$ points normally outward from the xy-plane for all the points between the two loops

17. 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) **[Adv. 2013]**

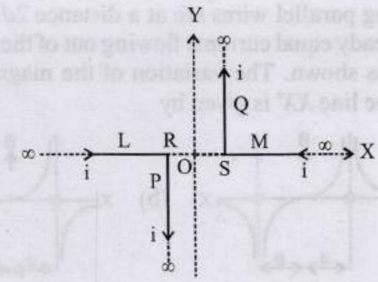
(a) In the region 0 < r < R, the magnetic field is non-zero
(b) In the region R < r < 2R, the magnetic field is along the common axis
(c) In the region R < r < 2R, the magnetic field is tangential to the circle of radius r, centered on the axis
(d) In the region r > 2R, the magnetic field is non-zero

18. A current I flows along the length of an infinitely long, straight, thin-walled pipe. Then **[1993-2 Marks]**

(a) the magnetic field at all points inside the pipe is the 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.

10 Subjective Problems

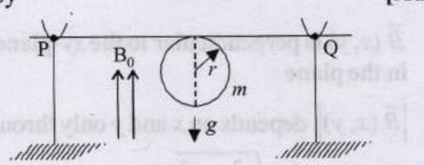
19. A pair of stationary and infinitely long bent wires are placed in the XY plane as shown in fig. The wires carry currents of $i = 10$ amperes each as shown. The segments L and M are along the X-axis. The segments P and Q are parallel to the Y-axis such that $OS = OR = 0.02$ m. Find the magnitude and direction of the magnetic induction at the origin O. **[1989 - 6 Marks]**



Topic-3: Force and Torque on Current Carrying Conductor

1 MCQs with One Correct Answer

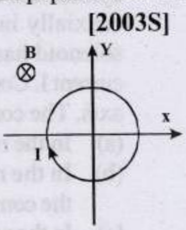
1. A thin stiff insulated metal wire is bent into a circular loop with its two ends extending tangentially from the same point of the loop. The wire loop has mass m and radius r and it is in a uniform vertical magnetic field B_0, as shown in the figure. Initially, it hangs vertically downwards, because of acceleration due to gravity g, on two conducting supports at P and Q. When a current I is passed through the loop, the loop turns about the line PQ by an angle θ given by **[Adv. 2024]**



(a) $\tan\theta = \dfrac{\pi r I B_0}{(mg)}$ (b) $\tan\theta = \dfrac{2\pi r I B_0}{(mg)}$

(c) $\tan\theta = \dfrac{\pi r I B_0}{(2mg)}$ (d) $\tan\theta = \dfrac{mg}{(\pi r I B_0)}$

2. A conducting loop carrying a current I is placed in a uniform magnetic field pointing into the plane of the paper as shown. The loop will have a tendency to **[2003S]**



(a) contract

(b) expand

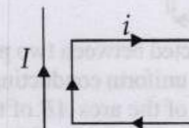
(c) move towards +ve x-axis

(d) move towards -ve x-axis.

3. Two thin long parallel wires seperated by a distance 'b' are carrying a current 'i' amp each. The magnitude of the force per unit lenght exerted by one wire on the other is **[1986 - 2 Marks]**

(a) $\dfrac{\mu_0 i^2}{b^2}$ (b) $\dfrac{\mu_0 i^2}{2\pi b}$ (c) $\dfrac{\mu_0 i}{2\pi b}$ (d) $\dfrac{\mu_0 i}{2\pi b^2}$

4. 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 : **[1985 - 2 Marks]**



(a) rotate about an axis parallel to the wire

(b) move away from the wire

(c) move towards the wire

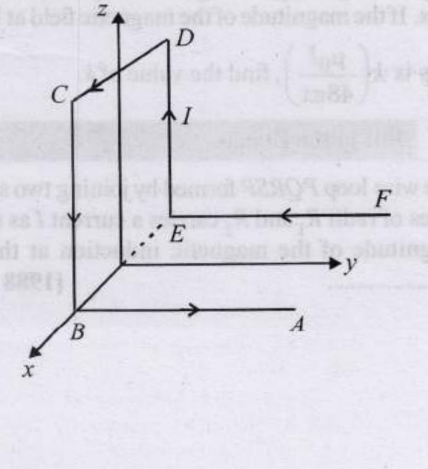
(d) remain stationary

2 Integer Value Answer

5. 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 $\dfrac{X_0}{X_1} = 3$, the value of $\dfrac{R_1}{R_2}$ is **[Adv. 2014]**

4 Fill in the Blanks

6. A wire $ABCDEF$ (with each side of length L) bent as shown in 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. **[1990 - 2 Marks]**



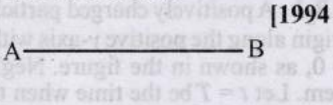
5 True / False

7. No net force acts on a rectangular coil carrying a steady current when suspended freely in a uniform magnetic field. **[1981- 2 Marks]**

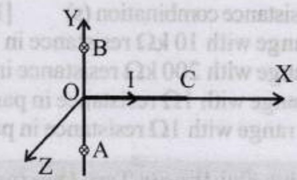
10 Subjective Problems

8. 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 $x = \pm d$. **[1997 - 5 Marks]**
   (i) Find the locus of the points for which the magnetic field B is zero.
   (ii) 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 wires is λ, find the frequency of oscillation.

9. A long horizontal wire AB, which is free to move in a vertical plane and carries a steady current of $20A$, 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 $30A$, as shown in figure. Show that when AB is slightly depressed, it executes simple harmonic motion. Find the period of oscillations. **[1994 - 6 Marks]**

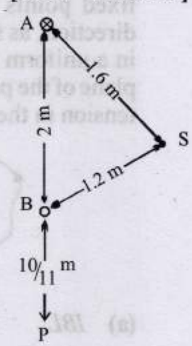


10. A straight segment OC (of length L meter) of a circuit carrying a current I amp is placed along the x-axis (Fig.). Two infinetely long straight wires A and B, each extending from $z = -\infty$ to $+\infty$, are fixed at $y = -a$ meter and $y = +a$ meter respectively, as shown in the figure.



If the wires A and B each carry a current I amp into the plane of the paper, obtain the expression for the force acting on the segment OC. What will be the force on OC if the current in the wire B is reversed? **[1992 - 10 Marks]**

11. Two long straight parallel wires are 2 metres apart, perpendicular to the plane of the paper (see figure). The wire A carries a current of 9.6 amps, directed into the plane of the paper. The wire B carries a current such that the magnetic field of induction at the point P, at a distance of $\frac{10}{11}$ metre from the wire B, is zero. **[1987 - 7 Marks]**
    Find :
    (i) The magnitude and direction of the current in B.
    (ii) The magnitude of the magnetic field of induction at the point S.
    (iii) The force per unit length on the wire B.



Topic-4: Galvanometer and its Conversion into Ammeter and Voltmeter

3 Numeric Answer

1. A moving coil galvanometer has 50 turns and each turn has an area $2 \times 10^{-4}\,m^2$. The magnetic field produced by the magnet inside the galvanometer is 0.02 T. The torsional constant of the suspension wire is $10^{-4}\,N\,m\,rad^{-1}$. When a current flows through the galvanometer, a full scale deflection occurs if the coil rotates by 0.2 rad. The resistance of the coil of the galvanometer is 50 Ω. This galvanometer is to be converted into an ammeter capable of measuring current in the range 0 –1.0 A. For this purpose, a shunt resistance is to be added in parallel to the galvanometer. The value of this shunt resistance, in *ohms*, is ________. **[Adv. 2018]**

6 MCQs with One or More than One Correct Answer

2. Two identical moving coil galvanometers have 10 resistance and full scale deflection at $2\mu A$ current. One of them is converted into a voltmeter of 100mV full scale reading and the other into an Ammeter of 1mA full scale current using appropriate resistors. There are then used to measure the voltage and current in the Ohm's law experiment with R – 1000Ω resistor by using an ideal cell. Which of the following statement(s) is/are correct? **[Adv. 2019]**
   (a) The resistance of the voltmeter will be $100k$
   (b) The measured value of R will be $978 < R < 982$
   (c) If the ideal cell is replaced by a cell having internal resistance of 5then the measured value of R will be more than 1000
   (d) The resistance of the Ammeter will be 0.02 (round off to 2nd decimal place)

3. Consider two identical galvanometers and two identical resistors with resistance R. If the internal resistance of the galvanometers $R_C < R/2$, which of the following statement(s) about any one of the galvanometers is (are) true? **[Adv. 2016]**
   (a) The maximum voltage range is obtained when all the components are connected in series
   (b) The maximum voltage range is obtained when the two resistors and one galvanometer are connected in series, and the second galvanometer is connected in parallel to the first galvanometer
   (c) The maximum current range is obtained when all the components are connected in parallel
   (d) The maximum current range is obtained when the two galvanometers are connected in series and the combination is connected in parallel with both the resistors

4. A microameter has a resistance of 100Ω and a full scale range of 50μA. It can be used as a voltmeter or as a higher range ammeter provided a resistance is added to it. Pick the correct range and resistance combination (s) **[1991 - 2 Marks]**
(a) 50 V range with 10 kΩ resistance in series
(b) 10 V range with 200 kΩ resistance in series
(c) 5 mA range with 1Ω resistance in parallel
(d) 10 mA range with 1Ω resistance in parallel

9 Assertion and Reason Type Questions

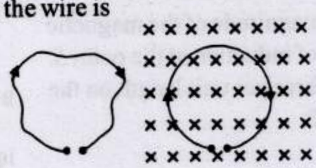
5. **Statement-1 :** The sensitivity of a moving coil galvanometer is increased by placing a suitable magnetic material as a core inside the coil.

Statement-2 : Soft iron has a high magnetic permeability and cannot be easily magnetized or demagnetized. **[2008]**
(a) **Statement**-1 is True, **Statement**-2 is True; **Statement**-2 is a correct explanation for **Statement**-1
(b) **Statement**-1 is True, **Statement**-2 is True; **Statement**-2 is NOT a correct explanation for **Statement**-1
(c) **Statement** -1 is True, **Statement**-2 is False
(d) **Statement** -1 is False, **Statement**-2 is True

Topic-5: Miscellaneous (Mixed Concepts) Problems

1 MCQs with One Correct Answer

1. 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 **[2010]**



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

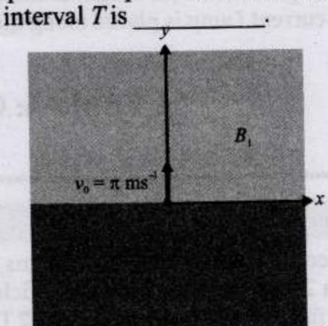
2. A circular loop of radius R, carrying current I, lies in x-y plane with its centre at origin. The total magnetic flux through x-y plane is **[1999S - 2 Marks]**
(a) directly proportional to I
(b) directly proportional to R
(c) inversely proportional to R
(d) zero

3. Two very long, straight, parallel wires carry steady currents I & -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 **[1998S - 2 Marks]**
(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

2 Integer Value Answer

4. An α-particle (mass 4 amu) and a singly charged sulfur ion (mass 32 amu) are initially at rest. They are accelerated through a potential V and then allowed to pass into a region of uniform magnetic field which is normal to the velocities of the particles. Within this region, the α-particle and the sulfur ion move in circular orbits of radii r_α and r_s, respectively. The ratio (r_s/r_α) is ____. **[Adv. 2021]**

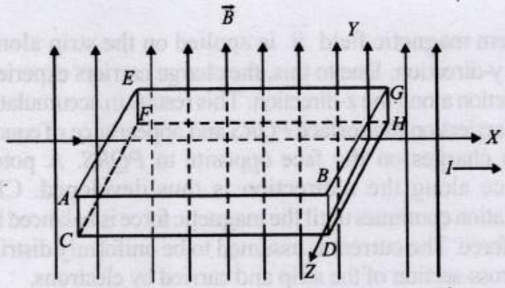
5. In the xy-plane, the region $y > 0$ has a uniform magnetic field $B_1\hat{k}$ and the region $y < 0$ has another uniform magnetic field $B_2\hat{k}$. A positively charged particle is projected from the origin along the positive y-axis with speed $v_0 = \pi$ ms^{-1} at $t = 0$, as shown in the figure. Neglect gravity in this problem. Let $t = T$ be the time when the particle crosses the x-axis from below for the first time. If $B_2 = 4B_1$, the average speed of the particle, in ms^{-1}, along the x-axis in the time interval T is ____ **[Adv. 2018]**



6. A long circular tube of length 10 m and radius 0.3 m carries a current I along its curved surface as shown. A wire-loop of resistance 0.005 ohm and of radius 0.1 m is placed inside the tube with its axis coinciding with the axis of the tube. The current varies as $I = I_0\cos(300\,t)$ where I_0 is constant. If the magnetic moment of the loop is $N\mu_0 I_0 \sin(300\,t)$, then 'N' is **[2011]**

4 Fill in the Blanks

7. A metallic block carrying current I is subjected to a uniform magnetic induction $\vec{B}$ as shown in 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. **[1996 - 2 Marks]**

6 MCQs with One or More than One Correct Answer

8. Two infinitely long straight wires lie in the xy-plane along the lines $x = \pm R$. The wire located at $x = +R$ carries a constant current I_1 and the wire located at $x = -R$ carries a constant current I_2. A circular loop of radius R is suspended with its centre at $(0, 0, \sqrt{3}R)$ and in a plane parallel to the xy-plane. This loop carries a constant current I in the clockwise direction as seen from above the loop. The current in the wire is taken to be positive if it is in the $+\hat{j}$ direction. Which of the following statements regarding the magnetic field $\vec{B}$ is (are) true? **[Adv. 2018]**

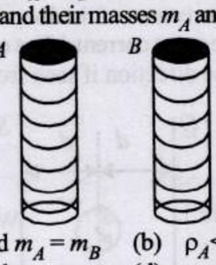
(a) If $I_1 = I_2$, then $\vec{B}$ **cannot** be equal to zero at the origin (0, 0, 0)

(b) If $I_1 > 0$ and $I_2 < 0$, then $\vec{B}$ can be equal to zero at the origin (0, 0, 0)

(c) If $I_1 < 0$ and $I_2 > 0$, then $\vec{B}$ can be equal to zero at the origin (0, 0, 0)

(d) If $I_1 = I_2$, then the z-component of the magnetic field at the centre of the loop is $\left(-\frac{\mu_0 I}{2R}\right)$

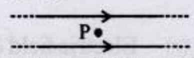
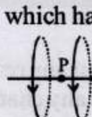
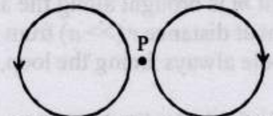
9. Two metallic rings A and B, identical in shape and size but having different resistivities ρ_A and ρ_B, are kept on top of two identical solenoids as shown in the figure. When current I is switched on in both the solenoids in identical manner, the rings A and B jump to heights h_A and h_B, respectively, with $h_A > h_B$. The possible relation(s) between their resistivities and their masses m_A and m_B is(are) **[2009]**



(a) $\rho_A > \rho_B$ and $m_A = m_B$ (b) $\rho_A < \rho_B$ and $m_A = m_B$
(c) $\rho_A > \rho_B$ and $m_A > m_B$ (d) $\rho_A < \rho_B$ and $m_A < m_B$

7 Match the Following

10. Two wires each carrying a steady current I are shown in four configurations in Column I. Some of the resulting effects are described in Column II. Match the statements in Column I with the statements in column II and indicate your answer by darkening appropriate bubbles in the 4 × 4 matrix given in the ORS. **[2007]**

Column I	Column II
(A) Point P is situated midway between the wires. 	(p) The magnetic fields (B) at P due to the currents in the wires are in the same direction.
(B) Point P is situated at the mid-point of the line joining the centers of the circular wires, which have same radii. 	(q) The magnetic fields (B) at P due to the currents in the wires are in opposite directions.
(C) Point P is situated at the mid-point of the line joining the centers of the circular wires, which have same radii. 	(r) There is no magnetic field at P.
(D) Point P is situated at the common center of the wires. 	(s) The wires repel each other.

