HINTS & SOLUTIONS

EXERCISE - 1

Single Choice

1. $B_1 = \frac{\mu_0}{2}\frac{I_1}{R} = 3\times10^{-5}\,T$

$B_2 = \frac{\mu_0}{2}\frac{I_2}{R} = 4\times10^{-5}\,T$

$B = \sqrt{B_1^2 + B_2^2} = 5\times10^{-5}\,T$

2. $\vec{B}_O = \vec{B}_{arc} + \vec{B}_{st.wire} = \frac{\mu_0}{2}\frac{I}{R}(-\hat{k}) + \frac{\mu_0}{2\pi}\frac{I}{R}(\hat{k})$

3. $B = \frac{\mu_0}{2}\frac{I}{R}\left(2\pi R = n2\pi r \Rightarrow r = \frac{R}{n}\right)$

$B' = \frac{\mu_0}{2}\frac{In}{(R/n)} = n^2 B$

4. $B_{axis} = \frac{1}{2}(B_{centre})$

$\Rightarrow \frac{\mu_0}{4\pi}\frac{2\pi R^2 I}{(R^2+x^2)^{3/2}} = \left(\frac{\mu_0}{4\pi}\frac{2\pi I}{R}\right)\times\frac{1}{2}$

$\Rightarrow x = 0.766\,R$

5. $\vec{B} = \vec{B}_{arc} + \vec{B}_{st.line} = 0 + \left(\frac{\mu_0}{4\pi}\frac{I}{R}\right)\times 2\hat{k}$

6. For radial component of magnetic field, the total force will be either in the upward or in the downward direction depending on the direction of current.
$\therefore$ Force $= ILB_{\perp} = I(2\pi a)B\sin\theta$

7. $\vec{B}$ due to XY wire on wire PQ is into the plane.

$\therefore$ Force on wire PQ $= \int i\vec{dl}\times\vec{B}$

$= \int i\,dl(-\hat{i})\times B(-\hat{k}) = \int i\,dl\,B(-\hat{j})$ (downward)

8. B due to closed loop is zero in all cases. B due to straight lead wires is non–zero in case (c).

9. Force $= I(L_{eff})B$

L_{eff} = length normal to $\vec{B} = \vec{RQ}$

$\therefore$ Force $= 5\times\frac{4}{100}\times 2 = 0.4\,N$

11. For constant velocity $a = 0 = g\sin\theta - \frac{ilB\cos\theta}{m}$

$\Rightarrow B = \frac{mg\tan\theta}{il}$

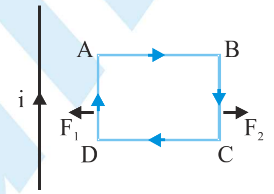
12. $F = \frac{\mu_0}{2\pi}\frac{I_1I_2}{d} = \frac{2\times10^{-7}\times1\times1}{1} = 2\times10^{-7}\,N/m$

13. $\vec{M} = NIA\hat{n}$

$= 1\times10\times0.1\times0.1\,(\hat{i}\cos60° - \hat{k}\cos30°)$

$= 0.05\,(\hat{i} - \sqrt{3}\hat{k})\,A - m^2$

14. $F_1 > F_2 \quad \therefore F_{net} = F_1 - F_2$ (attractive)



15. Angle between $\vec{M}$ and $\vec{B}$ is $\left(\frac{\pi}{2} + \theta\right)$

16. $B = \frac{\mu_0}{4\pi}\frac{(2e)}{r}\left(\frac{2\pi}{T}\right) = \frac{\mu_0\times1.6\times10^{-19}}{0.8\times2} = \mu_0\times10^{-19}\,T$

17. Force on electron, $\vec{F} = q\vec{v}\times\vec{B}$

$\Rightarrow F(\hat{j}) = -ev(\hat{i})\times B(\hat{B}) \Rightarrow \hat{B} = \hat{k}$

18. $F_e = \frac{1}{4\pi\epsilon_0}\frac{e^2}{r^2}$

$F_m = \frac{\mu_0}{4\pi}\frac{e^2v^2}{r^2}$

$\Rightarrow \frac{F_e}{F_m} = \frac{1}{\epsilon_0\mu_0 v^2} = \frac{c^2}{v^2}$

19. Force on cosmic rays,
$\vec{F} = ev(-\hat{k})\times B(\hat{j}) = evB\hat{i}$ (towards East)

20. Electrostatic force on electron, $\vec{F}_e = -eE\hat{j}$

$\therefore$ Magnetic force on electron,

$\vec{F}_m = -ev(-\hat{j}) \times B\hat{k} = evB\hat{i}$

The electron moves in circle with radius on x–axis.

21. $R = \frac{mv}{qB} = \frac{\sqrt{2mK}}{qB}$

$\therefore \frac{R_1}{R_2} = \sqrt{\frac{m_1}{m_2}}$

$\Rightarrow \frac{m_1}{m_2} = \left(\frac{R_1}{R_2}\right)^2$

22. Magnetic force acts normal to velocity and hence KE does not change but momentum changes.

25. $R = \frac{\sqrt{2mK}}{qB}$; $R_\alpha = \frac{\sqrt{8mK}}{2qB}$;

$R_P = \frac{\sqrt{2mK}}{qB}$; $R_d = \frac{\sqrt{4mK}}{qB}$

26. $B = \frac{\mu_0}{4\pi}\frac{I}{(a\cos 30°)}(\sin 30° + \sin 30°)$

$\left[1 - \frac{1}{2} + \frac{1}{3} - ....\right] \Rightarrow \vec{B} = \frac{\mu_0}{4\pi}\frac{I\ln 4}{\sqrt{3}a}\hat{k}$

27. $\vec{B} = \left[\frac{\mu_0}{4\pi}\frac{I}{2r}\pi + \frac{\mu_0}{4\pi}\frac{I}{r}\pi\right] \otimes = \frac{3\mu_0 I}{8r} \otimes$

28. $\vec{F} = q(\vec{v} \times \vec{B} + \vec{E}) = 0 \Rightarrow q(10\hat{i} \times B\hat{j} - 10^4\hat{k}) = 0$

$\Rightarrow B = 10^3 \text{ Wb/m}^2$

29. $\vec{B}_{z\text{ wire}} = 0$; $\vec{B}_{y\text{ wire}} = (-\hat{i})\left(\frac{\mu_0}{2\pi a}\right)$;

$\vec{B}_{x\text{ wire}} = (\hat{j})\left(\frac{\mu_0 i}{2\pi a}\right)$ $\therefore \vec{B} = \frac{\mu_0 i}{2\pi a}(\hat{j} - \hat{i})$

30. Magnetic field around a current carrying wire has circular symmetry. Hence zero $\vec{B}$ line lies in the same plane of wires. The locus of zero $\vec{B}$ is a straight line.

31. $q\left[|\vec{E}| - |v\vec{B}|\right] = 0 \Rightarrow v = \frac{E}{B}$

$\therefore$ Radius, $R = \frac{mv}{qB} = \frac{mE}{qB^2}$

$= \frac{9.1 \times 10^{-31} \times 3.2 \times 10^5}{1.6 \times 10^{-19} \times 4 \times 10^{-6}} = 0.455\text{m}$

32. $qE = \frac{mv_0^2}{r_1}$ and $qvB = \frac{mv_0^2}{r_2} \Rightarrow \frac{r_1}{r_2} = \frac{v_0 B}{E}$

33. $R = \frac{mv}{qB} = d \Rightarrow v = \frac{qBd}{m}$

34. $v = (g\sin\theta)t$

$N = mg\cos\theta - qvB = 0 \Rightarrow t = \frac{m\cot\theta}{qB}$

35. $R = \frac{mv}{qB} = \frac{\sqrt{2mqV}}{qB} = \frac{d}{2} \Rightarrow m = \frac{qB^2d^2}{8V}$

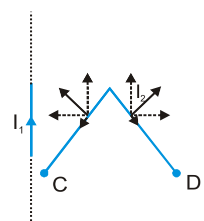
36. $\vec{M} \times \vec{B} = I\vec{\alpha}$

$\Rightarrow NIA \times B \times \sin 90° = \frac{MR^2}{2}\alpha$

$\Rightarrow 1 \times 4 \times \pi R^2 \times 10 \times 1 = \frac{2}{2}R^2 \times \alpha$

$\Rightarrow \alpha = 40\pi \text{ rad/s}^2$

37. Net force will have –x and +y components



38. $\left[\frac{E^2\mu_0 \in}{B^2}\right] = \left[\frac{v^2}{c^2}\right] = M^0L^0T^0$

EXERCISE - 2

Part # I : Multiple Choice

1. Effective resistance in each upper and lower arms are equal. Hence equal currents flows and produces zero M.F. in P and R configuration.