11. Column I gives certain situations in which a straight metallic wire of resistance R is used and Column II gives some resulting effects. Match the statements in Column I with the statements in Column II and indicate your answer by darkening appropriate bubbles in the 4 × 4 matrix given in the ORS. **[2007]**

Column I	Column II
(A) A charged capacitor is connected to the ends of the wire	(p) A constant current flows through the wire
(B) The wire is moved perpendicular to its length with a constant velocity in a uniform magnetic field perpendicular to the plane of motion	(q) Thermal energy is generated in the wire
(C) The wire is placed in a constant electric field that has a direction along the length of the wire	(r) A constant potential difference develops between the ends of the wire
(D) A battery of constant emf is connected to the ends of the wire.	(s) charges of constant magnitude appear at the ends of the wire

12. Match the following columns : [2006, 6M]

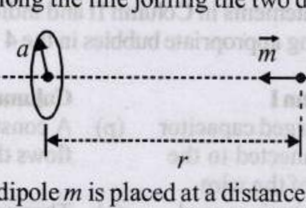
Column I	Column II
(A) Dielectric ring uniformly charged	(p) Constant electrostatic field out of system
(B) Dielectric ring uniformly charged rotating with angular velocity ω	(q) Magnetic field strength
(C) Constant current in ring i	(r) Electric field (induced)
(D) $i = i_0 \cos\omega t$	(s) Magnetic dipole moment

8 Comprehension/Passage Based Questions

Passage-1

A special metal S conducts electricity without any resistance. A closed wire loop, made of S, does not allow any change in flux through itself by inducing a suitable current to generate a compensating flux. The induced current in the loop cannot decay due to its zero resistance. This current gives rise to a magnetic moment which in turn repels the source of magnetic field or flux. Consider such a loop, of radius a, with its center at the origin. A magnetic dipole of moment m is brought along the axis of this loop from infinity to a point at distance r (>> a) from the center of the loop with its north pole always facing the loop, as shown in the figure below.

The magnitude of magnetic field of a dipole m, at a point on its axis at distance r, is $\frac{\mu_0}{2\pi}\frac{m}{r^3}$, where μ_0 is the permeability of free space. The magnitude of the force between two magnetic dipoles with moments, m_1 and m_2, separated by a distance r on the common axis, with their north poles facing each other, is $\frac{km_1m_2}{r^4}$, where k is a constant of appropriate dimensions. The direction of this force is along the line joining the two dipoles.



13. When the dipole m is placed at a distance r from the center of the loop (as shown in the figure), the current induced in the loop will be proportional to [Adv. 2021]

(a) $\frac{m}{r^3}$ (b) $\frac{m^2}{r^2}$ (c) $\frac{m}{r^2}$ (d) $\frac{m^2}{r}$

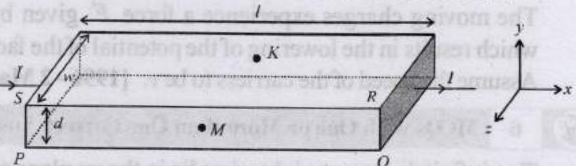
14. The work done in bringing the dipole from infinity to a distance r from the center of the loop by the given process is proportional to [Adv. 2021]

(a) $\frac{m}{r^5}$ (b) $\frac{m^2}{r^5}$ (c) $\frac{m^2}{r^6}$ (d) $\frac{m^2}{r^7}$

Passage-2

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 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.



15. Consider two different metallic strips (1 and 2) of the same material. Their lengths are the same, widths 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) [Adv. 2015]

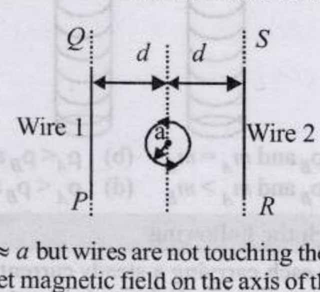
(a) If $w_1 = w_2$ and $d_1 = 2d_2$, then $V_2 = 2V_1$
(b) If $w_1 = w_2$ and $d_1 = 2d_2$, then $V_2 = V_1$
(c) If $w_1 = 2w_2$ and $d_1 = d_2$, then $V_2 = 2V_1$
(d) If $w_1 = 2w_2$ and $d_1 = d_2$, then $V_2 = V_1$

16. Consider two different metallic strips (1 and 2) of 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) [Adv. 2015]

(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 $V_2 = V_1$

Passage-3

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 wire are carrying the same current I. The current in the loop is in the counterclockwise direction if seen from above.



17. 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 [Adv. 2014]

(a) current in wire 1 and wire 2 in the direction PQ and RS, respectively and $h \approx a$

(b) current in wire 1 and wire 2 in the direction PQ and SR, respectively and $h \approx a$

(c) current in wire 1 and wire 2 in the direction PQ and SR, respectively and $h \approx 1.2a$

(d) current in wire 1 and wire 2 in the direction PQ and RS, respectively and $h \approx 1.2a$

18. 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). **[Adv. 2014]**

(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) $\frac{\sqrt{3}\mu_0 I^2 a^2}{2d}$

Passage-4

Advanced countries are making use of powerful electromagnets to move trains at very high speed. These trains are called maglev trains (abbreviated from magnetic levitation). These trains float on a guideway and do not run on steel rail tracks.

Instead of using a engine based on fossil fuels, they make use of magnetic field forces. The magnetized coils are arranged in the guide way which repels the strong magnets placed in the train's under carriage. This helps train move over the guideway, a technic called electro-dynamic suspension. When current passes in the coils of guideway, a typical magnetic field is set up between the undercarriage of train and guideway which pushes and pull the train along the guideway depending on the requirement.

The lack of friction and its aerodynamic style allows the train to more at very high speed.

19. The levitation of the train is due to **[2006 - 5M, –2]**

(a) Mechanical force (b) Electrostatic attraction

(c) Electrostatic repulsion (d) Magnetic repulsion

20. The disadvantage of maglev trains is that **[2006 - 5M, –2]**

(a) More friction (b) Less pollution

(c) Less wear & tear (d) High initial cost

21. The force which makes maglev move **[2006 - 5M, –2]**

(a) Gravitational field (b) Magnetic field

(c) Nuclear forces (d) Air drag

10 Subjective Problems

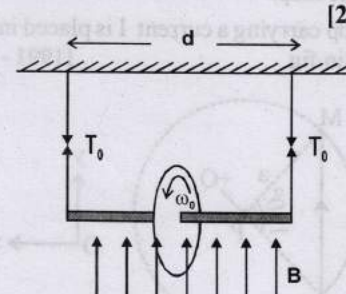
22. In a moving coil galvanometer, torque on the coil can be expressed as $\tau = ki$, where i is current through the wire and k is constant. The rectangular coil of the galvanometer having number of turns N, area A and moment of inertia I is placed in magnetic field B. Find **[2005 - 6 Marks]**

(a) k in terms of given parameters N, I, A and B

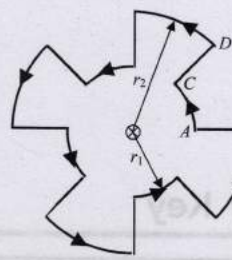
(b) the torsion constant of the spring, if a current i_0 produces a deflection of $\pi/2$ in the coil.

(c) the maximum angle through which the coil is deflected, if charge Q is passed through the coil almost instantaneously. (ignore the damping in mechanical oscillations).

23. A wheel of radius R having charge Q, uniformly distributed on the rim of the wheel is free to rotate about a light horizontal rod. The rod is suspended by light inextensible strings and a magnetic field B is applied as shown in the figure. The initial tensions in the strings are T_0. If the breaking tension of the strings are $\frac{3T_0}{2}$, find the maximum angular velocity ω_0 with which the wheel can be rotated. **[2003 - 4 Marks]**



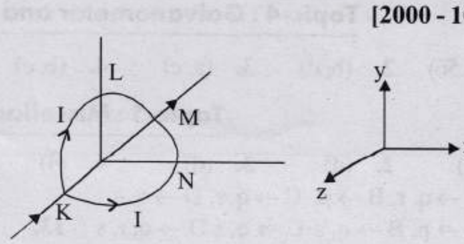
24. A current of 10 A flows around a closed path in a circuit which is in the horizontal plane as shown in the figure. The circuit consists of eight alternating arcs of radii $r_1 = 0.08$ m and $r_1 = 0.12$ m. Each arc subtends the same angle at the center. **[2001-10 Marks]**



(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 the arc AC and the straight segment CD due to the current at the center?

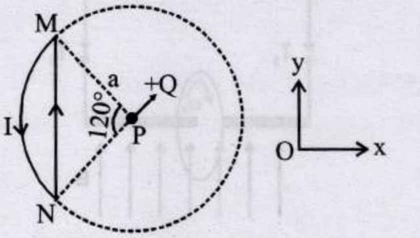
25. A circular loop of radius R is bent along a diameter and given a shape as shown in the figure. One of the semicircles (KNM) lies in the x-z plane and the other one (KLM) in the y-z plane with their centres at the origin. Current I is flowing through each of the semi circles as shown in figure. **[2000 - 10 Marks]**



(a) A particle of charge q is released at the origin with a velocity $\vec{v} = -v_0\hat{i}$. Find the instantaneous force $\vec{F}$ on the particle. Assume that space is gravity free.

(b) If an external uniform magnetic field $B_o\hat{j}$ is applied, determine the force $\vec{F_1}$ and $\vec{F_2}$ on the semicircles KLM and KNM due to the field and the net force $\vec{F}$ on the loop.

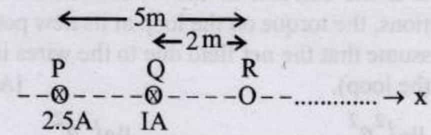
26. A wire loop carrying a current I is placed in the x-y plane as shown in fig. **[1991 - 4 + 4 Marks]**



(a) If a particle with charge $+Q$ and mass m is placed at the centre P and given a velocity $\vec{v}$ along NP (see figure), find its instantaneous acceleration.

(b) If an external uniform magnetic induction field $\vec{B} = B\hat{i}$ is applied, find the force and the torque acting on the loop due to this field.

27. Two long parallel wires carrying current 2.5 amperes 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. The points P and Q are located at a distance of 5 metres and 2 metres respectively from a collinear point R (see figure) **[1990 - 8 Marks]**



(i) An electron moving with a velocity of 4×10^5 m/s along the positive x - direction experiences a force of magnitude 3.2×10^{-20} N at the point R. Find the value of I.

(ii) Find all the positions at which a third long parallel wire carrying a current of magnitude 2.5 amperes may be placed so that the magnetic induction at R is zero.

Answer Key

Topic-1 : Motion of Charged Particle in Magnetic Field

1. (a) **2.** (b) **3.** (b) **4.** (b) **5.** (b) **6.** (c) **7.** (c) **8.** (a) **9.** (d) **10.** (c)
12. (False) **13.** (False) **14.** (True) **15.** (a, b) **16.** (a, b) **17.** (a, b, c) **18.** (a, c) **19.** (c, d) **20.** (b, d) **21.** (a, c, d)
22. (a, c) **23.** (a,b,d) **24.** (d) **25.** (a) **26.** (b)

Topic-2 : Magnetic Field Lines, Biot-Savart's Law and Ampere's Circuital Law

1. (a) **2.** (c) **3.** (a) **4.** (d) **5.** (b) **6.** (a) **7.** (a) **8.** (c) **9.** (d) **10.** (c)
11. (b) **12.** (d) **13.** (5) **14.** (7) **16.** (a, b) **17.** (a, d) **18.** (b)

Topic-3 : Force and Torque on Current Carrying Conductor

1. (a) **2.** (b) **3.** (b) **4.** (c) **5.** (3) **7.** (True)

Topic-4 : Galvanometer and its Conversion into Ammeter and Voltmeter

1. (5.56) **2.** (b, d) **3.** (a, c) **4.** (b, c) **5.** (c)

Topic-5 : Miscellaneous (Mixed Concepts) Problems

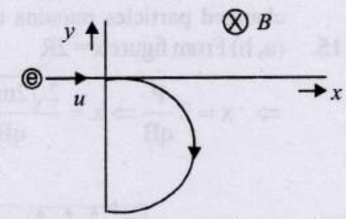
1. (c) **2.** (d) **3.** (d) **4.** (4) **5.** (2) **6.** (6) **8.** (a, b, d) **9.** (b, d)
10. A → q, r, B → p, C → q, r, D → q, s **11.** A → q, B → r, s C → s D → p, r, s
12. A → p, B → q, s C → q, s D → q, r, s **13.** (a) **14.** (c) **15.** (a, d) **16.** (a, c) **17.** (c) **18.** (b)
19. (d) **20.** (d) **21.** (b)

Hints & Solutions

Topic-1: Motion of Charged Particle in Magnetic Field

1. **(a)** Use the vector form of B and v in the formulae $\vec{F} = q(\vec{v} \times \vec{B})$ to get the instantaneous direction of force at $x = a$ and $x = 2a$.
In the region $a < x < 2a$ force must be in the direction $\hat{i} \times \hat{j}$ *i.e.*, $+z$-direction so vertically upward. And in the region $2a < x < 3a$ in $-z$-direction vertically downward.

2. **(b)** Magnetic force on the charged particle does not change its speed
$\therefore\ u = v$
The force acting on 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 below.

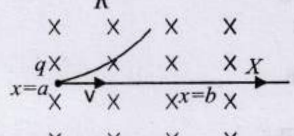


Hence electron comes out with speed $v = u$ and at $y < 0$.

3. **(b)** When $\vec{E} = 0$ then path of the charged particle beyond P will be helix hence option (a) and (c) are incorrect. The velocity at P is in the X-direction (given).
Let $\vec{v} = k\hat{i}$.
After P, the positively charged particle gets deflected in the $x - y$ plane toward $- y$ direction and the path is non-circular.
Now, $\vec{F} = q(\vec{v} \times \vec{B})$
$\Rightarrow\ \vec{F} = q[k\hat{i} \times (c\hat{k} + a\hat{i})]$ for option (b)
$= q[kc\hat{i} \times \hat{k} + ka\hat{i} \times \hat{i}] = kcq(-\hat{j})$
Since in option (b), electric field is also present $\vec{E} = a\hat{i}$, 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.

4. **(b)** When a charged particle is moving in a uniform megnetic field normal to its motion

$$qvB = \frac{mv^2}{R}$$



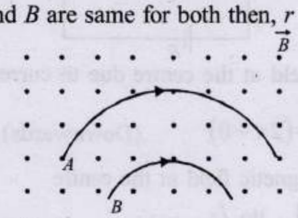
Width of the magnetic field region $(b - a) \le R$; where 'R' is its radius of curvature inside magnetic field,

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

5. **(b)** When a charged particle is moving normal to the magnetic field then a force acts on it which behaves as a centripetal force and moves the particle in circular motion.

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

If q and B are same for both then, $r \propto mv$



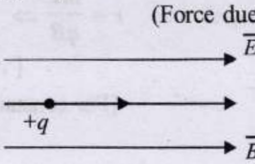
Since $r_A > r_B$
$\Rightarrow\ m_A v_A > m_B v_B$

6. **(c)** Given electric field along $+x$ direction, $\vec{E} = E.\hat{i}$ and magnetic field along $+z$ direction $\vec{B} = B.\hat{k}$
Velocity of the ionised particle will be along direction determined by $q.\vec{E}$
or velocity $\vec{v} = AqE\hat{i}$ where A is a positive constant.
Here A, E and B are positive constants.
Charge on ions (q) may be positive or negative
Magnetic force $\vec{F} = q(\vec{v} \times \vec{B})$
$\therefore\ \vec{F} = q[(AqE\hat{i}) \times (B\hat{k})] = q^2\ AEB(\hat{i} \times \hat{k})$
$= q^2\ AEB(-\hat{j}) = (\pm q)^2\ AFB$, along negative y-direction.
As magnetic force is along negative y-axis hence all ions, whether positive or negative will deflect towards negative y-axis.

7. **(c)** The angular momentum of the particle
$L = mvr = mr^2\omega$ where $\omega = 2\pi n$. [$\because\ v = r\omega$]
$\therefore$ Frequency $n = \frac{\omega}{2\pi}$; Further $i = \frac{q}{t} = q \times n = \frac{\omega q}{2\pi}$
Magnetic moment, $M = iA = \frac{\omega q}{2\pi} \times \pi r^2 \Rightarrow M = \frac{\omega q r^2}{2}$

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

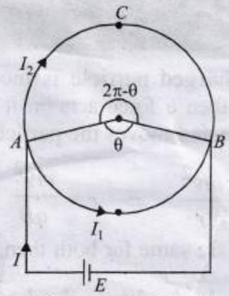
8. **(a)** Uniform electric field $\vec{E}$ and magnetic field $\vec{B}$ are parallel to each other.
$F_E = qE$ (Force due to electric field)
$F_B = evB \sin\theta = qvB \sin 0 = 0$
(Force due to magnetic field)



Since force due to magnetic field is zero. So force due to electric field will make the charged particle accelerate or decelerate parallel to itself in straight line.

9. **(d)** Magnetic field at the centre due to current in arc *AB*

$B_1 = \frac{\mu_0}{4\pi}\frac{I_1}{r}\theta$ (Upwards)



Magnetic field at the centre due to current in arc *ACB*

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

∴ Net magnetic field at the centre

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

Also, $I_1 = \frac{E}{R_1} = \frac{E}{\rho\ell_1/A} = \frac{EA}{\rho r\theta}\left[\because R = \rho\frac{\ell}{A}\right]$

and $I_2 = \frac{E}{R_2} = \frac{E}{\rho\ell_2/A} = \frac{EA}{\rho r(2\pi-\theta)}$

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

10. **(c)** After entering the magnetic field, a magnetic force acts on the charged particle which moves the charged particle in circular path

$$\therefore \; \frac{mv^2}{R} = qvB \;\Rightarrow\; R = \frac{mv}{qB} \;\text{ or, }\; R = \frac{\sqrt{2mK}}{qB}$$

Here, *K*, *q*, *B* are equal ∴ $R^2 \propto m$

Hence, $\frac{m_1}{m_2} = \frac{R_1^2}{R_2^2}$

11. Here undeviated path C is of chargeless particle neutron. According to Fleming's left hand rule, the force on electrons (negative charge) will be towards right *i.e.*, track *D*. Also, by the same rule we find that the force on proton and α-particle *i.e.*, +(ve)ly charged particle is towards left. Now since the magnetic force will behave as centripetal force,

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

For proton $r \propto \frac{1}{1} = 1$; For α-particle $r \propto \frac{4}{2} = 2$

i.e., $(r)_\alpha > (r)_p$ ∴ α-particle will take path *B*.

12. **False** Kinetic energy, $K_{proton} = K_{electron} = K$

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

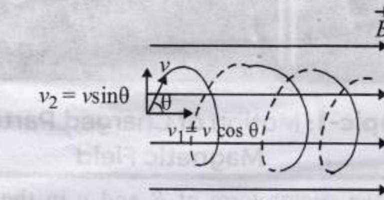
$[\because mv = P = \sqrt{2mk}\,]$

∴ $r \propto \sqrt{m}$ [For constant *q*, *K* and *B*]

∴ $r \propto \sqrt{m}$

Since mass of proton > mass of electron therefore radius of proton will be more.

13. **False** The path of a particle is a circle when it enters normal to the magnetic field. 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.

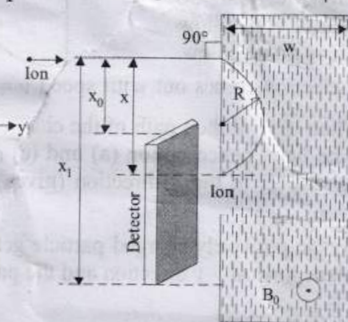
14. **True** The magnetic force acting on a charged particle is in a direction perpendicular to the direction of velocity and hence it cannot change the speed of the charged particle.

Therefore, the kinetic energy $\left(=\frac{1}{2}mv^2\right)$ does not change.

As work done by this force is zero so the energy of moving changed particles remains unchanged.

15. **(a, b)** From figure x = 2R

$$\Rightarrow \; x = 2\frac{P}{qB} \Rightarrow x = \frac{2\sqrt{2mqV}}{qB} \Rightarrow x = \frac{2}{B}\sqrt{\frac{2mV}{q}}$$



For $H^+ \to m = \frac{5}{3}\times10^{-27}$ kg and V = 192 given

$$\therefore \; x = \frac{2}{0.1}\sqrt{\frac{2\times\frac{5}{3}\times10^{-27}\times192}{1.6\times10^{-19}}} = 4\text{cm}$$

so option (a) is correct.

For $A_m = 144$

$$x = \frac{2}{0.1}\sqrt{\frac{2\times144\times\frac{5}{3}\times10^{-27}\times192}{1.6\times10^{-19}}} = 48\text{cm}$$

so option (b) is correct

For $A_m = 1$

x = 4 cm & for $A_m = 196$

x = 56 cm.

so x_0 = 4cm × x_1 = 56 cm

∴ $x_1 - x_0$ = 52 cm

so option (c) is incorrect

For $A_M = 196$

Minimum width $W_{min} = \frac{P}{qB} = \frac{\sqrt{2mqV}}{qB} = \frac{1}{B}\sqrt{\frac{2mV}{q}}$

$$\therefore \ \text{W min} = R = \frac{1}{0.1}\sqrt{\frac{2\times196\times\frac{5}{3}\times10^{-27}\times192}{1.6\times10^{-19}}} = 28\text{cm}$$

so option (d) is incorrect.

16. (a, b) (a) For the charge +Q to return region 1.

$$\frac{mv^2}{(3R/2)} = QvB \ \Rightarrow \frac{2p}{3R} = QB \quad \left[\text{Here, radius } r = \frac{3}{2}R\right]$$

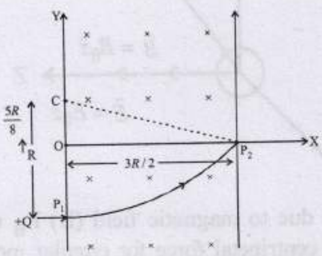
$$\therefore \ B = \frac{2p}{3QR}$$

Therefore for $B \geq \frac{2p}{2QR}$, the particle will re-enter region 1.

(b) When $B = \frac{8p}{13QR}$

$$\frac{mv^2}{r} = Qv\left(\frac{8p}{13QR}\right) \qquad \therefore \ r = \frac{13R}{8}$$

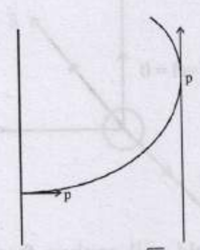
Thus 'C' is the of the centre of circular path of radius $\frac{13R}{8}$



Also $CP_2 = \sqrt{CO^2 + OP_2^2} = \sqrt{\left(\frac{5R}{8}\right)^2 + \left(\frac{3R}{2}\right)^2}$

$$\therefore \text{CP}_2 = \frac{13R}{8}$$

Thus the particle will enter region 3 through the point P_1 on X-axis



(c) Change in momentum = $\sqrt{2}\,p$

(d) Further $\frac{mv^2}{r} = qvB \ \therefore \ r = \frac{mv}{qB} \quad \therefore \ r \propto m$

i.e., Distance is directly proportional to mass.

17. (a, b, c) Magnetic force acting on a current carrying wire, placed in a uniform magnetic field,

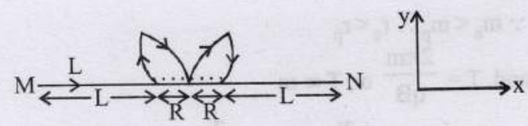
$\vec{F} = I(\vec{l} \times \vec{B})$

Here, $\vec{l}$ = displacement of the wire = $2(L + R)\,\hat{x}$

$\therefore \quad \vec{F} = 2I(L+R)(\hat{x}\times\vec{B})$

If $\vec{B} = B\hat{x}$ then

$\vec{F} = 2I(L+R)(\hat{x}\times\hat{x})\,B = 0$



If $\vec{B} = B\hat{y}$ then

$\vec{F} = 2I(L+R)(\hat{x}\times\hat{y})B = 2IB(L+R)\,\hat{z}$

or $\quad F \propto (L+R)$

If $\vec{B} = B\hat{z}$ then

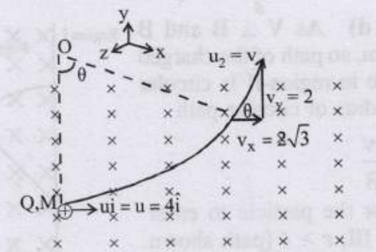
$\vec{F} = 2I(L+R)(\hat{x}\times\hat{z})B = -2IB(L+R)\hat{y}$

or, $\ F \propto (L+R)$.

18. (a, c) According to Fleming's left hand rule, magnetic field should be in the –z direction.

From figure, $\tan\theta = \frac{v_y}{v_x} = \frac{2}{2\sqrt{3}}$

$\therefore \ \theta = \frac{\pi}{6}$

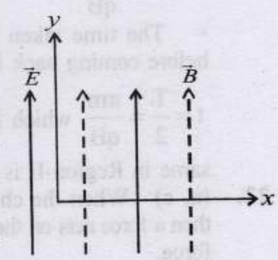


Angle rotated by the particle = $\frac{\text{arc}}{\text{radius}} = \frac{\text{speed}\times\text{time}}{\text{radius}}$

$$\frac{\pi}{6} = \frac{4\times10\times10^{-3}}{M\times4/QB} \qquad \left[\because \text{radius} = \frac{\text{Mv}}{\text{QB}}\right]$$

$$\therefore \ B = \frac{50\pi M}{3Q}$$

19. (c, d) If θ = 0°, the charged particle is projected along *x*-axis, due to magnetic field, $\vec{B}$ the charged particle will tend to move in a circular path in *y*-*z* plane but due to force of electric field $\vec{E}$, the particle will move in a helical path with increasing pitch. Hence options (A) and (B) are wrong.



If θ = 10°, we can resolve velocity into two rectangular components. One along *x*-axis (*v* cos 10°) and one along *y*-axis (*v* sin 10°). Due to *v* cos 10°, the particle will move in circular path and due to *v* sin 10° plus the force due to electric field, the particle will undergo helical motion with its pitch increasing.

If θ = 90°, the charge is moving along the magnetic field. Therefore the force due to magnetic field is zero. But the force due to electric field will accelerate the particle along *y*-axis.

20. (b, d) The entry and exit of electron & proton in the magnetic field makes the same angle with AB as shown. Therefore both will come out travelling in parallel paths.

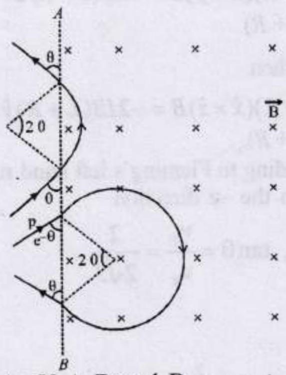
Also, $r = \frac{\text{mv}}{\text{qB}}$ or, $r \propto m$

$\because m_e < m_p \therefore r_e < r_p$

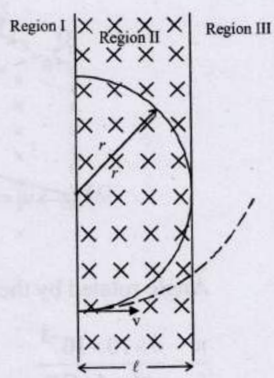
and, $T = \dfrac{2\pi m}{qB}$ or, $T \propto m$

$\therefore \quad T_e < T_p, t_e = \dfrac{T_e}{2}$ and $t_p = \dfrac{T_p}{2}$

or, $t_e < t_p$



21. **(a, c, d)** As $V \perp B$ and B uniform, so path of the charged particle in region-II is circular and radius of circular path



$r = \dfrac{mv}{qB}$

- For the particle to enter region III, $r > \ell$ (path shown by daished line)

$\dfrac{mv}{qB} > \ell \Rightarrow v > \dfrac{q\ell B}{m}$

- **For maximum path length** in region II, $r = \ell$

$\therefore \quad \ell = \dfrac{mv}{qB} \Rightarrow v = \dfrac{q\ell B}{m}$

- The time taken by the particle to move in region II before coming back in region I

$t = \dfrac{T}{2} = \dfrac{\pi m}{qB}$ which is independent of v *i.e.*, time spent is same in Region-II is same for any velocity.