2. $\frac{B_1}{B_2} = \frac{\mu_0 i_1}{2r} \times \frac{2(2r)}{\mu_0 i_2} = \frac{1}{3} \Rightarrow \frac{i_1}{i_2} = \frac{1}{6}$

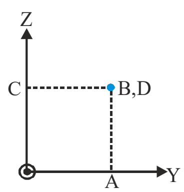
3. $I_g = \frac{150}{10} \times 10^{-3} = 0.015\,A$

$V_g = \frac{150}{2} \times 10^{-3} = 0.075\,V \therefore G = \frac{V_g}{I_g} = 5\,\Omega$

If R = resistance to be added in series, I (G+R)=V

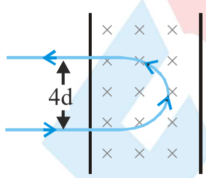
$\Rightarrow 0.015\,(5+R) = 150 \times 1 \Rightarrow R = 9995\,\Omega$

4.



5. A and B observe electrostatic fields. But B observes magnetic field due to moving charge.
A and C have same M.F. and B and D have same M.F.

6. $R = \frac{mv}{qB} = \frac{v}{\alpha B} = 2d$



Angle substended at the centre = π

Time to stay in magnetic field $= \frac{T}{2} = \frac{\pi}{\alpha B}$

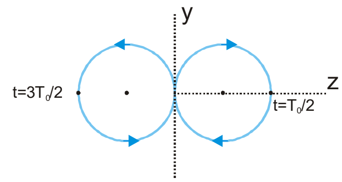
7. $\vec{B} = \frac{\mu_0}{2\pi}\frac{I_1}{(AP)}\hat{k} + \frac{\mu_0}{2\pi}\frac{I_2}{(PB)}\hat{j}$

$= \left[\frac{2 \times 10^{-7} \times 2}{10^{-2}}\right]\hat{k} + \left[\frac{2 \times 10^{-7} \times 3}{2 \times 10^{-2}}\right]\hat{j}$

$= (3 \times 10^{-5}\,T)\hat{j} + (4 \times 10^{-5}\,T)\hat{k}$

8. In B_1 and B_4 M.F. add up.
In B_2 and B_3, M.F. oppose each other.

9.



10. Effective length, length normal to $\vec{B}$, remains same.

11. $T = \frac{2\pi m}{qB} = 2\pi \Rightarrow R = \frac{mv}{qB} = \frac{|x|}{|x|} = 1\,m$

At $t = \pi$; charge will complete half circle.

$\therefore x = 0;\ y = \frac{1}{2}\left(\frac{qE}{m}\right)t^2 = \frac{1}{2}\left(\frac{1 \times 1}{1}\right)\pi^2 = \frac{\pi^2}{2}$

$z = 2R = 2m$

12. $\vec{F} = q\vec{v} \times \vec{B} = 1\frac{1}{2}(\sqrt{3}\hat{i} + \hat{j}) \times 1\hat{k} = \left(\frac{\hat{i} - \sqrt{3}\hat{j}}{2}\right)$

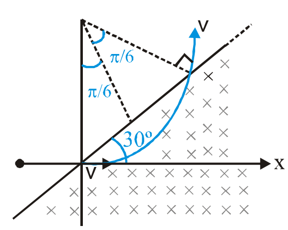
$R = \frac{mv}{qB} = \frac{1 \times 1}{1 \times 1} = 1 \Rightarrow \vec{R} = \vec{r}_2 - \vec{r}_1 = \left(\frac{\hat{i} - \sqrt{3}\hat{j}}{2}\right)$

$\Rightarrow \vec{r}_2$ = centre's coordinates $= \left(\frac{\hat{i} - \sqrt{3}\hat{j}}{2}\right) + (-\sqrt{3}\hat{i} - \hat{j})$

13. $\frac{\theta}{t} = \frac{\pi/2}{t} = \frac{2\pi}{T} = \frac{2\pi}{(2\pi m/qB)}$

$\Rightarrow t = \frac{\pi m}{2qB} = \frac{\pi R}{2v}\left(\because R = \frac{mv}{qB}\right)$

14. $t = \frac{\theta}{\omega} = \frac{2 \times \pi/6}{qB/m} = \frac{\pi m}{3qB}$



Distance travelled

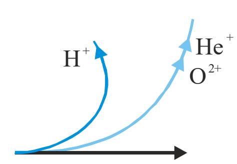
$= RQ = \frac{\pi m v}{3qB}$

Velocity of exit = $v_0(\cos 60\hat{i} + \sin 60\hat{j})$

15. $R_{H^+} = \frac{\sqrt{2mK}}{qB} = R$

$R_{He^+} = \frac{2\sqrt{2mK}}{qB} = 2R$

$R_{O^{2+}} = 2\frac{\sqrt{2mK}}{qB} = 2R$



H^+ is deflected most

16. Work done by E.F. $= qE2a = \frac{1}{2}m(4v^2 - v^2)$

$$\Rightarrow E = \frac{3mv^2}{4qa}$$

Rate of work done by E.F. at

$$P = q\vec{E}.\vec{v} = \left(\frac{3}{4}\frac{mv^2}{qa}\right)qv = \frac{3mv^3}{4a}$$

Rate of work done by E.F. and

M.F. at Q : $q(\vec{E}.\vec{v} + (\vec{v}\times\vec{B}).\vec{v}) = 0$

17. Ampere's Law $\Rightarrow B2\pi\frac{d}{2} = \mu_0 J\left(\frac{\pi d^2}{4}\right)$

$$B = \left(\frac{\mu_0}{4\pi}.\pi dJ\right)\hat{j} \;\therefore\; B_{net} = 2B = \left(\frac{\mu_0}{2\pi}\right)\pi dJ\hat{j}$$

18. From work energy theorem

$$W = \Delta KE \;\Rightarrow qE_0x_0 = \frac{1}{2}mv^2$$

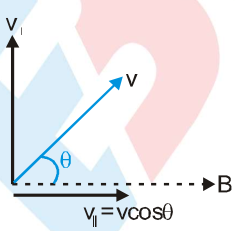
$$\Rightarrow \alpha E_0x_0 = \frac{1}{2}(4^2+3^2) \Rightarrow x_0 = \frac{25}{2\alpha E_0}$$

19. $\vec{F} = -qv\left(\frac{\hat{i}-\hat{j}}{\sqrt{2}}\right)\times B(-\hat{k}) = qvB\left(\frac{-\hat{i}-\hat{j}}{\sqrt{2}}\right)$

$$\therefore \hat{F} = -\left(\frac{\hat{i}+\hat{j}}{\sqrt{2}}\right)$$

20. $T_1 = \frac{2\pi M}{QB} = T_0$

$$T_2 = \frac{2\pi(2M)}{QB} = 2T_0$$



They will meet at time $2T_0$.

$\therefore$ Distance from origin=vcos $\theta \times 2T_0 = \frac{4\pi Mv\cos\theta}{QB}$

21. $\vec{F} = -e\vec{v}\times\vec{B}$

$$\Rightarrow -2\hat{j} = -e\left[2\hat{i}\times(B_1\hat{i}+B_2\hat{j}+B_3\hat{k})\right] \Rightarrow B_2 = 0$$

$$\Rightarrow 2\hat{i} = -e\left[2\hat{j}\times(B_1\hat{i}+B_2\hat{j}+B_3\hat{k})\right] \Rightarrow B_1 = 0$$

Then $\vec{F} = -e\left[2\hat{k}\times(B_3\hat{k})\right] = 0$

22. $\Sigma F = 0 \Rightarrow mg\sin\theta - f = 0,\; f = mg\sin\theta$ ...(i)

$\Sigma T = 0 \Rightarrow MB\sin\theta - fR = 0$

$$\Rightarrow i\pi R^2 B\sin\theta = mg\sin\theta R \Rightarrow B = \frac{mg}{\pi iR}$$

23. Impulse = change in momentum

$$\Rightarrow (i\ell B\Delta t) = m(\sqrt{2gh} - 0) \Rightarrow (i\Delta t) = \Delta q = \frac{m\sqrt{2gh}}{lB}$$

24. In configurations (C) and (D), equal currents flow in each arm. Hence $\vec{B}$ at centre will be zero.

25. $\vec{\tau} = \vec{M}\times\vec{B} = \frac{IA}{2}(-\hat{k})\times B(-\hat{j}) = \frac{IAB}{2}(-\hat{i})$ (Leftward)

26. $\vec{F} = q(v\cos\alpha\hat{j} + v\sin\alpha\hat{k})\times B\hat{j} = qvB\sin\alpha(-\hat{i})$

Hence the x-coordinate of proton can never be +ve.

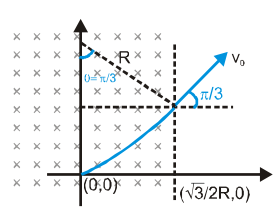
27. $\vec{F} = q\vec{v}\times\vec{B} = qv_0(\hat{i}+\hat{j})\times\vec{B} = (-)qv_0B\hat{k}$

$$T = \frac{2\pi m}{qB} \;\therefore\; \omega t = \frac{2\pi}{T}t = \frac{2\pi qB}{2\pi m}\times\frac{\pi}{qB} = \pi$$

$$\therefore X = v_0t = \frac{v_0\pi}{B_0\alpha};\; Y = 0$$

$$Z = -2R = \frac{-2Mv_0}{2B_0} = -\frac{2v_0}{\alpha B_0}$$

28. $R\sin\theta = \frac{\sqrt{3}}{2}\frac{mv_0}{qB_0} = \frac{\sqrt{3}}{2}\frac{v_0}{\alpha B_0} = \frac{\sqrt{3}}{2}R$; $\theta = \pi/3$



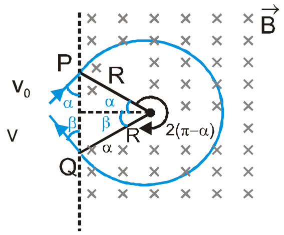
$\therefore$ x-coordinate

$$= \frac{\sqrt{3}}{2}R + v_0\cos\theta\left(t - \frac{\theta}{\omega}\right) = \frac{\sqrt{3}v_0}{2B_0\alpha} + \frac{v_0}{2}\left(t - \frac{\pi}{3B_0\alpha}\right)$$

29. $L_{effective} = AB = 4\hat{i}$

$$\therefore |\vec{F}| = |I\vec{L}\times\vec{B}| = IL_{eff}B = 2.4\hat{i}\times4(-\hat{k}) = -32\hat{j}\,N$$

30. In magnetic fieldy the path is circle and the motion is uniform.



$\therefore v = v_0$

$$PQ = 2R\sin\alpha = \frac{2mv_0}{qB}\sin\alpha \Rightarrow \frac{2\pi}{T} = \frac{\theta}{t}$$

$$\Rightarrow \frac{2\pi}{\left(\frac{2\pi m}{qB}\right)} = \frac{2(\pi-\alpha)}{t} \Rightarrow t = \frac{2m(\pi-\alpha)}{Bq}$$

31. $\vec T = \vec M \times \vec B$

Torque is directed at right angle to hour hand. Hence minute hand will be in the direction of torque after 20 minutes.

$T = M \times B \times \sin\theta = NIAB\sin 90$

$$= \frac{6\times 2\times \pi(0.15)^2\times 70\times 1}{1000} = 0.0594\,\text{Nm}$$

32. $\vec F = I\vec L \times \vec B \Rightarrow I\left(R\left(-\hat j\right)\times B\hat\mu\right) = \sqrt2 IRB_0\hat k$

Possible values of $\therefore \vec B = \frac{B_0}{\sqrt2}\hat i$ and $\vec B = \frac{B_0}{\sqrt2}(\hat i + \hat j)$

33. Force acting on unit length = $B_0 I$

34. Magnetic field exerts force on a moving charge normal to it and the force also acts normal to both of them and hence kinetic energy remains same.

35. The lines of force will be concentric circles with centres on wire.

All points lying on the circle have same magnitude of magnetic field.

Magnetic field at a point from the wire varies inversely with distance from the wire.

37. $a = \frac{T_1}{T_2} = \frac{2\pi m}{qB}\Big/\frac{2\pi m}{qB} = 1$

$$b = \frac{mv\sin 30°}{qB}\Big/\frac{mv\sin 60}{qB} = \tan 30°$$

$$c = v_{||}\times T = \frac{v\sin 60° T}{v\sin 30 T} = \tan 60°$$

$\therefore bc = 1 = a \Rightarrow abc = 1$

38. $\vec F = q[\vec E + \vec v\times\vec B] = 0 \Rightarrow |\vec E| = |\vec v\times\vec B| = vB$

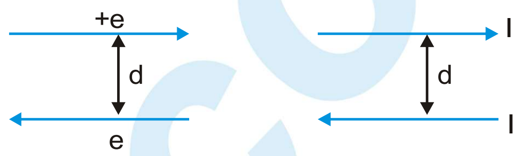
$\therefore E = |1.5\times10^{-6}(-\hat j)\times 1(-\hat k)| = |1.5\times10^{-6}(-\hat i)|$ N/C

$$\frac{R_A}{R_B} = \frac{(mv/qB)_A}{(mv/qB)_B} = \frac{m_A}{m_B} = \frac{12}{13}$$

39. $\vec F = q[\vec E + \vec v\times\vec B] = 0 \Rightarrow |\vec E| = |-\vec v\times\vec B| = |-vB| = vb$

$v = \frac{E}{B} = \frac{2E}{2B}$ (direction remaining same)

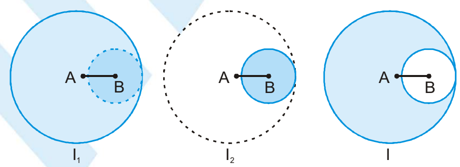
40.



$\vec B$ at mid point = 0 Equivalent form

41. $\vec B_P = \frac{\mu_0}{4\pi}\frac{I}{R/\sqrt2}(\sin 90° - 45°) = \frac{(\sqrt2-1)\mu_0 I}{4\pi R}(-\hat k)$

42.



$$I_1 = \frac{IR^2}{\pi\left(\frac{3R^2}{4}\right)};\ I_2 = \frac{I(R/2)^2}{\pi\left(\frac{3R^2}{4}\right)}$$

Field at A $= B_{I_1} + B_{I_2} = 0 + \frac{\mu_0 i}{3\pi R}\hat j$

Field at B $= B_{I_1} + B_{I_2} = \frac{\mu_0 I}{3\pi R}\hat j + 0$

43. For inner cylinder $B = \frac{\mu_0}{2\pi}\frac{ir}{R_1^2}$

For air space $B = \frac{\mu_0}{2\pi}\frac{i}{r}$

For outer cylinder $B = \frac{\mu_0}{2\pi}\frac{i}{r} - \frac{\mu_0 i}{2\pi r}\left(\frac{r^2 - R_2^2}{R_3^2 - R_2^2}\right)$

44. $\vec B$ add up is the left and the right zone. But in the middle zone $\vec B$ becomes zero.

45. $B_C = B_{I_1} + B_{I_2} = \frac{\mu_0 ic}{2\pi(b^2 - a^2)} + 0$

46. $W = MB(1-\cos 60^\circ) = \frac{MB}{2}$

$|\vec{T}| = MB\sin 60^\circ = \sqrt{3}\,\frac{MB}{2} = \sqrt{3}\,W$

47. $B_{\text{axial point}} = 2\left(\frac{\mu_0}{4\pi}\right)\frac{M}{r^3} = \frac{2\times10^{-7}\times 8}{(0.2)^3} = 2\times10^{-4}\,T$

$B_{\text{eq. point}} = \left(\frac{\mu_0}{4\pi}\right)\frac{M}{r^3} = 10^{-4}\,T$

48. Both rings experience torque due to other's magnetic field.

49. $MB\sin\theta = T \Rightarrow M\times 0.16\times\frac{1}{2} = 0.032 \Rightarrow M = 0.4\ J/T$

50. $\vec{F} = q\vec{v}\times\vec{B} \Rightarrow (4\hat{i}+3\hat{j})\times10^{-13} = -1.6\times10^{-19}$

$\left[(2.5\times10^{7})\hat{k}\times(B_1\hat{i}+B_2\hat{j}+B_3\hat{k})\right]$

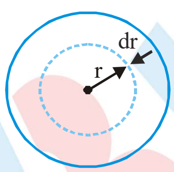
$\Rightarrow B_1 = -0.075,\ B_2 = +0.1$

Again : $\vec{F} = q\vec{v}\times\vec{B}$; $q = -1.6\times10^{-19}$

$\left[(1.5\hat{i}-2\hat{j})10^{7}\right]\times(0.075\hat{i}+0.1\hat{j}+B_3\hat{k})$