22. **(a, c)** When the charged particles enter a magnetic field then a force acts on the particle which will act as a centripetal force.

$qvB = \dfrac{mv^2}{r} \Rightarrow r = \dfrac{mv}{qB}$ or, $r = \dfrac{\sqrt{2mk}}{qB}$

$\therefore \quad r \propto \dfrac{\sqrt{m}}{q}$ [Kinetic energy, 'k' and 'B' are same]

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

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

Hence He^+ and O^{++} will be deflected equally.
H^+ will be deflected the most since its radius is smallest.

23. **(a,b,d)** There is no change in velocity. It can be possible when

- Electric and magnetic fields are absent, *i.e.*, E = 0, B = 0
  So, F_e and F_m both are zero.
- Or when electric and magnetic fields are present but force due to electric field is equal and opposite to the magnetic force *i.e.*, $F_e + F_m = 0$ (*i.e.*, $E \neq 0, B \neq 0$).
- Or when E = 0. $B \neq 0$ provided
  $F = qvB \sin\theta = 0$

$\sin\theta = 0$, *i.e.*, $\theta = 0 \Rightarrow v$ and B are parallel or anti-parallel.

24. **(d)** For the particle to move in straight line with constant velocity

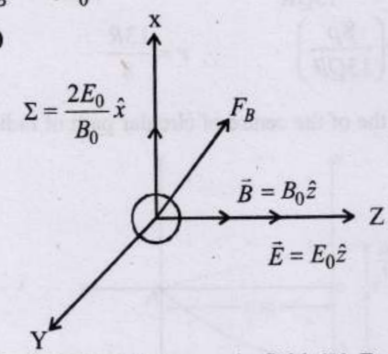
$\vec{F}_e + \vec{F}_B = 0$

$\vec{F}_E = -e\vec{E} = -e(-E_0\hat{x}) = eE_0\hat{x}$

$\vec{F}_B = q(v \times \vec{B}) = -e\left[\dfrac{E_0}{B_0}\hat{y} \times B_0\hat{z}\right]$

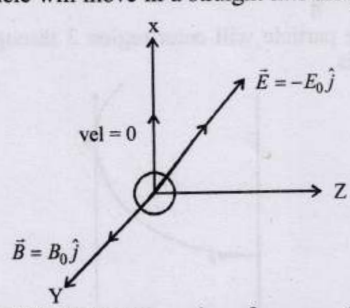
$\vec{F}_B = -eE_0\hat{x}$

25. **(a)**



The force due to magnetic field (B) F_B will provide the necessary centripetal force for circular motion which will be in X-Y plane. The force due to electric field (E) F_E will accelerate proton in Z-direction. Thus the path will be helical with increasing pitch.

26. **(b)** Particle will move in a straight line along-$\hat{y}$



If the electric field will apply a force on –Y axis thereby accelerating the charge along –Y axis.
And magnetic force, $F_B = qv B \sin\theta = 0$
Here $\theta = 180°$

27. Here, $\dfrac{mv^2}{r} = qvB \Rightarrow r = \dfrac{mv}{qB}$ ...(i)

Potential energy = kinetic energy

$qV = \dfrac{1}{2}mv^2$ or, $V = \sqrt{\dfrac{2qv}{m}}$ ...(ii)

From eq. (i) and (ii)

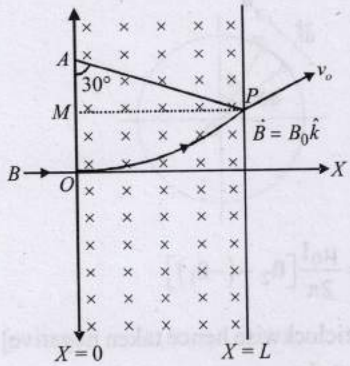
$r = \dfrac{m}{qB} \times \sqrt{\dfrac{2qV}{m}}$ or $r = \dfrac{\sqrt{2qVm}}{qB}$

or, $r \propto \sqrt{\frac{m}{q}}$

$$\therefore \quad \frac{r_p}{r_q} = \sqrt{\frac{m_p}{m_\alpha}} \times \sqrt{\frac{q_\alpha}{q_p}} = \sqrt{\frac{1}{4}} \times \sqrt{\frac{2}{1}} = \frac{1}{\sqrt{2}}$$

28. Let the charged particle enter at 'O' and emerge out from the region of magnetic field at point *P*. Then the velocity vector $\vec{v}_0$ makes an angle 30° with *x*-axis. The perpendicular to circular path at *P* intersects the negative *y*-axis at point *A*.

(a)



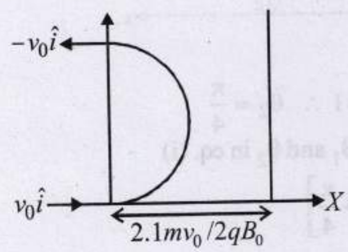
$\therefore AO = AP = R$ = radius of circular path.

$$\frac{mv_0^2}{R} = B_0 q v_0 \Rightarrow R = \frac{mv_0}{qB_0} \quad \text{... (i)}$$

In ΔAPM, $\frac{L}{R} = \sin 30° \Rightarrow R \sin 30° = L \Rightarrow \frac{R}{2} = L$ ... (ii)

From eq. (i) and (ii), $L = \frac{mv_0}{2qB_0}$.

(b) Now the magnetic field extends upto 2.11



So new region of magnetic field

$= \frac{2.1R}{2} > R.$

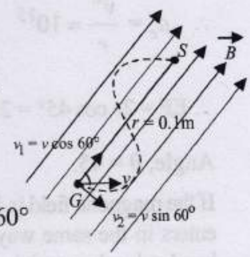
Thus, the required final velocity $= -v_0\hat{i}$.

From figure, the charged particle covers half the circle in the region of magnetic field.

Since the time period for complete revolution, $T = 2\pi m/qB_0$. Therefore the time taken by the particle to cross the region of magnetic field *i.e.*, half the circle $= \frac{T}{2} = \pi m/qB_0$.

29. **(a)** The velocity of electron makes an angle 60° with magnetic field B. v_1 component of velocity move the charge particle in the direction of the magnetic field whereas v_2 component for revolving the charged particle in circular motion. Therefore overall path is helical. The particles will hit 's' with minimum value of B if pitch of helix.

$$T \times v_1 = GS \Rightarrow \frac{2\pi m}{qB} \times v \cos 60° = 0.1$$



$$B = \frac{2\pi mv \cos 60°}{q \times 0.1}$$

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

$$\therefore \quad B = \frac{2\pi m}{q \times 0.1} \times \sqrt{\frac{2E}{m}} \times \cos 60°$$

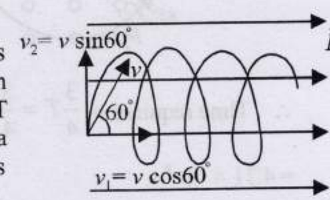
$$= \frac{2\pi}{q \times 0.1} \times \sqrt{2mE} \times \cos 60° = \frac{2 \times 3.14}{1.6 \times 10^{-19} \times 0.1}$$

$$= \sqrt{2 \times 9.1 \times 10^{-31} \times 2 \times 10^3 \times 1.6 \times 10^{-19}} \times \frac{1}{2}$$

$$= \frac{149.8}{10^{-19}} \times 0.316 \times 10^{-23} = 47.37 \times 10^{-4}$$

or, $B = 4.737 \times 10^{-3}$ T

30. A beam of protons enters a uniform magnetic field B = 0.3T at an angle $\theta = 60°$ with a velocity $V = 4 \times 10^5$ m/s



Here V_1 provides horizontal motion and V_2 circular motion to the beam of protons, so protons follow a helical path.

$$\therefore \quad \frac{mv_2^2}{r} = qv_2 B$$

$$r = \frac{mv_2}{qB} = \frac{1.76 \times 10^{-27} \times 4 \times 10^5 \times \sqrt{3}}{1.6 \times 10^{-19} \times 0.3 \times 2} = 0.012 \text{ m}$$

Pitch of helix $= v_1 \times T$

where $T = \frac{2\pi r}{v_2} = \frac{2\pi r}{v \sin\theta}$

$$\therefore \quad \text{Pitch of helix} = v\cos\theta \times \frac{2\pi r}{v \sin\theta}$$

$= 2\pi r \cot\theta = 2 \times 3.14 \times 0.012 \times \cot 60° = 0.044$ m

31. $m = 1.6 \times 10^{-27}$ kg, $q = 1.6 \times 10^{-19}$ C

$B = 1$ T

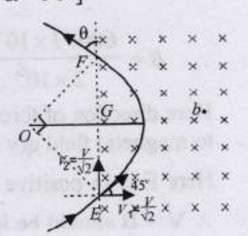
$v = 10^7$ m/s

$F = q \cdot v\, B \sin\alpha$

(acting towards *O* by Fleming's left hand rule)

$\Rightarrow \quad F = qvB \qquad [\because \alpha = 90°]$

$$qvB = ma \Rightarrow a = \frac{qvB}{m}$$



$$= \frac{1.6 \times 10^{-19} \times 10^7 \times 1}{1.6 \times 10^{-27}}$$

$= 10^{15}$ m/s^2

$\angle OEF = 45° \qquad (\because OE$ act as a radius)

By symmetry $\angle OFE = 45°$

$\therefore \quad \angle EOF = 90°$ (by geometry)

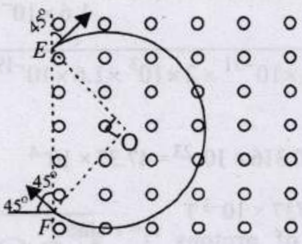
This is the centripetal acceleration

$$\therefore \; a_c = \frac{v^2}{r} = 10^{15} \quad \Rightarrow r = \frac{10^{14}}{10^{15}} = 0.1\,\text{m}.$$

$$\therefore EF = 2r\cos 45° = 2 \times 0.1 \times \frac{1}{\sqrt{2}} = 0.141\,\text{m}.$$

Angle, θ = 45.

If the magnetic field is in the outward direction and the particle enters in the same way at E, then according to Fleming's left hand rule, the particle will turn towards clockwise direction and cover 3/4th of a circle as shown in the figure.



$$\therefore \quad \text{Time required} = \frac{3}{4}T = \frac{3}{4}\left(\frac{2\pi}{\omega}\right) = \frac{3}{4} \times \left[\frac{2\pi r}{v}\right]$$

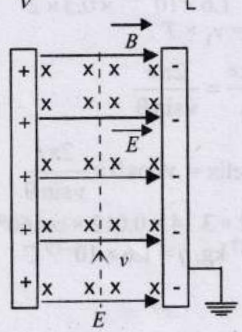
$= 4.71 \times 10^{-8}$ s.

32. As electron passes undeviated,

∴ Force due to electric field = force due to magnetic field.

$eE = evB$

$$\therefore \; B = \frac{E}{v} = \frac{V/d}{v} \qquad \left[\because E = \frac{V}{d}\right]$$



(Given : $V = 600$ V, V = 2×10^6 m/s and d = 3 mm $= 3 \times 10^{-3}$ m

$$\therefore \quad B = \frac{600/3\times10^{-3}}{2\times10^6} = \frac{600}{3\times10^{-3}\times2\times10^6} = 0.1 \text{ tesla}$$

Here direction of force due to electric field (qE) is opposite to magnetic field q(v × B)

Here E is in positive direction

∴ V × B should be in negative x-direction or B should be in –(ve) z-direction ⊥ to paper inwards.

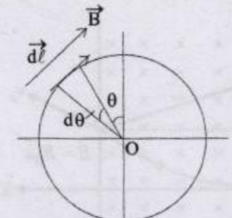
Topic-2: Magnetic Field Lines, Biot-Savart's Law and Ampere's Circuital Law

1. **(a)** From figure

$|\vec{d\ell}| = r d\theta$

Magnetic field, $|\vec{B}| = \frac{\mu_0 I}{2\pi r}$

$$\int \vec{B}.\vec{d\ell} = \int |\vec{B}||\vec{d\ell}|\cos\theta° = \int\left(\frac{\mu_0 I}{2\pi r}\right) \times (r d\theta)$$

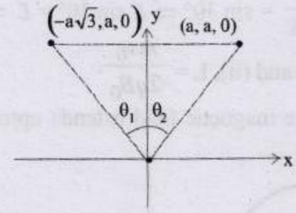


$$= \int_{\theta_1}^{\theta_2} \frac{\mu_0 I}{2\pi} d\theta = \frac{\mu_0 I}{2\pi}\left[\theta_2 - (-\theta_1)\right]$$

[θ, is anticlockwise hence taken negative]

or, $\int B.dl = \frac{\mu_0 I}{2\pi}[\theta_2 + \theta_1]$

Here, $\tan\theta_1 = \frac{a\sqrt{3}}{a} = \sqrt{3} \;\therefore\; \theta_1 = \frac{\pi}{3}$



and $\tan\theta_2 = \frac{a}{a} = 1 \;\therefore\; \theta_2 = \frac{\pi}{4}$

Putting value of θ_1 and θ_2 in eq. (i)

$$\int \vec{B}.\vec{d\ell} = \frac{\mu_0 I}{2\pi}\left[\frac{\pi}{3} + \frac{\pi}{4}\right]$$

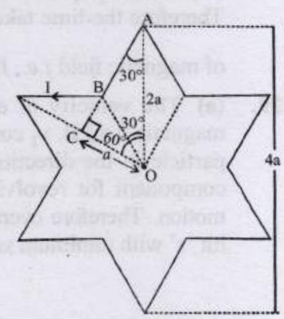
or, $$\int \vec{B}.\vec{d\ell} = \frac{\mu_0 I}{2\pi}\left[\frac{4\pi + 3\pi}{12}\right] = \frac{7\mu_0 I}{24}$$

2. **(c)** $$\vec{B} = \frac{\mu_0 I}{4\pi L}\sin 45°\left(-\hat{k}\right) + \frac{\mu_0 I \pi}{4\pi \frac{L}{2}}\left(-\hat{k}\right) + \frac{\mu_0 I}{4\pi \frac{L}{4}} \times \frac{\pi}{2}\left(-\hat{k}\right)$$

$$= \frac{-\mu_0 I}{L}\left[\frac{1}{4\pi\sqrt{2}} + 1\right]\hat{k}$$

3. **(a)** From figure,

In Δ OAC,



$$\cos 60° = \frac{OC}{OA} = \frac{OC}{2a}$$

$$\therefore OC = 2a \times \frac{1}{2} = a$$

Magnetic field at 'O' due to element AB

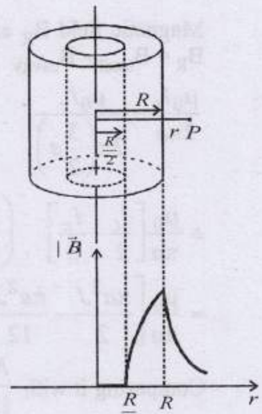
$= \frac{\mu_0}{4\pi}\frac{I}{a}[\sin 60° - \sin 30°]$

$= \frac{\mu_0}{4\pi}\frac{I}{a}\left[\frac{\sqrt{3}}{2} - \frac{1}{2}\right] = \frac{\mu_0 I}{4\pi a} \times \frac{1}{2}(\sqrt{3}-1)$

$\therefore$ Magnetic field at the centre, due to complete loop

$= \left[\frac{\mu_0}{4\pi}\frac{I}{a} \times \frac{1}{2}(\sqrt{3}-1)\right] \times 12 = \frac{\mu_0}{4\pi}\frac{I}{a} \times 6(\sqrt{3}-1)$

4. **(d)** For $r < \frac{R}{2}$, $B = 0$



For $\frac{R}{2} \le r < R$,

$B = \frac{\mu_0}{2}\left[r - \frac{R^2}{2r}\right]J$

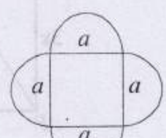
For $r > R$, $B = \frac{\mu_0}{2\pi r}i$

i.e., $B \propto \frac{1}{r}$

Hence graph (*d*) correctly depicts $|\vec{B}|$ versus *r* graph.

5. **(b)** Magnetic moment of a current carrying loop $\vec{M} = NI\vec{A}$

Here $N = 1, A = a^2 + 2\pi\left(\frac{a}{2}\right)^2 = a^2\left[1 + \frac{\pi}{2}\right]$



From Screw law, direction of *m* is outward or in +ve z-direction.

$\therefore \quad \vec{M} = Ia^2\left[1 + \frac{\pi}{2}\right]\hat{k}$

6. **(a)**

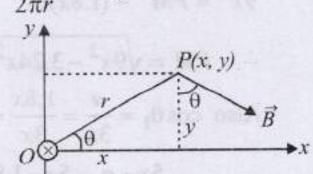
7. **(a)** The wire carries a current *I* in the negative *z*-direction. We have to consider the magnetic vector field $\vec{B}$ at (*x*, *y*) in the *z* = 0 plane.

Magnetic field $\vec{B}$ is perpendicular to *OP*.

$\therefore \ \vec{B} = B\sin\theta\hat{i} - B\cos\theta\hat{j}$

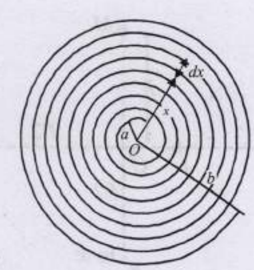
$\sin\theta = \frac{y}{r}, \cos\theta = \frac{x}{r} \quad B = \frac{\mu_0 I}{2\pi r}, x^2 + y^2 = r^2$

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



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

8. **(c)** Let us consider an element of thickness *dx* of wire. Let it be at a distance *x* from the centre *O*.



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

$\therefore$ Number of turns in thickness $dx = \frac{N}{b-a}dx$

Magnetic field due to this small element at *O*

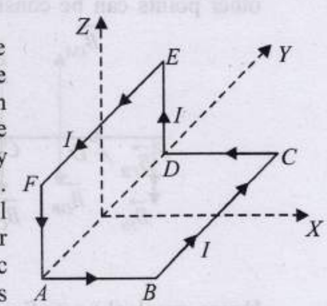
$dB = \frac{\mu_0}{2}\frac{NI}{(b-a)}\frac{dx}{x}$

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

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

$\therefore \quad B = \frac{\mu_0}{2}\frac{NI}{(b-a)}\ln\frac{b}{a}$

9. **(d)** Here loop *ADEFA* in *y-z* plane and loop *ABCDA* in the *x* – *y* plane.



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*. Effectively there is no current in AD. Hence these two cancel out the effect of each other as far as creating magnetic field at the point *P* is considered.

The point (a, 0, a) is in the *X-Z* plane.

The magnetic field due to current in *ABCDA* will be in + ve *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.

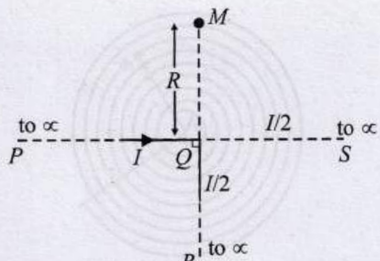
$\therefore$ The direction of resultant magnetic field at *P*(*a*, 0, *a*)

$\vec{B} = \frac{1}{\sqrt{2}}(\hat{i} + \hat{k}).$

10. **(c)** Magnetic field at *M* due to *PQ* and *QR*

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

[$\because$ Magnetic field $B = 0$ at any point on the current carrying straight conductor]



Now when wire QS 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)

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

$$\therefore \quad \frac{H_1}{H_2} = \frac{\mu_0 I}{4\pi R} \Big/ \frac{3\mu_0 I}{8\pi R} = \frac{2}{3}$$

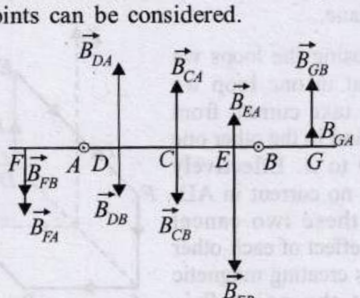
11. **(b)** Here current flowing out of the plane of paper so magnetic field at points to the right of the wire will be upwards and to the left will be downwards. Let us consider certain points.

Point C (mid point between A and B) : 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.

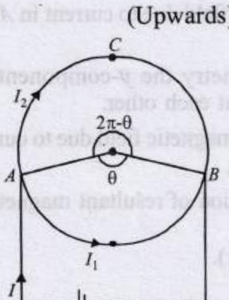
Point D : $|\vec{B}_{DA}| > |\vec{B}_{DB}|$. Net field upwards. Similarly, other points can be considered.



Hence graph (b) satisfies these condition.

12. **(d)** Magnetic field at the centre due to current in arc AB

$$B_1 = \frac{\mu_0}{4\pi}\frac{I_1}{r}\theta \qquad \text{(Upwards)}$$



Magnetic field at the centre due to current in arc ACB

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

$\therefore$ Net magnetic field at the centre

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

Also, $I_1 = \frac{E}{R_1} = \frac{E}{\rho \ell_1 / A} = \frac{EA}{\rho r\theta} \quad \left[\because R = \rho\frac{\ell}{A}\right]$

and $I_2 = \frac{E}{R_2} = \frac{E}{\rho \ell_2 / A} = \frac{EA}{\rho r(2\pi - \theta)}$

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

13. (5) Current density $J = \frac{\text{current}}{\text{area}} = \frac{I}{A} \Rightarrow I = \text{JA}$

Magnetic field B_R after removing cavity (C)

$B_R = B_{total} - B_{cavity}$

$$\frac{\mu_0 I_t}{2\pi a} - \frac{\mu_0 I_c}{2\pi\left(\frac{3}{2}a\right)}$$

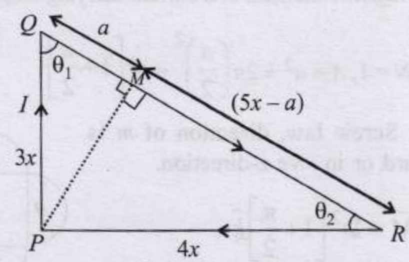
$$= \frac{\mu_0}{\pi a}\left[\frac{I_t}{2} - \frac{I_c}{3}\right] \quad \left(\text{here } I_t = J(\pi a^2)\ I_c = J\left(\frac{\pi a^2}{4}\right)\right)$$

$$= \frac{\mu_0}{\pi a}\left[\frac{\pi a^2 J}{2} - \frac{\pi a^2 J}{12}\right] \text{ or, } B_R = \frac{5\mu_0 aJ}{12}$$

Comparing it with $\frac{N}{12}\mu_0 aJ$ We get $N = 5$

14. (7)

The magnetic field B due to wires PR and PQ = 0. Only wire QR will produce magnetic field at P. From point P, PM ⊥ QR



Magnetic field at 'P' due to wire RQ

$$B = \frac{\mu_0}{4\pi}\frac{I}{PM}(\cos\theta_1 + \cos\theta_2) \qquad \ldots\text{(i)}$$

In ΔPQM, $9x^2 = PM^2 + a^2$ ... (ii)

In ΔPRM, $16x^2 = PM^2 + (5x - a)^2$ ... (iii)

$\Rightarrow \quad 7x^2 = 25x^2 - 10xa \Rightarrow 10xa = 18x^2$

$\Rightarrow \quad a = 1.8\,x$ ... (iv)

From eq. (ii) & (iv),

$$9x^2 = PM^2 + (1.8x)^2$$

$$\therefore PM = \sqrt{9x^2 - 3.24x^2} = \sqrt{5.76x^2} = 2.4x \quad \ldots\text{(v)}$$

Also $\cos\theta_1 = \frac{a}{3x} = \frac{1.8x}{3x} = 0.6$ ... (vi)

$$\cos\theta_2 = \frac{5x - a}{4x} = \frac{5x - 1.8x}{4x} = \frac{3.2}{4} = 0.8 \quad \ldots\text{(vii)}$$

Therefore, from eq. (i), (v), (vi) and (vii),

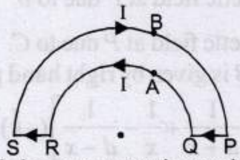
$$B = \frac{\mu_0}{4\pi} \times \frac{I}{2.4x}[0.6 + 0.8] = \frac{\mu_0}{4\pi} \times \frac{I}{2.4x} \times 1.4 = 7\left[\frac{\mu_0 I}{48\pi x}\right]$$

Comparing it with $B = k\left[\frac{\mu_0 I}{48\pi x}\right]$, we get, k = 7.

15. The magnetic field at centre C due to current carrying wires PQ and RS is zero.

Magnetic field due to current in semi-circular arc QAR

$$B_1 = \frac{1}{2}\left[\frac{\mu_0}{2}\frac{I}{R_1}\right] \quad [\perp \text{ to paper outwards}]$$



Magnetic field due to current in semi-circular arc SBP

$$B_2 = \frac{1}{2}\left[\frac{\mu_0}{2}\frac{I}{R_2}\right] \quad [\perp \text{ to paper inwards}]$$

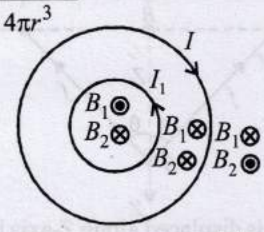
$\therefore$ Net Magnetic field $B = B_1 - B_2$

$$= \frac{1}{2}\left[\frac{\mu_0}{2}\frac{I}{R_1}\right] - \frac{1}{2}\left[\frac{\mu_0}{2}\frac{I}{R_2}\right] \text{ or, } B = \frac{\mu_0 I}{4}\left[\frac{1}{R_1} - \frac{1}{R_2}\right].$$

Directed towards the reader perpendicular to plane of paper.

16. **(a,b)** As per Biot-savart's law,

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



i.e., $\vec{B}$ is perpendicular to both $id\ell$ and $\vec{r}$

$d\ell$ is in xy plane and $\vec{r}$ is also in xy plane

$\therefore$ $d\vec{B}$ is perpendicular to xy plane

Due to symmetry it depends only on distance from centre,

radial distance $r = \sqrt{x^2 + y^2}$

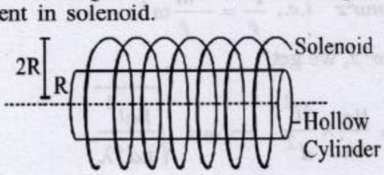
At centre $B_1 = \frac{\mu_0 I_1}{2R}$ and $B_2 = \frac{\mu_0 I_2}{4R}$ clearly, $B_2 > B_1$

As we approach towards first loop B_1 increases to infinity hence B_1 dominates.

So it would be zero at some point between inner loops and centre.

Field will be in opposite direction inside and outside the loop.

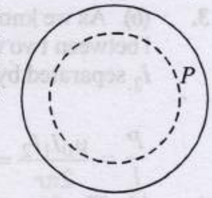
17. **(a, d)** In the region 0 < r < R, the net magnetic field is due to current in solenoid.



In the region $r > 2$ R, the magnetic field is present due to the current in the cylinder.

For the region R < r < 2R, the magnetic field is neither along the common axis, nor tangential to the circle of radius r.

18. **(b)** The magnetic field at every point inside the loop is zero. Consider any point P inside the thin walled pipe. Let us consider a circular loop and using Ampere's circuital law,

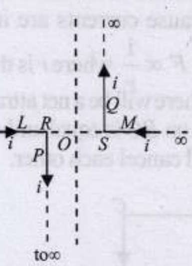


$$\oint \vec{B} \cdot d\vec{\ell} = \mu_0 I$$

Since current inside the loop is zero.

$\therefore$ Magnetic field, $\vec{B} = 0$

19.



$\therefore$ Magnetic field due to current carrying conductor P at point O

$$B_1 = \frac{\mu_0}{4\pi}\frac{i}{(OR)} \quad [\perp \text{ to paper outwards}]$$

Magnetic field due to current carrying conductor Q at point O

$$B_2 = \frac{\mu_0}{4\pi}\frac{i}{(OS)} \quad [\perp \text{ to paper outwards}]$$

Magnetic field due to current carrying conductors L and M at O is zero.