$\Rightarrow B_3 = 0 \ \therefore \vec{B} = -0.075\hat{i}+0.1\hat{j}$

51. Charge per unit area $= \frac{Q}{\pi R^2}$



Charge on elemental ring,

$dQ = \left(\frac{Q}{\pi R^2}\right)2\pi r dr = \frac{2Qrdr}{R^2}$

$\therefore$ B at centre $= \int \frac{\mu_0}{2}\left(\frac{dQ}{r}\frac{\omega}{2\pi}\right)$

$= \frac{\mu_0\omega}{4\pi}\left(\frac{2Q}{R^2}\right)\int_0^R dr = \frac{\mu_0 Q\omega}{2\pi R}\,e$

52. $v_y = v_0$

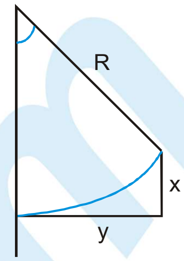
$v_x = \left(\frac{qE_0}{m}\right)t$; $v = \sqrt{v_0^2+\left(\frac{qE_0}{m}t\right)^2} = 2v_0 \Rightarrow t = \frac{\sqrt{3}mv_0}{qE}$

53. $\vec{B}_0 = \frac{\mu_0}{4\pi}\frac{I}{R}\theta(-\hat{k}) + \frac{\mu_0}{4\pi}\frac{I}{R\cos\frac{\theta}{2}}\left(\sin\frac{\theta}{2}+\sin\frac{\theta}{2}\right)\hat{k}$

$\Rightarrow \vec{B}_0 = \frac{\mu_0}{4\pi}\frac{I}{R}\left(2\tan\frac{\theta}{2}-\theta\right)\hat{k} > 0$

$\therefore \vec{B}_0$ is directed outwards.

54. Radius, $R = \frac{mv}{qB} \Rightarrow mv = qBR$



where $R\sin\theta = y$; $R(1-\cos\theta) = x$

$\Rightarrow R = \frac{1}{2}\left(\frac{y^2}{x}+x\right)$

$\therefore mv = \frac{qB}{2}\left(\frac{y^2}{x}+x\right)$

55. $T = \frac{2\pi m}{qB}$ (Time period of rotation)

For motion in E.F.

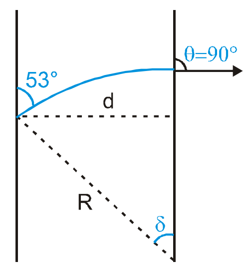
$s = ut + \frac{1}{2}at^2 \Rightarrow 0 = vt - \frac{1}{2}\left(\frac{qE}{m}\right)t^2$

$\Rightarrow t = \frac{2mv}{qE} = nT \Rightarrow n = \frac{vB}{\pi E}$ = An integer

56. $R = \frac{mv}{qB}$

The radius may be decease if v decreases or B increases.

57. $R\sin\delta = d$

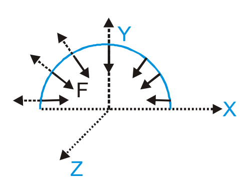


$\frac{mv}{qB}\sin\delta = \frac{3mv}{5qB}$

$\delta = 37^\circ$

$\therefore \theta = 53^\circ + \delta = 90^\circ$

58. Since $\vec{B}$ depends on x-coordinate the net force acts along -x axis.



Part # II : Assertion & Reason

1. D **2.** A **3.** D **4.** D

EXERCISE - 3

Part # I : Matrix Match Type

1. $R = \frac{mv}{qB} = R_0$

	Position
$R_A = 2R_0$	$\rightarrow 4$
$R_B = -4R_0$	$\rightarrow 1$
$R_C = -2R_0$	$\rightarrow 2$
$R_D = +R_0$	$\rightarrow 3$

2. **(A)** $I = \frac{q}{T}\left(T = \frac{2\pi m}{qB}\right) \Rightarrow I \propto v^0$

(B) $M = IA = \frac{q}{T}\pi R^2 = \frac{q}{T}\pi\left(\frac{Mv}{qB}\right)^2 \Rightarrow M \propto v^2$

(C) $B = \frac{\mu_0}{4\pi}\frac{qv}{r^2} \quad B \propto v^2$

3. **(A)** Magnetic moment $= NIA\,\hat{k}$

(B) Torque $= M\hat{k} \times B\hat{k} = 0$

(C) P.E. $= -M\hat{k}\cdot B\hat{k} = -MB$

(D) P.E. is minimum, equilibrium is stable

4. Since magnetic moment = 0 hence torque = 0

(A) $\vec{B} = B_0\hat{i} \Rightarrow |\vec{F}| = \left(\frac{i}{2}lB\right)\times 2 = ilB$

(B) $\vec{B} = B_0\hat{j} \Rightarrow |\vec{F}| = \left(\frac{i}{2}lB\right)\times 2 = ilB$

(C) $\vec{B} = B_0(\hat{i}+\hat{j}) \Rightarrow |\vec{F}| = \frac{i}{2}\times l_{eff}\times B = 0 \; (L_{eff}=0)$

(D) $\vec{B} = B_0\hat{k} \Rightarrow \vec{F} = \sqrt{\left(\frac{ilB}{2}\times 2\right)^2 + \left(\frac{ilB}{2}\times 2\right)^2} = \sqrt{2}\,ilB$

5. **(A)** $\oint_{loop-1} \vec{B}\cdot d\vec{l} = \mu_0(i - i - i) = -\mu_0 i$

(B) $\oint_{loop-2} \vec{B}\cdot d\vec{l} = \mu_0(i + i - i) = \mu_0 i$

(C) $\oint_{loop-3} \vec{B}\cdot d\vec{l} = \mu_0(i - i - i) = -\mu_0 i$

(D) $\oint_{loop-4} \vec{B}\cdot d\vec{l} = \mu_0(i - i + i) = \mu_0 i$

6. **(A)** $M = \frac{q\omega}{2\pi}\times\pi r^2 = \frac{q\omega r^2}{2}$

(B) $M = \frac{q\omega}{2\pi}\times\pi r^2 = \frac{q\omega r^2}{2}$

(C) $M = \int_0^R \frac{q(2\pi r dr)}{\pi R^2}\times\frac{\omega}{2\pi}\times\pi r^2 = \frac{q\omega r^2}{4}$

(D) $M = \int_{-\pi/2}^{+\pi/2} \frac{q}{4\pi R^2}(2\pi R\cos\theta)(Rd\theta)\times\frac{\omega}{2\pi}\times\pi(R\cos\theta)^2$

$= \frac{q\omega r^2}{3}$

(E) $M = \int_{-R}^{+R} \frac{q}{\left(\frac{4}{3}\pi R^3\right)}\pi(R^2 - y^2)dy \times \frac{\omega}{2\pi}\times\pi(R^2 - y^2) = \frac{q\omega r^2}{5}$

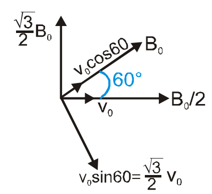
7. A charge at rest produces E.F.

A charge with uniform velocity produces M.F. + E.F.

An accelerated charge produces M.F. + E.F. +EM waves.

Part # II : Comprehension

Comprehension#1



1. Pitch $= v_0\cos60\left(\frac{2\pi m}{qB_0}\right) = v_0 \times \frac{1}{2}\left(\frac{2\pi m}{qB_0}\right) = \frac{\pi M v_0}{qB_0}$

2. z component of velocity is $\frac{\sqrt{3}}{2}v_0$ after

$t = \frac{T}{4} = \frac{\pi m}{2B_0 q}$

3. (z-coordinate)$_{max}$ $\Rightarrow 2R = 2\left(\frac{mv_0}{qB_0}\frac{\sqrt{3}}{2}\right) = \frac{\sqrt{3}mv_0}{qB_0}$

4. When z-co-ordinate has maximum value its velocity =

$v_0\cos60°\,(\hat{i}\cos60 + \hat{j}\sin60)$

$= \left(\frac{\hat{i}+\sqrt{3}\hat{j}}{2}\right)\frac{v_0}{2} = \frac{v_0}{4}(\hat{i}+\sqrt{3}\hat{j})$

Comprehension#2

1. $\tau = I\alpha \Rightarrow \vec{M} \times \vec{B} = I\alpha$

$\Rightarrow (3\hat{i} - 4\hat{j}) \times (4\hat{i} + 3\hat{j}) = I\alpha = 10^{-2}\alpha$

$\Rightarrow \alpha = 2500 \text{ rad/s}^2$

2. $\frac{1}{2} I\omega^2 = \Delta U \Rightarrow \frac{1}{2} \times 10^{-2} \times \omega^2 = U_{max} - U_{min} = 25$

$\Rightarrow \omega = 50\sqrt{2}$ rad/s

Comprehension#4

From graph :

1. $r_c > r_a$

2. $(B_{max})_a > (B_{max})_c$

3. $B = \frac{\mu_0 J r}{2}$ for a and c : $J_a r_a = J_c r_c$

$J_a > J_c$ ($\because r_c > r_a$)

Comprehension#6

1. Force per unit length

$$= \frac{mg}{l} = \lambda g = \frac{\mu_0 I_1 I_2}{2\pi d}$$

$$\Rightarrow d = \frac{\mu_0 I_1 I_2}{2\pi\lambda g}$$

2. For equilibrium, the magnetic force must be repulsive for the upper wire. Hence currents must be opposite in each wire.

3. Total mechanical energy changes due to displacement from mean position.

4. If P.E. due to M.F. is same, the P.E. due to gravity is different.

EXERCISE - 4

Subjective Type

1. $\vec{B}_O = \vec{B}_{SM} + \vec{B}_{SQ} + \vec{B}_{LR} + \vec{B}_{RP}$

$$= 0 + \left(\frac{\mu_0}{4\pi}\frac{i}{d}\right)\hat{k} + 0 + \left(\frac{\mu_0}{4\pi}\frac{i}{d}\right)\hat{k}$$

$= 10^{-4}\hat{k}$ T (d = 0.02 m, i = 10A)

2. From Biot–Savart law :

$$\vec{B}_P = \frac{\mu_0}{4\pi}\frac{i\vec{dl} \times \vec{r}}{r^3} = \frac{10^{-7} \times 10(\Delta x\hat{i} - \Delta y\hat{j}) \times (\hat{i} + \hat{j})}{(1^2 + 1^2)^{3/2}}$$

$= 7.07 \times 10^{-10}\hat{k}$ T where $(\Delta x = \Delta y = 10^{-3} \text{ m})$

3. $\vec{B}_P = \vec{B}_{\substack{\text{due to}\\\text{long wire}}} + \vec{B}_{\substack{\text{due to}\\\text{square}}}$

$$= \left[\frac{\mu_0}{2\pi}\frac{i}{(a/2)} - \frac{\mu_0}{4\pi}\frac{i}{(a/2)}\left(\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}\right) \times 4\right]\hat{k}$$

$$|\vec{B}_P| = \frac{(2\sqrt{2} - 1)\mu_0 i}{\pi a}$$

4. $B_0 = B_{arc} + B_{st. wires} = \frac{\mu_0}{4\pi}\frac{I\theta}{R} - \left(\frac{\mu_0}{4\pi}\frac{I}{R}\right) \times 2 = 0$

$\Rightarrow \theta = 2$ radian

5. $\vec{B}_O = \vec{B}_{PQ} + \vec{B}_{QS} + \vec{B}_{SR} + \vec{B}_{RP} = 2\vec{B}_{PQ} + 2\vec{B}_{QS}$

$$= 2 \times \frac{\mu_0}{4\pi} \times \frac{I}{(b/2)}\left[\frac{a}{\sqrt{a^2 + b^2}} + \frac{a}{\sqrt{a^2 + b^2}}\right]\hat{k}$$

$$+2 \times \frac{\mu_0}{4\pi} \times \frac{I}{(a/2)}\left[\frac{b}{\sqrt{a^2 + b^2}} + \frac{b}{\sqrt{a^2 + b^2}}\right]\hat{k}$$

$$\Rightarrow |\vec{B}_0| = \frac{2\mu_0 I}{\pi ab}\sqrt{a^2 + b^2}$$

6. $\oint \vec{B} \cdot \vec{dl} = \mu_0 I = \mu_0 (I_1 + I_2 + I_3 - I_4 - I_6)$

$= \mu_0 (1 + 2 + 3 - 1 - 4) = \mu_0$

7. $\vec{B}_O = \vec{B}_{arc} + \vec{B}_{MN}$

$$= \frac{\mu_0}{4\pi}\frac{I}{R}\left(\frac{3\pi}{2}\right) + \frac{\mu_0}{4\pi}\frac{I}{(R/\sqrt{2})} \times \left(\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}\right)$$

$\Rightarrow B_0 = 3.35 \times 10^{-5}$ T e

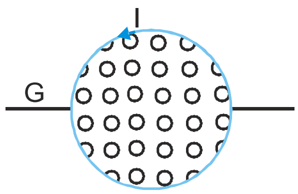
8. $\vec{B}_0 = \frac{\mu_0}{4\pi} I\theta\left(\frac{1}{r} - \frac{1}{2r} + \frac{1}{3r}\right) = \frac{5\mu_0 I\theta}{24\pi r} \otimes$

9. $F = qv_dB = e\left(\frac{J}{\rho e}\right)B = e\left(\frac{I}{A\rho e}\right)B$

$= \frac{IB}{A\rho} = \frac{5 \times 0.1}{10^{-5} \times 10^{29}} = 5 \times 10^{-25} N$

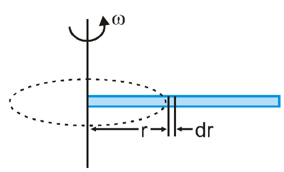
10. **(i)** Initial torque $= |\vec{M} \times \vec{B}| = MB \sin 90° = MB$

Final torque $= MB \sin 0° = 0$



(ii) $\Delta KE = -\Delta U;\ \frac{1}{2}I\omega^2 = MB,\ \omega = \sqrt{\frac{2MB}{I}}$

11. Magnetic moment of the system



$= \int Adi = \int \frac{Adq}{T} = \int_0^l \pi r^2 \left[\frac{\left(\frac{q}{l}dr\right)}{2\pi}\omega\right] = \frac{q\omega l^2}{6}$

12. For wire $\pi r + 2r = ●;\ r = \frac{1}{\pi + 2}$

$\therefore$ Magnetic moment, $M = \frac{I\pi r^2}{2} = \frac{I\pi}{2}\left(\frac{1}{\pi + 2}\right)^2$

13. **(i)** Torque on solenoid $= MB\sin\theta$

$= NIA\, B \sin 30°$

$= 1000 \times 2 \times 2 \times 10^{-4} \times 0.16 \times 1/2 = 3.2 \times 10^{-2}$ Nm

(ii) Work done $= \Delta U$

$= MB(\cos 0° - \cos 90°)$

$= 1000 \times 2 \times 2 \times 10^{-4} \times 0.16 \times (1 - 0) = 0.064$ J

14. **(i)** Magnetic moment, $M = NIA$

$= 2000 \times 4 \times 1.6 \times 10^{-4} = 1.28\ Am^2$

(ii) Torque, $T = |\vec{M} \times \vec{B}| = MB \sin\theta$

$= 1.28 \times 7.5 \times 10^{-2} \times \frac{1}{2} = 0.048$ Nm

Force, $F_{net} = 0$

15. Net force on electron

$\Rightarrow I = 4A\ \ e\vec{E} + e\vec{v} \times \vec{B} = 0 \Rightarrow \frac{V}{d}\hat{i} + v\hat{j} \times \vec{B} = 0$

$\Rightarrow |\vec{B}| = \frac{600}{3 \times 10^{-3} \times 2 \times 10^6} = 0.1$ T and $\vec{B} = -\hat{k}$

16. **(i)** Configurations AB_1 and AB_2 have zero force and non–zero torques.

(ii) Potential energy of the configurations are

$U_{AB_1} = 0; U_{AB_4} > 0;\ U_{AB_3} < 0;\ U_{AB_2} = 0$

$U_{AB_5} > 0;\ U_{AB_6} > 0$

AB_4 and AB_5 are unstable and AB_3 and AB_6 are stable configurations.

(iii) Configuration AB_6 has lower energy than configuration AB_3 as magnetic field due to A at B_3 is half of the magnitude of magnetic field at B_6.

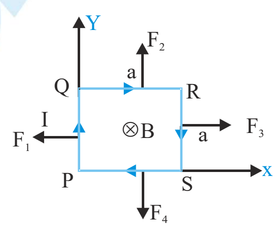
18. Force on arc $= I \times L_{eff} \times B = I\left(\sqrt{2}R\right)B$

where L_{eff} is the shortest length of the arc.

19. $\vec{B} = \vec{B}_{smaller\ arc} + \vec{B}_{bigger\ arc} + \vec{B}_{st.\ line}$

$= \frac{1}{4}\frac{\mu_0 I}{2R}\hat{k} + \frac{1}{4}\frac{\mu_0 I}{4R}\hat{k} + \frac{\mu_0 I}{4\pi R}\hat{j} = \frac{\mu_0}{4}\frac{I}{R}\left(\frac{3}{4}\hat{k} + \frac{\hat{j}}{\pi}\right)$

20.