$\therefore$ Resultant magnetic field at O

$B = B_1 + B_2$

(As B_1 and B_2 are in the same direction)

$$B = \frac{\mu_0}{4\pi}\frac{i}{OR} + \frac{\mu_0}{4\pi}\frac{i}{OS} = \frac{\mu_0}{4\pi}i\left[\frac{1}{OR} + \frac{1}{OS}\right]$$

$$= 10^{-7} \times 10 \times \left[\frac{1}{0.02} + \frac{1}{0.02}\right] = 10^{-4}\text{ T.}$$

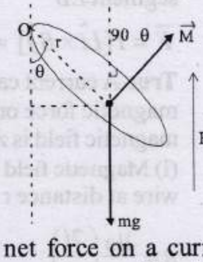
Topic-3: Force and Torque on Current Carrying Conductor

1. **(a)** Let loop makes angle θ with vertical

In equilibrium $\tau_{net} = 0$

$\tau_0 = \text{MB}\sin(90 - \theta) - \text{mg.r}\sin\theta = 0$

$\text{I}.\pi r^2.\text{B}_0\cos\theta = \text{mg r.}\sin\theta$



$$\therefore \quad \frac{\sin\theta}{\cos\theta} = \frac{\text{I}\pi r^2\text{B}_0}{\text{mgr}}$$

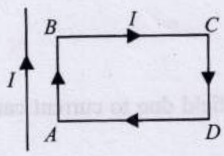
$$\therefore \quad \tan\theta = \frac{\pi r\text{IB}_0}{\text{mg}}$$

2. **(b)** In uniform magnetic field, net force on a current carrying loop is zero. Hence loop cannot move. Fleming's left hand rule, we find that a force is acting in the radially outward direction throughout the circumference of the conducting loop.

3. (b) As we know, the force per unit length f/l between two wires carrying currents I_1 and I_2 separated by a distance r.

$$\frac{P}{l}=\frac{\mu_0 I_1 I_2}{2\pi r}=\frac{\mu_0 i^2}{2\pi b}\quad [\because I_1=I_2=i \text{ and } r=b]$$

4. (c) The loop will move towards the wire AB part of the rectangular loop will get attracted to the long straight wire as the currents are parallel and in the same direction whereas CD part will be repelled because currents are in opposite direction. But since this force $F\propto\frac{1}{r}$ where r is the distance between the wires. Therefore, there will be a net attractive force on the rectangular loop. Force on BC is equal and opposite to that on AD, so these forces will cancel each other.



5. (3) $\frac{mv^2}{R}=qvB\Rightarrow R=\frac{mv}{qB}$

or $R\propto\frac{1}{B}$ $\quad[\because m, q, v$ are the same$]$

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

$$\text{or, } \frac{R_1}{R_2}=\frac{\frac{\mu_0}{4\pi}\times 2I\left[\frac{1}{X_1}+\frac{1}{X_0-X_1}\right]}{\frac{\mu_0}{4\pi}\times 2I\left[\frac{1}{X_1}-\frac{1}{X_0-X_1}\right]}$$

$$=\frac{X_0-X_1+X_1}{X_0-X_1-X_1}=\frac{X_0}{X_0-2X_1}\quad\left[\text{Given } \frac{X_0}{X_1}=3\right]$$

$$\therefore\ \frac{R_1}{R_2}=\frac{\frac{X_0}{X_1}}{\frac{X_0}{X_1}-2}=\frac{3}{3-2}=3$$

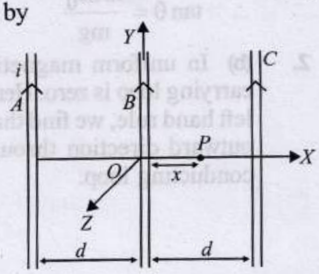
6. Here, net force on the loop $EDCBE$ will be zero. Also force due to segment FE and BA will be zero. Force due to segment EB

$\vec{F}=I[L\hat{i}\times B\hat{j}]=ILB\hat{k}$ in the positive z direction.

7. **True** A current carrying coil is a magnetic dipole. The net magnetic force on a magnetic dipole placed in a uniform magnetic field is zero.

8. (i) Magnetic field due to an infinitely long current carrying wire at distance r is given by

$$B=\frac{\mu_0}{4\pi}\left(\frac{2i}{r}\right)$$



In case of three identical wires, resultant field can be zero only if the point P is between the two wires, otherwise field B due to all the wires will be in the same direction and so resultant B cannot be zero. Hence, if point P is at a distance x from the central wire as shown in figure, then,

$\vec{B}_P=\vec{B}_{PA}+\vec{B}_{PB}+\vec{B}_{PC}$

where $\vec{B}_{PA}$ = magnetic field at P due to A

$\vec{B}_{PB}$ = Magnetic field at P due to B

$\vec{B}_{PC}$ = Magnetic field at P due to C.

Direction of B is given by right hand palm rule.

$$\vec{B}_P=\frac{\mu_0}{4\pi}2i\left[\frac{1}{d+x}+\frac{1}{x}-\frac{1}{d-x}\right](-\hat{k}).$$

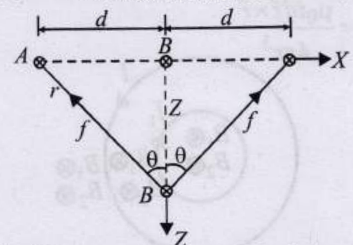
For $\vec{B}_P=0$, $\frac{1}{d+x}+\frac{1}{x}=\frac{1}{d-x}$

Solving we get, $x=\pm\frac{d}{\sqrt{3}}$

(ii) The force per unit length between two parallel current carrying wires

$\frac{\mu_0}{4\pi}\frac{2i_1i_2}{r}=f$(say)

Attractive if currents are in the same direction.



If the wire B is displaced along Z-axis by a small distance Z, the restoring force per unit length $\frac{F}{\ell}$ on the wire B due to wires A and C will be

$$\frac{F}{\ell}=2f\cos\theta=2\frac{\mu_0}{4\pi}\frac{2i_1i_2}{r}\times\frac{z}{r}\quad\left[\text{as }\cos\theta=\frac{z}{r}\right]$$

or $\frac{F}{\ell}=\frac{\mu_0}{4\pi}\frac{4i^2z}{(d^2+z^2)}$ $\quad$ [as $I_1=I_2$ and $r^2=d^2+z^2$]

or $\frac{F}{\ell}=-\frac{\mu_0}{4\pi}\left(\frac{2i}{d}\right)^2 z$ [as $d\gg z$ and F is opposite to z] ...(i)

The components of force along x-axis will be cancelled.

Here $F\propto -z$, the motion is simple harmonic.

Comparing eq. (i) with the standard equation of S.H.M.

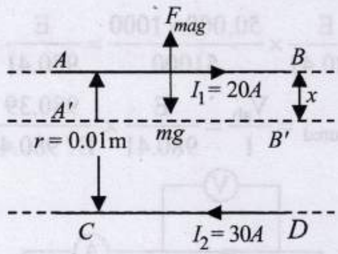
$F=-m\omega^2 z$ i.e., $\frac{F}{\ell}=-\frac{m}{\ell}\omega^2 z$

$=-\lambda\,\omega^2 z$, we get

$$\lambda\omega^2=\frac{\mu_0}{4\pi}\times\frac{4i^2}{d^2}\Rightarrow\omega=\sqrt{\frac{\mu_0 i^2}{\pi d^2\lambda}}$$

$$\Rightarrow 2\pi f=\frac{i}{d}\sqrt{\frac{\mu_0}{\pi\lambda}}\Rightarrow f=\frac{i}{2\pi d}\sqrt{\frac{\mu_0}{\pi\lambda}}$$

9. When wire AB is slightly depressed, force of repulsion due to current. In it opposite to the wire CD will push it upwards and AB may vibrate. If force of attraction exists, CD will attraction AB and vibration of AB will not be possible.
When the rod is depressed by a distance x, then the force acting on the upper wire increases and behaves as a restoring force.



Restoring force/length $= \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r-x} - \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r}$

$= \frac{\mu_0}{4\pi}2I_1I_2\left[\frac{1}{r-x}-\frac{1}{r}\right] = \frac{\mu_0}{4\pi}\frac{2I_1I_2x}{r(r-x)}$

When x is small *i.e.*, $x << r$ then $r = x \approx r$

Restoring force/length $F = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r^2}x = \frac{mg}{r}$

Since, $F \propto x$ and directed to equilibrium position. Therefore the motion is simple harmonic

$\therefore \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r^2} =$ (mass per unit length) $\omega^2 (\because a = \ell\omega^2)$ ...(i)

At equilibrium, $\frac{mg}{r} = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r}$

Mass per unit length $= \frac{\mu_0}{4\pi}\frac{2I_1I_2}{rg}$ ...(ii)

From eq. (i) and (ii)

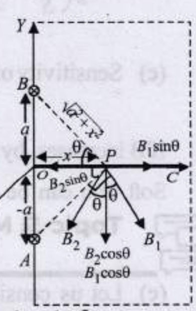
$$\frac{\mu_0}{4\pi}\frac{2I_1I_2}{r^2} = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{rg}\times\omega^2$$

$$\Rightarrow \omega = \sqrt{\frac{g}{r}}$$

$$\Rightarrow \frac{2\pi}{T} = \sqrt{\frac{g}{r}}$$

$$\therefore T = 2\pi\sqrt{\frac{r}{g}} = 2\pi\sqrt{\frac{0.01}{9.8}} = 0.2\,\text{s}$$

10. Let the magnetic field due to currents in A and B at P be B_1 and B_2 respectively in the directions perpendicular to AP and BP as shown in figure.
Let $\angle BPO = \angle APO = \theta$



$$|\vec{B}_1| = \frac{\mu_0}{4\pi}\frac{2I}{\sqrt{a^2+x^2}} = |\vec{B}_2|$$

On resolving B_1 and B_2 we get that the $\sin\theta$ components cancel out and the $\cos\theta$ components add up.

$\therefore B = 2B_1\cos\theta$

$$= \frac{2\mu_0}{4\pi}\frac{2I}{\sqrt{a^2+x^2}}\times\frac{x}{\sqrt{a^2+x^2}} = \frac{\mu_0}{4\pi}\frac{4Ix}{(a^2+x^2)}$$

(towards $-Y$ direction)

Let us consider a small portion of wire OC at P of length dx. (Because magnetic field produced at different points on OC will be different). The small amount of force acting on that small portion

$d\vec{F} = I(d\vec{x}\times\vec{B}) \quad \therefore dF = I\,dx\,B\sin 90°$

$$\Rightarrow dF = I\,dx\times\frac{\mu_0}{4\pi}\times\frac{4Ix}{(a^2+x^2)}$$

$$\Rightarrow dF = \frac{\mu_0}{4\pi}4I^2\frac{xdx}{(a^2+x^2)}$$

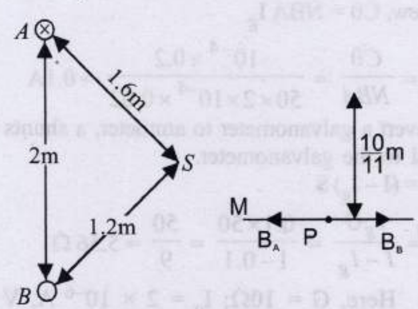
$$\therefore \text{ Total force, } F = \frac{\mu_0}{4\pi}\times 4I^2\int_0^L\frac{xdx}{(a^2+x^2)}$$

$$= \frac{\mu_0}{4\pi}\times 4I^2\left[\frac{1}{2}\log_e(a^2+x^2)\right]_0^L$$

$$\Rightarrow F = \frac{\mu_0}{4\pi}\times 2I^2\left[\log_e\frac{a^2+L^2}{a^2}\right]$$

The direction of $\vec{F}$ is towards $-Z$ direction as per Fleming's left hand rule.
When direction of current in B is reversed, net magnetic field is along the current, hence force.
$F = I\ell B\sin\theta$ and $\theta = 180°$ is zero.

11. The two parallel wires are perpendicular to the plane of the paper. The wire A carries current directed into the plane of paper.
The current in wire B should be in upward direction so as to cancel the magnetic field due to A at P. (By right hand Thumb rule)



(i) The magnetic field at P due to current in wire A.

$$B_A = \frac{\mu_0}{4\pi}\frac{2I_A}{r_{AP}} = \frac{\mu_0}{4\pi}\times\frac{2\times 9.6}{\left(2+\frac{10}{11}\right)} \text{ (Direction } P \text{ to } M) \text{ ...(i)}$$

The magnetic field at P due to current in wire B

$$B_B = \frac{\mu_0}{4\pi}\times\frac{2I_B}{\left(\frac{10}{11}\right)} \text{ ...(ii)}$$

From eq. (i) and (ii)

$$\frac{\mu_0}{4\pi}\times\frac{2\times 9.6}{\left(2+\frac{10}{11}\right)}=\frac{\mu_0}{4\pi}\times\frac{2I_B}{\left(\frac{10}{11}\right)}$$

$$\Rightarrow \frac{9.6\times 11}{32}=\frac{I_B\times 11}{10}\Rightarrow I_B=\frac{96}{32}=3\text{A}$$

(ii) The dimensions given shows that
$SA^2+SB^2=AB^2$ ∴ $\angle ASB=90°$
(By pythagorous theorem)

Magnetic field due to A at S

$$B_{SA}=\frac{\mu_0}{4\pi}.\frac{2I_A}{r_{SA}}=\frac{\mu_0}{4\pi}\times\frac{2\times 9.6}{1.6}\quad \text{(Directed } S \text{ to } B)$$

Magnetic field due to B at S

$$B_{SB}=\frac{\mu_0}{4\pi}.\frac{2I_B}{r_{SB}}=\frac{\mu_0}{4\pi}\frac{2\times 3}{1.2}\quad \text{(Directed } S \text{ to } A)$$

Since B_{SA} and B_{SB} are mutually perpendicular
∴ net magnetic field,

$$B=\sqrt{B_{SA}^2+B_{SB}^2}=\frac{\mu_0}{4\pi}\sqrt{\left(\frac{9.6}{0.8}\right)^2+\left(\frac{3}{0.6}\right)^2}$$
$$=10^{-7}\times 13=1.3\times 10^{-6}\text{ T}$$

(iii) Force per unit length on wire B

$$=\frac{\mu_0}{4\pi}\frac{2I_AI_B}{r_{AB}}$$
$$=\frac{10^{-7}\times 2\times 9.6\times 3}{2}=28.8\times 10^{-7}\text{ N/m}$$

Topic-4: Galvanometer and its Conversion into Ammeter and Voltmeter

1. **(5.56)** [Given: B = 0.02T, C = 10^{-4} Nm rad^{-1}
$\theta = 0.2$ rad
N = 50 and
A = 2×10^{-4} m^2]
We know, $C\theta = NBA\,I_g$

$$\therefore\ I_g=\frac{C\theta}{NBA}=\frac{10^{-4}\times 0.2}{50\times 2\times 10^{-4}\times 0.02}=0.1\text{A}$$