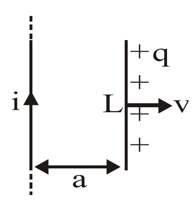


$\vec{F}_4 = iL(-\hat{i}) \times B(-\hat{k}) = 0$ as (B=0)

$\vec{F}_1 + \vec{F}_3 = 0$

$\vec{F}_2 = iL\hat{i} \times B(-\hat{k}) = iLB\,\hat{j} = ia(\alpha a)\,\hat{j} = i\alpha a^2\,\hat{j}$

21.



$\vec{F} = qv\hat{i} \times B(-\hat{k}) = qvB\,\hat{j}$

$\vec{F}_{external} = -\vec{F} = qvB(-\hat{j})$

22. Current $I = \mu n_e$ (μn no. of protons falling per sec)

Force, $F = mv\,\dot{n} = mv\ \frac{I}{e} = \frac{mIE}{eB}$ $[\because E = vB]$

23. For interval point :

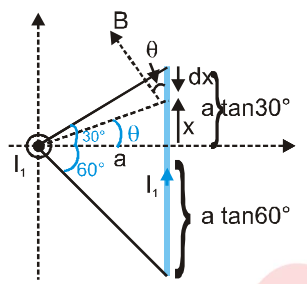
(i) $B.2\pi r_1 = \mu_0 \int_0^{r_1} br(2\pi r dr) = \frac{\mu b(2\pi)r_1^3}{3}$

$\therefore B = \frac{\mu_0 b r_1^2}{3}$

(ii) For external point :-

$B2\pi r_2 = \mu_0 \int_0^{R} (br)(2\pi r dr) \Rightarrow B = \frac{\mu_0 b R^3}{2r_2}$

24. $F = \int I_2 dx B \sin\theta = \int_{-a\tan 60}^{+a\tan 30} I_2 dx \frac{\mu_0 I_1}{2\pi\sqrt{a^2+x^2}} \frac{x}{\sqrt{a^2+x^2}}$



$= \frac{\mu_0 I_1 I_2}{2\pi} \int_{-\sqrt{3}a}^{+a/\sqrt{3}} \frac{x dx}{a^2+x^2} = \frac{\mu_0}{4\pi} I_1 I_2 \ln 3$ (along –z axis)

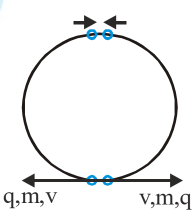
26. From work energy theoram :

$W_{MF} + W_{gravity} = \Delta KE$

$\Rightarrow -\Delta U_{MF} - \Delta U_g = 0 \Rightarrow MB = \frac{mgl}{2}$

$\Rightarrow I\ell^2 B = \frac{mgl}{2} \Rightarrow B = \frac{mg}{2Il}$

27. Both particles collide after completing semi-circle.



Time to collide $= \frac{T}{2} = \frac{2\pi m}{2qB} = \frac{\pi m}{qB}$

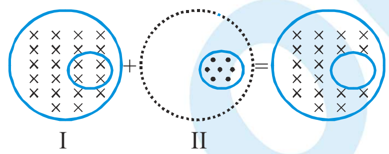
28. $F.\Delta T = m(v-u)$

$\Rightarrow ILB\Delta t = m(\sqrt{2gh} - 0) \Rightarrow qLB = m\sqrt{2gh}$

$\Rightarrow q = \frac{10}{1000} \times \sqrt{2 \times 10 \times 3} \times \frac{1}{0.2 \times 0.1}$

$\Rightarrow q = \sqrt{15}$ C

29. (i)

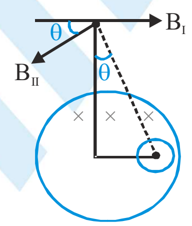


$\vec{B}_I .2\pi(2R) = \mu_0 J\pi R^2 (-\hat{k})$

$\vec{B}_{II} .2\pi(2R - b) = \mu_0 J\pi a^2 (\hat{k})$

$\therefore \vec{B}_{x=2R} = \mu_0 J\left[\frac{R}{4} - \frac{a^2}{4R - 2b}\right](-\hat{k})$

(ii)



$B = \sqrt{(B_I - B_{II}\cos\theta)^2 + (B_{II}\sin\theta)^2}$

$= \sqrt{\left(\frac{\mu_0 JR}{4} - \frac{\mu_0 JRa^2}{4R^2 + b^2}\right)^2 + \left(\frac{\mu_0 Ja^2 b}{2(4R^2 + b^2)}\right)^2}$

30. Let $\vec{v} = v_x\hat{i} + v_y\hat{j}$

We know $\sqrt{v_x^2 + v_y^2} = v_0$ ...(i)

$\vec{F} = q(\vec{v} \times \vec{B}) = q\begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ v_x & v_y & 0 \\ 0 & 0 & -B_0\left(1 + \frac{y}{d}\right) \end{vmatrix}$

$\Rightarrow m\vec{a} = -qB_0\left(1 + \frac{y}{d}\right)v_y\hat{i} + \hat{j}qv_x B_0\left(1 + \frac{y}{d}\right)$

$m\left(a_x\hat{i} + a_y\hat{j}\right) = -qB_0 v_y\left(1 + \frac{y}{d}\right)\hat{i} + qB_0 v_x\left(1 + \frac{y}{d}\right)$

$$\Rightarrow ma_x = -qB_0 v_y\left(1+\frac{y}{d}\right) \ \& \ ma_y = qB_0 v_x\left(1+\frac{y}{d}\right)$$

$$\Rightarrow mv_y\frac{dv_y}{dy} = qB_0\sqrt{v_0^2 - v_y^2}\left(1+\frac{y}{d}\right)$$

{By using equation (i)}

$$\Rightarrow \int_0^{v_y}\frac{v_y}{\sqrt{v_0^2-v_y^2}}dv_y = \frac{qB_0}{m}\int_0^d\left(1+\frac{y}{d}\right)dy$$

$$\Rightarrow v_y = \sqrt{v_0^2 - \left(v_0 - \frac{3qB_0 d}{2m}\right)^2}$$

$$\Rightarrow v_x = v_0 - \frac{3}{2}\left(\frac{qB_0 d}{m}\right)$$

31. **(A)** $\vec{M}\times\vec{B}+\vec{R}\times M\vec{g} = 0 \Rightarrow |\vec{M}\times\vec{B}| = |\vec{R}\times M\vec{g}|$

$$\Rightarrow NIA\times B = mgr \Rightarrow I = \frac{mg}{\pi r\sqrt{B_x^2+B_y^2}}$$

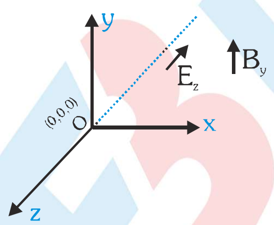
(B) $I = \dfrac{mg}{\pi rBx}$ (B_z has no effect on torque)

32. $m = 1\times10^{-26}\,kg$

$q = 1.6\times10^{-19}\,C$

$v = 1.28\times10^{6}\,m/s$

$E_z = -102.4\,\dfrac{kV}{m}$



$B_y = 8\times10^{-2}\,wb/m^2$

Force by electric field

$\vec{F}_E = q\vec{E} = 1.6\times10^{-19}\times102.4\times10^{3}(-\hat{k})N$

Force by magnetic field = $F_m = q(\vec{v}\times\vec{B})$

$= 1.6\times10^{-19}\times1.28\times10^{6}\hat{i}\times8\times10^{-2}\hat{j}N$

$= 1.6\times10^{-19}\times102.4\times10^{3}\hat{k}N$

$\vec{F}_E = -\vec{F}_M$ {Till $t = 6\times10^{-6}$ sec}

So till $t = 5\times10^{-6}$ sec it moves without deflection

So x coordinate $= vt = 1.28\times10^{6}\times5\times10^{-6}$

$= 6.4$ m

So coordinate = (6.4 m, 0, 0)

After 2 sec $\vec{E}$ is switched off, so force on the particle is due to magnetic field which is towards +z axis.