To convert a galvanometer to ammeter, a shunts is used in parallel to the galvanometer.
$I_g\times G=(I-I_g)\,S$

$$\therefore\ S=\frac{I_gG}{I-I_g}=\frac{0.1\times 50}{1-0.1}=\frac{50}{9}=5.56\,\Omega$$

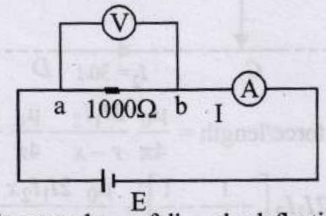
2. **(b, d)** Here, G = 10Ω; $I_g = 2\times 10^{-6}$ A, V = 100 m
V = 0.1V, I = 10^{-3}A
Using, V = I_g (G + R) [R = resistance connected in series with galvanometer]
$\Rightarrow 0.1 = 2\times 10^{-6} R_v$
∴ $R_v = 5\times 10^4\,\Omega$ (Resistance of voltmeter)
Also $I_g G = (I - I_g)s$
$2\times 10^{-6}\times 10 = (10^{-3} - 2\times 10^{-6})s$
∴ S = $2\times 10^{-2}\,\Omega$ (Resistance of ammeter)

$$R_A=\frac{GS}{G+S}=\frac{10\times 0.02}{10+0.02}\approx 0.02\Omega$$

$$I=\frac{E}{\frac{50{,}000\times 1000}{51000}+0.02}=\frac{E}{980.41}$$

$$V_{ab}=\frac{E}{980.41}\times\frac{50{,}000\times 1000}{51000}=\frac{E}{980.41}\times 980.39$$

$$\therefore\ R_{measured}=\frac{V_{ab}}{I}=\frac{E}{980.41}\times\frac{980.39}{E/980.41}=980.39\Omega$$



If the voltmeter shows full scale deflection, then

$$0.1=\frac{E}{980}\times\left(\frac{1000}{51000}\right)\times 5\times 10^4$$

∴ $E = 999.6$ mv.
Since $i_A = 10^{-3}$A

$$\therefore\ \text{Maximum reading of } R=\frac{999.6\times 10^{-3}}{1\times 10^{-3}}=999.6\,\Omega$$

3. **(a, c)** The range of voltmeter.
$V = I_g(R_{eq} + G)$
∴ Maximum voltage can be obtained if equivalent resistance of components is maximum, *i.e.* when all the components are connected in series.
The range of ammeter

$$I=I_g\left(1+\frac{G}{S_{eq}}\right)$$

∴ Maximum current range can be obtained if equivalent shunt resistance is minimum, *i.e.*, when all the components are connected in parallel.

4. **(b, c)** To convert ammeter into a volt meter a high resistance is connected in series and alow resistance is connected in parallel to convert a galvanometer into an ammeter.
For $V = I_g(G + R) = 5\times 10^{-5}\,[100 + 200{,}000] = 10$V

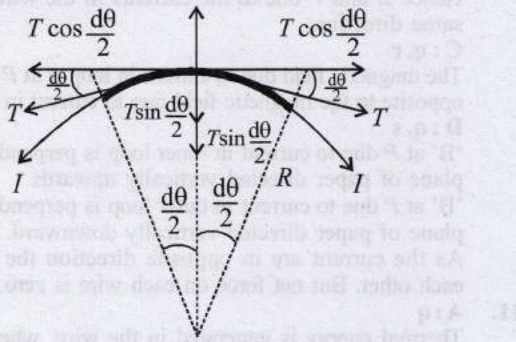
$$\text{For } I=I_g\left(\frac{G}{S}+1\right)=5\times 10^{-5}\left[\frac{100}{1}+1\right]=5\text{mA}.$$

5. **(c)** Sensitivity of a moving coil galvanometer, $=\frac{\theta}{I}=\frac{NBA}{C}$.

If B increases, by using iron core $\frac{\theta}{I}$ *i.e.*; sensitivity increases.
Soft iron can be easily magnetised and de magnetized.

Topic-5: Miscellaneous (Mixed Concepts) Problems

1. **(c)** Let us consider an elemental length *dl* subtending an angle $d\theta$ at the centre of the circle 'O'. Let F_B be the magnetic force acting on this length.



$\therefore\ F_B = BI(dl)$ (upwards)

$= BI(Rd\theta) \qquad \left[\because \text{angle}(d\theta) = \frac{\text{arc}(dl)}{\text{radius } R}\right]$

$= BI\left(\frac{L}{2\pi}\right)d\theta \qquad \left[\because 2\pi R = L \Rightarrow R = \frac{L}{2\pi}\right]$

Let T be the tension in the wire acting along both ends of the elemental length.

At equilibrium $2T\sin\left(\frac{d\theta}{2}\right) = BI\frac{L}{2\pi}d\theta$

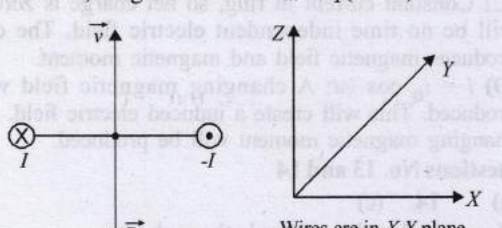
$\Rightarrow 2T\frac{d\theta}{2} = BI\frac{L}{2\pi}d\theta \qquad \left[\because \frac{d\theta}{2} \text{ very-very small}\right]$

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

2. **(d)** The magnetic lines of force created due to current will be in such a way that on $x-y$ plane these lines will be perpendicular. These lines will be in circular loops. The number of lines moving downwards in $x-y$ plane will be same in number to that coming upwards of the $x-y$ plane. Therefore, total magnetic flux through $x-y$ plane will be zero.

3. **(d)** The net magnetic field due to both the wires will be downward as shown below in the figure. Since angle between $\vec{v}$ and $\vec{B}$ is 180°,

Therefore, magnetic force $F_m = q(\vec{v}\times\vec{B}) = 0$



Wires are in X-Y plane and velocity in Z-direction

4. **(4)** Here, force $F = qVB$ is balanced by centripetal force

$$F_e = \frac{mV^2}{r}$$

$$\therefore\ qVB = \frac{mV^2}{r}$$

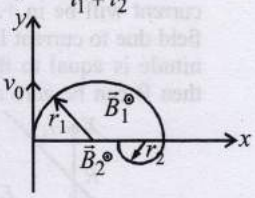
$$\text{or}\quad r = \frac{mV}{qB} = \frac{\sqrt{2mqV}}{qB}$$

$$\frac{P^2}{2m} = \text{K.E.} = qV$$

$$\frac{r_s}{r_\alpha} = \sqrt{\frac{m_s}{q_s}}\times\sqrt{\frac{q_a}{m_a}} = \sqrt{\frac{32}{1}\times\frac{2}{4}} = 4$$

$$\therefore\ \frac{r_s}{r_\alpha} = 4$$

5. **(2)** Average speed along x-axis, $v_x = \frac{d_1+d_2}{t_1+t_2}$



Here, $r_1 = \frac{mv_0}{qB_1}$ and $r_2 = \frac{mv_0}{qB_2}$

$\because\ B_1 = \frac{B_2}{4} \qquad \therefore\ r_1 = 4r_2$

Time spent by charged particle in B_1, $t_1 = \frac{\pi m}{qB_1}$

Time spent by charged particle in B_2, $t_2 = \frac{\pi m}{qB_2}$

Total distance along x-axis

$d_1 + d_2 = 2r_1 + 2r_2 = 2(r_1 + r_2) = 2(5r_2) = 10r_2$

Average speed $= \frac{10r_2}{5t_2} = 2\frac{mv_0}{qB_2}\times\frac{qB_2}{\pi m}$

$= 2\text{ms}^{-1} \qquad (\because v_0 = \pi\text{ms}^{-1})$

6. **(6)** Consider the circular tube as a long solenoid. The wires are closely wound. Magnetic field B inside the solenoid $B = \mu_0 ni$

$\therefore\ B = \frac{\mu_0 I}{L} \qquad \left[\because ni = \frac{I}{L}\right]$

Flux passing through the circular coil

$$\phi = BA = \left(\frac{\mu_0 I}{L}\right)(\pi r^2)$$

Induced emf $e = -\frac{d\phi}{dt} = -\left(\frac{\mu_0\pi r^2}{L}\right).\frac{dI}{dt}$

Induced current, $i = \frac{e}{R} = -\left(\frac{\mu_0\pi r^2}{LR}\right).\frac{dI}{dt}$

Magnetic moment, $M = iA = i\pi r^2$

or $M = -\left(\frac{\mu_0\pi^2 r^4}{LR}\right).\frac{dI}{dt}$ ...(i)

Given, $I = I_0\cos(300t)$

$\therefore\ \frac{dI}{dt} = -300I_0\sin(300t)$

$$M = \left(\frac{300\,\pi^2 r^4}{LR}\right)\mu_0 I_0\sin(300t)$$

$$N = \frac{300\,\pi^2 r^4}{LR}$$

$$\frac{300\,(22/7)^2(0.1)^4}{(10)(0.005)} = 5.926 \text{ or } N \approx 6$$

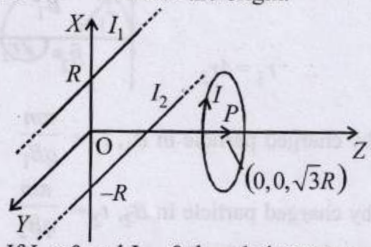
7. The force experience by moving charge. $\vec{F} = q(\vec{v} \times \vec{B})$

$= (-e)(-v\hat{i} \times B\hat{j}) = evB\hat{k}$

The direction of flow of electrons is opposite to that of current. Due to this force, the lowering of the potential of the face ABCD as electron collected at this face.

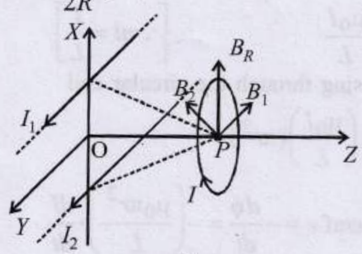
8. **(a, b, d)** (a) If $I_1 = I_2$, then the magnetic fields due to I_1 and I_2 at origin 'O' will cancel out each other. But the magnetic field at 'O' due to the ring will be present. Therefore B cannot be zero at origin.

(b) If $I_1 > 0$ and $I_2 < 0$, then the magnetic field due to both current will be in $+Z$ direction and add-up. The magnetic field due to current I will be in $-Z$ direction and if its magnitude is equal to the combined magnitudes of I_1 and I_2 then B can be zero at the origin.



(c) If $I_1 < 0$ and $I_2 > 0$ then their net magnetic field at origin will be in $-Z$ direction and the magnetic field due to I at origin will also be in $-Z$ direction. Therefore $\vec{B}$ at origin cannot be zero.

(d) If $I_1 = I_2$ then the resultant of the magnetic field B_R at P is along $+X$ direction. Therefore the magnetic field at P is only due to the current I which is in $-Z$ direction and is equal to $\vec{B} = \frac{\mu_0 I}{2R}(-\hat{k})$.



9. **(b, d)** Induced emf $e = -\frac{d\phi}{dt}$. For identical rings induced emf will be same. But currents will be different. Given $h_A > h_g$.

Hence, $V_A > V_B$ as $\left(h = \frac{v^2}{2g}\right)$.

If $\rho_A > \rho_B$, then, $I_A < I_B$. In this case given condition can be fulfilled if $m_A < m_B$.

If $\rho_A < \rho_B$, then $I_A > I_B$. In this case given condition can be fulfilled if $m_A \le m_B$.

10. **A : q, r**

B at P due to upper wire in downward direction and due to lower wire in upward direction.

Hence, q is correct.

As P is the mid point, the two magnetic fields, cancel out each other. Therefore, r is correct.

B : p

B at P, due to current in loop A is along the axial line towards right and due to current in loop B is also along the axial line towards right.

Hence B and P due to the currents in the wires are in the same direction.

C : q, r

The magnetic field due to current in loop A at P is equal and opposite to the magnetic field due to current in loop B at P.

D : q, s

'B' at P due to current in inner loop is perpendicular to the plane of paper directed vertically upwards.

'B' at P due to current in outer loop is perpendicular to the plane of paper directed vertically downward.

As the current are in opposite direction the wires repel each other. But net force on each wire is zero.

11. **A : q**

Thermal energy is generated in the wire, when a charged capacitor is connected to the ends of the wire, a variable current (decreasing in magnitude with time) passes through the wire (shown as resistor). The potential difference across the wire also decreases with time. The charge on the capacitor plate also decreases with time.

B : r, s

The wire is moved perpendicular to its length (ℓ) with a constant velocity (v) in a uniform magnetic field (B) $\perp$ to the plane of motion $e = B\ell v$

When B, ℓ, v are constant, e is constant

A constant potential difference develops across the ends of the wire and charges of constant magnitude appear at the ends of the wire.

C : s

When wire is placed ma constant electric field that has a direction along the length of the wire. The free electrons move under the influence of electric field opposite to the direction of electric field. This movement of e^- continues till the electric field inside the wire is zero. Charges of constant magnitude appear at the ends of the wire.

D : p, q, r

Since emf of the battery E, R are constant, a constant current flows in the wire. Due to heating effect of current, thermal energy is generated in the wire. Also a constant potential difference develops between the ends of the wire.

12. **A – p; B – q, s; C – q, s; D – q, r, s**

(A) Charge on dielectric ring will create electrostatic field which is time independent.

(B) The rotating charge is like a current. This will create a magnetic field and a magnetic moment.

(C) Constant current in ring, so net charge is zero there will be no time independent electric field. The current produces magnetic field and magnetic moment.

(D) $i = i_0 \cos \omega t$; A changing magnetic field will be produced. This will create a induced electric field. Also a changing magnetic moment will be produced.