$t_2 = 7.45\times10^{-6}$ sec

$t_2 - t_1 = 2.45\times10^{-6}$ sec

$$T = \frac{2\pi m}{qB} = \frac{2\times3.14\times10^{-26}}{1.6\times10^{-19}\times8\times10^{-2}} = 4.90\times10^{-6}\,sec$$

So $t_2 - t_1 = \dfrac{T}{2}$

So particle cover 2r distance in +z direction in circle So z-coordinate

$$= \frac{2\times m\times v}{qB} = \frac{2\times10^{-26}\times1.28\times10^{6}}{1.6\times10^{-19}\times8\times10^{-2}} = 2m$$

So coordinates = (6.4m, 0, 2m)

33. **(A)** $\vec{B}$ at centre $= (B_{st.wire} - B_{arc})(-\hat{k})$

$$= \left[\frac{\mu_0}{4\pi}\frac{I}{R\cos60}(2\sin60) - \frac{\mu_0}{4\pi}\frac{I}{R}\left(\frac{2\pi}{3}\right)\right](-\hat{k})$$

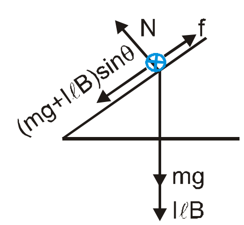
$$= \frac{\mu_0 I}{6a}\left(\frac{3\sqrt{3}}{\pi}-1\right)(-\hat{k})$$

For charge particle - $qvB = ma \Rightarrow a = \dfrac{qv\mu_0 I}{6ma}\left(\dfrac{3\sqrt{3}}{\pi}-1\right)$

(B) $\vec{T} = \vec{M}\times\vec{B} = NIA(\hat{k})\times B\hat{j}$

$$\Rightarrow \vec{T} = I\left(\frac{\pi}{3}a^2 - \frac{\sqrt{3}}{4}a^2\right)B\hat{j}$$

34. $f = \mu N;\ N = mg\cos\theta + I\ell B\cos\theta$



$\therefore f_{ext} = (mg + I\ell B)\sin\theta \pm f$

$= (mg + I\ell B)\sin\theta \pm \mu(mg\cos\theta + I\ell B\cos\theta)$

$$= \frac{3}{4}\pm\frac{\sqrt{3}}{2}\times\frac{3}{2}\times0.1 = 0.75\pm0.13$$

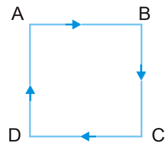
$\Rightarrow f_{ext} = 0.62$ N or 0.88 N

35. Work done by external agent in rotating the conductor in one full turn $= F2\pi r = iLB_0$.

$2\pi r$ Power $= W.n = i\ell B_0(2\pi r)n$

36. $\vec{B}_{centre} = 4\vec{B}_{AB} = 4 \times \frac{\mu_0}{4\pi}\frac{I}{(a/2)}\left[\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}\right]$

$= \frac{2\sqrt{2}\mu_0 I}{\pi a} \otimes$



$\vec{B}_{vertex'A'} = \vec{B}_{AB} + \vec{B}_{BC} + \vec{B}_{CD} + \vec{B}_{DA}$

$= 0 + \frac{\mu_0}{4\pi}\frac{I}{a}\left(\frac{1}{\sqrt{2}}\right) + \frac{\mu_0}{4\pi}\frac{I}{a}\left(\frac{1}{\sqrt{2}}\right) + 0 = \frac{\sqrt{2}\mu_0}{4\pi}\frac{I}{a} \otimes$

$\frac{B_{centre}}{B_{vertex}} = \frac{2\sqrt{2}}{\sqrt{2}} \times 4 = 8:1$

37. $v_{\parallel}$ = velocity parallel to $\vec{B} = v\cos 60°$

Pitch $= v_{\parallel} \times T = v\cos 60\left(\frac{2\pi m}{eB}\right) = \frac{2\pi\cos 60}{eB}\sqrt{2mk}$

$0.1 = \frac{2\pi \times \left(\frac{1}{2}\right)}{B} \times \sqrt{\frac{2 \times 9.1 \times 10^{-31} \times 2 \times 10^{3}}{1.6 \times 10^{-19}}}$

$\Rightarrow B = 4.7 \times 10^{-3}$ T

38. For B to be zero at P, current in B should directed upward

(i) $B_P = \frac{\mu_0}{2\pi}\left[\frac{I_A}{\left(2 + \frac{10}{11}\right)} - \frac{I_B}{\left(\frac{10}{11}\right)}\right] = 0 \Rightarrow I_B = 3A$

(ii) $\vec{B}_S = \vec{B}_A + \vec{B}_B$ and $(\vec{B}_A \perp \vec{B}_B)$

$\vec{B}_S = \sqrt{B_A^2 + B_B^2} = \sqrt{\left(\frac{\mu_0}{2\pi}\frac{9.6}{1.6}\right)^2 + \left(\frac{\mu_0}{2\pi}\frac{30}{1.2}\right)^2}$

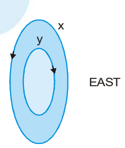
$= 13 \times 10^{-7}$ T

(iii) Force per unit length on the wire B_1

$F = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{d} = \frac{2 \times 10^{-7} \times 9.6 \times 3}{2} = 2.88 \times 10^{-6}$ N/m

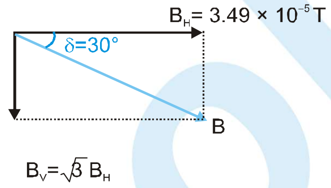
39. $\vec{B}_{centre} = \left[\frac{\mu_0}{4\pi}\frac{I_x(N_x 2\pi)}{R_x} - \frac{\mu_0}{4\pi}\frac{I_y(N_y 2\pi)}{R_y}\right]\hat{i}$

$= -1.6 \times 10^{-3}\,\hat{i}$ T



40. For vertical coil, $\frac{\mu_0}{2}\frac{I_1 N_1}{r_1} = B_H$

$\Rightarrow I_1 = \frac{3.49 \times 10^{-5} \times 2 \times 0.2}{100 \times 4\pi \times 10^{-7}} = 0.111$ A



For horizontal coil; $\frac{\mu_0}{2}\frac{I_2 N_2}{r_2} = B_V \Rightarrow I_2 = 0.096$ A

41. **(i)** Force on electron, evB = F

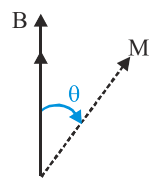
$\Rightarrow 1.6 \times 10^{-19} \times 4 \times 10^{5} \times B = 3.2 \times 10^{-20}$

$\Rightarrow B = 5 \times 10^{7}\ T = \frac{\mu_0}{2\pi}\left(\frac{2.5}{5} + \frac{I}{2}\right) \Rightarrow I = 4A$

(ii) For $\vec{B}$ to be zero at R; the position of third wire

$= \frac{\mu_0}{2\pi}\frac{I}{B} = \frac{2 \times 10^{7} \times 2.5}{5 \times 10^{7}} = 1m$

42. For the coil



If the coil is turned through angle 'θ', the restoring torque, $-MB\sin\theta$; $-MB\theta = I\alpha$

$\Rightarrow -Ia^2B\theta = \frac{ma^2}{6}\alpha = \frac{ma^2}{6}(-\omega^2\theta)$

$\Rightarrow \omega = \sqrt{\frac{6IB}{m}} = \frac{2\pi}{T}$

$\Rightarrow T = 2\pi\sqrt{\frac{m}{6IB}} = 0.57$ s (where a = side of square)

EXERCISE - 5

Part # I : AIEEE/JEE-MAIN

1. Magnetic field at the centre of the coil is $\frac{\mu_0 i}{2R}$

$$\therefore\ B_A = \frac{\mu_0 i}{2R};\ B_B = \frac{\mu_0 2i}{2(2R)} \quad \text{Hence} \quad \frac{B_A}{B_B} = 1$$

2. Radius of the circular path in magnetic field,

$$r = \frac{mv}{qB} = \frac{p}{qB}$$

If momenta of two charged particles is same then

$$r \propto \frac{1}{q}$$

As electrons and protons have same charges; so their radius of curvature will be same; though their sense of rotation will be opposite.

3. Parallel currents attract and antiparallel currents repel each other. If a current is made to pass through the spring; the spring will compress as due to parallel currents; the turns will attract each other.

4. Time period of a charge particle in a magnetic field is

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

The time period is independent of radius or speed of the charged particle.

5. $$F = \left| i_2 \left(d\vec{l} \times \vec{B}\right) \right| = i_2 \left(\frac{\mu_0 i_1}{4\pi r}(2\cos\theta) \right) dl$$

$$= \frac{\mu_0 i_1 i_2 dl \cos\theta}{2\pi r}$$

6. $\vec{F} = q\left(\vec{v} \times \vec{B}\right)$; The force due to magnetic field is always perpendicular $\vec{v}$ (i.e. $d\vec{s}$) ; hence this force can never do the work on a charged particle.