For Questions No. 13 and 14

13. **(a)** 14. **(c)**

Sol. Magnetic flux due to dipole through ring

$$\phi = Li = \frac{\mu_0 m}{2\pi r^3} \times \pi a^2 \Rightarrow i = \frac{\mu_0 m \pi a^2}{2\pi r^3 L}$$

or $i \propto \frac{m}{r^3}$

Magnetic moment, $m' = iA = \pi a^2 i = \frac{\mu_0 m \pi^2 a^4}{2\pi r^3 L}$

$$F = \frac{kmm'}{r^4} = \frac{km^2\pi^2a^4}{2\pi r^7 L}$$

Therefore work done in bringing the dipole,

$$W = \int F dr \propto \int \frac{m^2 dr}{r^7} \text{ or, } W \propto \frac{m^2}{r^6}$$

15. **(a, d)** When megnetic force balances electric force

$F_B = F_E \Rightarrow q v_d B = q E$

$\therefore v_d B = \frac{V}{w}$ $[\because V = E \times w]$

$\therefore V = wv_d B = w\left[\frac{I}{newd}\right] \times B$ $\left[v_d = \frac{I}{neA} = \frac{I}{newd}\right]$

$\therefore V = \frac{I}{ned} \times B$

or, $V \propto \frac{1}{d} \Rightarrow V_1 d_1 = V_2 d_2$

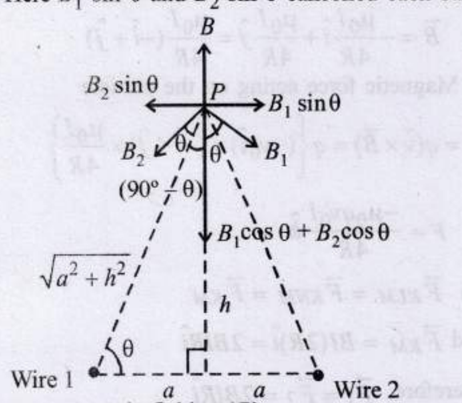
If $d_1 = 2d_2$, $V_2 = 2V_1$
and if $d_1 = d_2$, $V_2 = V_1$

16. **(a, c)** $\because V = \frac{I}{ne_d} \times B$

$\therefore V \propto \frac{B}{n} \Rightarrow \frac{V_1 n_1}{B_1} = \frac{V_2 n_2}{B_2}$

If $B_1 = B_2$ and $n_1 = 2n_2 \Rightarrow V_2 = 2V_1$
and vf $B_1 = 2B_2$ and $n_1 = n_2 \Rightarrow V_2 = 0.5V_1$

17. **(c)** Here $B_1 \sin\theta$ and $B_2 \sin\theta$ cancelled each other.



For zero magnetic field at 'P'
Magnetic field due to current carrying circular loop = Magnetic field due to straight wires
$B = B_1 \cos\theta + B_2 \cos\theta = 2 B_1 \cos\theta$

$$\frac{\mu_0 I a^2}{2\left(a^2+h^2\right)^{3/2}} = 2\left[\frac{\mu_0 I}{2\pi\sqrt{a^2+h^2}}\right] \times \frac{a}{\sqrt{a^2+h^2}}$$

Solving we get,
$h \approx 1.2a$
The current is from P to Q and R to S in wire 1 and wire 2 respectively.

18. **(b)** We know torque

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

$$= \left(I \times \pi a^2\right) \times \left[2 \times \frac{\mu_0 I}{2\pi d}\right] \sin 30°$$

$$\therefore \tau = \frac{\mu_0 I^2 a^2}{2d}$$

19. **(d)** The levitation of the train is due to magnetic repulsion. The magnetised coils running along the track repel large magnets on the train's under carriage.

20. **(d)** High initial cost.

21. **(b)** Maglev is the abbreviation of magnetic levitation. The magnetic force will pull the maglev trains.

22. (a) Torque acting on a rectangular coil placed in a uniform magnetic field

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

$M = N i A$ and $\theta = 90°$ (for moving coil galvanometer)
$\therefore \tau = N i A B \sin 90° = N i A B$
$\tau = k i$ (given)
$\therefore k i = NiAB \Rightarrow k = NAB$

(b) Torsion constant, $C = \frac{\tau}{\theta} = \frac{NiAB}{\theta}$

Given, $i = i_0$, $\theta = \pi/2$

$\therefore C = \frac{2N i_0 AB}{\pi}$ ... (i)

(c) $\int \tau dt = \int NiAB\, dt = NAB \int i\, dt$ $(\because \tau = NiAB)$
$= NABQ$
$\int \tau\, dt = I\omega$

$\therefore I\omega = NABQ \Rightarrow \omega = \frac{NABQ}{I}$

Let us apply the law of energy conservation to find the angle of rotation.
Rotational kinetic energy of coil = potential energy at maximum deflection

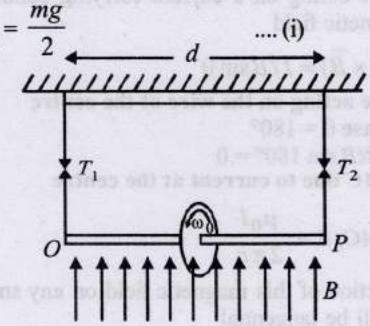
$$\frac{1}{2}I\omega^2 = \frac{1}{\lambda}C\theta^2 \text{ max}$$

$$\frac{1}{2}I\left(\frac{NABQ}{I}\right)^2 = \frac{1}{2}\left(\frac{2NIAB}{\pi}\right)\theta^2_{max}$$

$$\therefore \theta_{max} = Q\sqrt{\frac{\pi BNA}{2I}}$$

23. When the wheel is not rotating
Wt. of wheel = tension in string
$mg = 2T_0$

$\therefore T_0 = \frac{mg}{2}$ .... (i)



When the wheel is rotating and magnetic field is applied magnetic moment

$$M = iA = \frac{Q}{T} \times \pi r^2 = \frac{Q}{2\pi}\omega \times \pi R^2$$

Now, the tensions in the strings will become unequal. Let the tensions in the strings be T_1 and T_2.

For translational equilibrium

$T_1 + T_2 = mg$ ... (ii)

Torque acting on the ring about the centre of ring

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

$\tau = M \times B \times \sin 90°$

$$\tau = \frac{Q}{2\pi}\omega \times \pi R^2 \times B = \frac{Q\omega BR^2}{2}$$

For rotational equilibrium, the torque about the centre of ring should be zero.

$$\therefore \quad T_1 \times \frac{d}{2} - T_2 \times \frac{d}{2} = \frac{Q\omega BR^2}{2}$$

$$\Rightarrow T_1 - T_2 = \frac{Q\omega BR^2}{d} \quad \text{... (iii)}$$

From eq. (ii) and (iii),

$$T_1 = \frac{mg}{2} + \frac{Q\omega BR^2}{2d}$$

But the maximum tension or breaking tension $= \dfrac{3T_0}{2}$

$$\therefore \quad \frac{3T_0}{2} = T_0 + \frac{Q\omega_{\max}BR^2}{2d} \quad \left[\because T_0 = \frac{mg}{2}\right]$$

$$\therefore \quad \omega_{\max} = \frac{dT_0}{BQR^2}$$

24. Magnetic field produced by the circuit at its centre,

$B = B_{\text{inner arcs}} + B_{\text{outer arcs}}$

as straight part of the circuit will produce zero magnetic field at the centre.

$$\therefore \quad B = \frac{\mu_0 i}{4r_1} + \frac{\mu_0 i}{4r_2}$$

[Given $i = 10_A$, $r_1 = 0.08$ m and $r_2 = 0.12$ m]

$$\text{or,} \quad B = \frac{\mu_0}{4} \times 10 \times \left(\frac{1}{0.08} + \frac{1}{0.12}\right)$$

$\therefore \quad B = (6.54 \times 10^{-5})T$ [⊥ to the paper outwards.] (from right hand thumb rule)

(b) Force acting on a current carrying conductor placed in a magnetic field

$\vec{F} = I(\vec{\ell} \times \vec{B}) = I\ell B \sin\theta$

For force acting on the wire at the centre

In this case $\theta = 180°$

$\therefore \quad F = I\ell B \sin 180° = 0$

On arc *AC* due to current at the centre

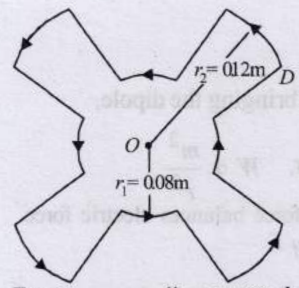
$$|\vec{B}| \text{ on } AC, B = \frac{\mu_0 I}{2\pi r_1}$$

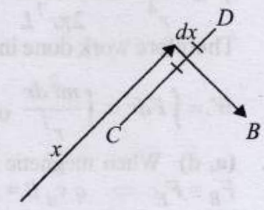
The direction of this magnetic field on any small segment of AC will be tangential

$\therefore \theta = 180° \Rightarrow F = 0$

On segment *CD*.

Magnetic field at a distance x due to central wire $B = \dfrac{\mu_0 I}{2\pi x}$





Force on a small segment dx distant r from O.

$dF = I\,dxB$

$$= 10 \times dx \times \frac{\mu_0 I}{2\pi x} = \frac{5\mu_0 I}{\pi}\frac{dx}{x}$$

On integrating

$$\therefore \quad F = \frac{5\mu_0 I}{\pi}\int_{r_1}^{r_2}\frac{dx}{x} \qquad \therefore \quad F = \frac{5\mu_0 I}{\pi}\left[\log_e x\right]_{r_1}^{r_2}$$

$$\therefore \quad F = \frac{5\mu_0 I}{\pi}\log_e\frac{r_2}{r_1} = \frac{5\mu_0 \times 10}{\pi}\log_e\left(\frac{0.12}{0.08}\right)$$

$= 8.1 \times 10^{-6}$ N (inwards)

(By Fleming Left Hand rule).

25. (a) Magnetic field $(\vec{B})$ at the origin = magnetic field due to semicircle KLM + magnetic field due to other semicircle KNM.

$$\therefore \ \vec{B} = \frac{\mu_0 I}{4R}(-\hat{i}) + \frac{\mu_0 I}{4R}(\hat{j})$$

[∵ KLM lies in the y-z plane and KNM in the x-z plane]

$$\text{or,} \quad \vec{B} = -\frac{\mu_0 I}{4R}\hat{i} + \frac{\mu_0 I}{4R}\hat{j} = \frac{\mu_0 I}{4R}(-\hat{i} + \hat{j})$$

∴ Magnetic force acting on the particle

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

$$\text{or,} \quad F = \frac{-\mu_0 q v_0 I}{4R}\hat{k}$$

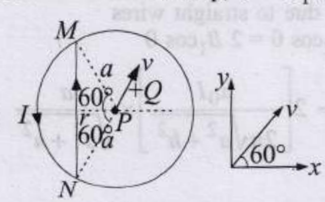
(b) $\vec{F}_{KLM} = \vec{F}_{KNM} = \vec{F}_{KM}$

and $\vec{F}_{KM} = BI(2R)\hat{i} = 2BIR\hat{i}$

Therefore, $\vec{F}_1 = \vec{F}_2 = 2BIR\hat{i}$

∴ Total force on the loop, $\vec{F} = \vec{F}_1 + \vec{F}_2 \Rightarrow \vec{F} = 4BIR\hat{i}$

26. (a)



(i) Current I through the arc MN and straight wire NM setup a magnetic field at the centre P.

The charged particle is acted upon by the magnetic force due to these fields. The magnetic force produces an instantaneous acceleration in the charged particle. Field due to arc MN.

$B_1 = \frac{1}{3}\frac{\mu_0 I}{2a}$ outwards

or $B_1 = \frac{\mu_0 I}{6a}$ outwards $= \frac{0.16\,\mu_0 I}{a}$ outwards

or $\vec{B}_1 = \frac{0.16\,\mu_0 I}{a}\hat{k}$

Field due to straight wire *NM*

$B_2 = \frac{\mu_0 I}{4\pi r}(\sin 60° + \sin 60°)$, where $r = a\cos 60°$

or $B_2 = \frac{\mu_0}{4\pi}\frac{I}{a\cos 60°}(2\sin 60°)$

or $B_2 = \frac{\mu_0 I}{2\pi a}\times\sqrt{3}$ (inwards)

or $\vec{B}_2 = -\frac{0.27\,\mu_0 I}{a}\hat{k}$

$\therefore\ \vec{B}_{net} = \vec{B}_1 + \vec{B}_2$

or $\vec{B}_{net} = -\frac{0.11\,\mu_0 I}{a}\hat{k}$

$\vec{v} = v\cos 60°\ \hat{i} + v\sin 60°\ \hat{j}$

or $\vec{v} = \frac{v}{2}\hat{i} + \frac{\sqrt{3}v}{2}\hat{j}$

$\therefore$ Magnetic force

$\therefore\ \vec{F}_m = Q(\vec{v}\times\vec{B}_{net}) = \frac{0.11\mu_0 IQv}{2a}(\hat{j} - \sqrt{3}\hat{i})$

$\therefore$ Acceleration mass $\vec{a} = \frac{\vec{F}_m}{m}$

or $\vec{a} = \frac{0.11\mu_0 IQv}{2ma}(\hat{j} - \sqrt{3}\hat{i})$

(ii) Force and torque on the loop:

In uniform magnetic field $\vec{B} = B\hat{i}$, force on current loop is zero.

Torque on loop = $\vec{M}\times\vec{B}$

$\vec{M} = (IA)\hat{k}$

or $A = \frac{\pi a^2}{3} - \frac{a^2}{2}\sin 120°$ or $A = 0.61\,a^2$

$\therefore\ \vec{M} = (0.61\,Ia^2)\hat{k} \qquad \vec{B} = B\hat{i}$

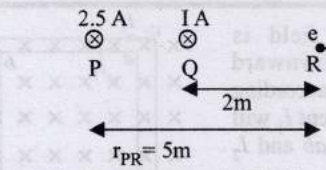
$\therefore\ \vec{\tau} = \vec{M}\times\vec{B}$ or $\vec{\tau} = (0.61\,Ia^2 B)(\hat{k}\times\hat{i})$

or $\vec{\tau} = (0.61 Ia^2 B)\hat{j}$

27. (i) Magnetic field due to current in wire *P* at *R*

$B_1 = \frac{\mu_0}{4\pi}\times\frac{2I_P}{r_{PR}} = \frac{\mu_0}{4\pi}\times\frac{2\times 2.5}{5} = \frac{\mu_0}{4\pi}$

[in the plane of paper downwards]



Similarly, the magnetic field due to current in wire *Q* at *R*

$B_2 = \frac{\mu_0}{4\pi}\times\frac{2\times I}{2} = \frac{\mu_0}{4\pi}I$ [in the plane of paper downwards]

Total magnetic field at *R* [due to *P* and *Q*]

$B = B_1 + B_2 = \frac{\mu_0}{4\pi} + \frac{\mu_0}{4\pi}I = \frac{\mu_0}{4\pi}(1+I)$

[in the plane of paper downwards]

Force experienced by the electron

$F = qvB\sin\theta$

$= \pi vB\sin 90° = 1.6\times 10^{-19}\times 4\times 10^5\times\frac{\mu_0}{4\pi}(1+I)$

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

or, $I = 4$ A

(ii) For net field at *R* to be zero, magnetic field due to third wire carrying a current of 2.5 A should be

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

Let *r* be the distance of this wire from R

$\therefore\ 5\times 10^{-7} = \frac{\mu_0}{4\pi}\times\frac{2\times 2.5}{r}$ or, $r = 1$m

i.e., either left or right 1m from R direction of current outwards and inwards respectively.