7. For the charged particle to pass undeflected through a cross $\vec{E}$ and $\vec{B}$; the necessary condition is

$\vec{F} = \vec{F}_E + \vec{F}_B = 0$ i.e., $q\vec{E} + q\left(\vec{v} \times \vec{B}\right) = 0$

or $\vec{E} = -\left(\vec{v} \times \vec{B}\right)$

If $\vec{v} \perp \vec{B}$ then $|\vec{E}| = |\vec{v}\vec{B}|$

$$B = \frac{E}{v} = \frac{10^4}{10} = 10^3\ \text{Wb/m}^2$$

8. $W = U_f - U_i = -MB\cos 60^0 - (-MB\cos 0)$

$$= \frac{-MB}{2} + MB = \frac{MB}{2} \Rightarrow MB = 2W$$

Torque $= \vec{\tau} = \vec{M} \times \vec{B} \Rightarrow \tau = MB \sin 60°$

$$\tau = MB\left(\frac{\sqrt{3}}{2}\right) \Rightarrow \tau = (2W)\left(\frac{\sqrt{3}}{2}\right) = \sqrt{3}W$$

9. Inside a bar magnet; magnetic lines of force run from south to north pole.

10. No magnetic field is ever present at any point inside thin walled current carrying tube.

11. $B_{\text{centre of circular loop}} = \frac{\mu_0}{4\pi}\frac{2\pi ni}{R}$ ...(i)

For a given length L = n2πR

$R = \frac{L}{n2\pi}$ ...(ii)

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

$$B = \frac{\mu_0}{4\pi}\frac{2\pi ni}{L}(n2\pi) \Rightarrow B \propto n^2$$

So, $\frac{B_f}{B_i} = \frac{n^2}{1^2} \Rightarrow B_f = n^2 B_i$

13. When they are carrying current in same direction, they attract each other with a force

$$\frac{F_1}{l_1} = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{d}$$

When the direction of current in one of the conductors is reversed, the force will become repulsive with a value

$$\frac{F_2}{l_1} = \frac{\mu_0}{4\pi}\frac{2(2I_1)I_2}{3d};\ \frac{F_2}{l_1} = \frac{2}{3}\frac{F_1}{l_1};\ \vec{F}_2 = -\frac{2}{3}\vec{F}_1$$

14. Resistance of galvanometer

$$R_g = \frac{\text{current sensitivity}}{\text{voltage sensitivity}} = \frac{10}{2} = 5\Omega$$

As galvanometer is to be converted into a voltmeter of range $1 \times 150 = 150$V.

So resistance to be connected in series

$$= \frac{V}{I_g} - R_g = \frac{150}{\left(\frac{150}{10} \times 10^{-3}\right)} - 5 = 10000 - 5 = 9995\ \Omega$$

16. Magnetic induction due to a coil at its centre is along the axis of the coil. When two coils are held perpendicular to each other, their axes are also perpendicular to each other, hence the magnetic induction will also be perpendicular to each other, so B_{net} at their common centre will be

$$B = \sqrt{B_1^2 + B_2^2}$$

$$B = \sqrt{\left[\frac{\mu_0}{4\pi}\frac{2\pi i_1}{R_1}\right]^2 + \left[\frac{\mu_0}{4\pi}\frac{2\pi i_2}{R_2}\right]^2} = \frac{\mu_0}{4\pi}\frac{2\pi}{R}\sqrt{i_1^2 + i_2^2}$$

$$= 10^{-7} \times \frac{2\pi}{2\pi \times 10^{-2}}\sqrt{3^2 + 4^2} = 5 \times 10^{-5}\text{T}$$

17. The time taken by charged particle to complete circle will be $T = \frac{2\pi m}{qB}$

18. Magnetic needle kept in non-uniform field experiences both force as well as torque.

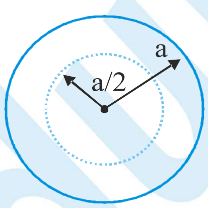
19. In a parallel uniform electric and magnetic field , if a charged particle is released then it experiences an electric force due to which it moves in a straight line.

20. $B_{solenoid} = \mu_0 ni$

$$\frac{B_2}{B_1} = \frac{n_2 i_2}{n_1 i_1} = \frac{100 \times i/3}{200 \times i}$$

$$B_2 = \frac{B_1}{6} = \frac{6.28 \times 10^{-2}}{6} = 1.05 \times 10^{-2}\text{T}$$

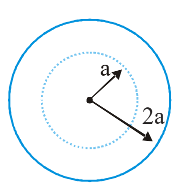
21. Magnetic field at a point inside the straight long conductor at a distances $\frac{a}{2}$ from its centre will be obtained.



On applying Ampere's circulated law, we get

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

$$B_1 = \frac{\mu_0 I}{4\pi a} \quad ...\text{(i)}$$



Magnetic field at a point outside the conductor at a distance 2a from the centre will be obtained as

$$B_2\left[2\pi(2a)\right] = \mu_0 I$$

$$B_2 = \frac{\mu_0 I}{4\pi a} \quad ...\text{(ii)}$$

On dividing equation (i) by (ii), we get $\frac{B_1}{B_2} = 1$

22. As the thin walled pipe does not enclose any net current, hence the net magnetic field at any point inside the thin walled pipe will be zero, whereas for the outside points it behaves as a straight long current carrying conductor.

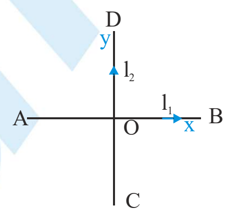
23. When charged particle goes undeflected then

$$q\vec{E} = q\vec{v} \times \vec{B} \Rightarrow qE = qvB \Rightarrow v = \frac{E}{B}$$

These two forces must be opposite to each other if and only if $\vec{v}$ is along $\vec{E} \times \vec{B}$

$$\therefore v = \frac{EB}{BB} = \left|\frac{\vec{E} \times \vec{B}}{B^2}\right| \Rightarrow \vec{v} = \left(\frac{\vec{E} \times \vec{B}}{B^2}\right)$$

24.



$\vec{B}_P = \vec{B}_1 + \vec{B}_2$

Let the point P is situated at 'd' from O outside the plane of the paper

$$\vec{B}_1 = \frac{\mu_0}{4\pi}\frac{2I_1}{d}\left(-\hat{j}\right); \quad \vec{B}_2 = \frac{\mu_0}{4\pi}\frac{2I_2}{d}\hat{i}$$

$$\vec{B}_P = \frac{\mu_0}{4\pi}\frac{2}{d}\left[I_1\left(-\hat{j}\right) + I_2\hat{i}\right] \Rightarrow \left|\vec{B}_P\right| = \frac{\mu_0}{2\pi d}\sqrt{I_1^2 + I_2^2}$$

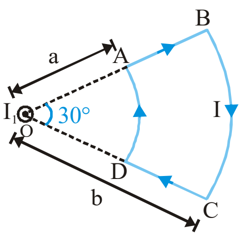
25. The magnetic field can never produce a charge in the speed of the charged particle, hence it can never produce a change in kinetic energy.

Whereas it produces a change in velocity of the charged particle by changing the direction of motion of charged particle.

From this we can conclude that magnetic field cannot produce a change in kinetic energy whereas it can produce change in momentum of the charged particle.

26. $B = \frac{\mu_0}{2\pi}\frac{i}{R} = \frac{4\pi \times 10^{-7}}{4} = 5 \times 10^{-6}$ T southward

27.



$$B_0 = B_1 - B_2 = \frac{\mu_0 I}{2a}\left(\frac{\pi}{6 \times 2\pi}\right) - \frac{\mu_0 I}{2b}\left(\frac{\pi}{6 \times 2\pi}\right)$$

$$= \frac{\mu_0 I}{24ab}(b - a)$$

30. Net magnet field due to both elements

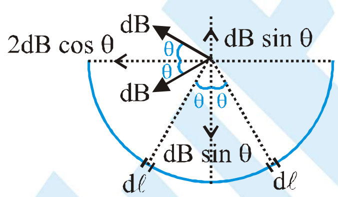
$= 2\ (dB) \cos\theta$

$$= 2 \times \frac{\mu_0}{2\pi R} dI \cos\theta \quad \left(\text{here } dI = \frac{I}{\pi R} dl\right)$$

$$= 2 \times \frac{\mu_0}{2\pi R}\frac{I}{\pi R} dl \cos\theta$$

$$= 2 \times \frac{\mu_0}{2\pi R}\frac{I}{\pi R} R d\theta \cos\theta$$

$$B = \int_0^{\pi/2} \frac{\mu_0}{\pi^2 R} \cos\theta\, d\theta = \frac{\mu_0 I}{\pi^2 R}$$



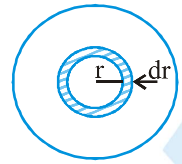
31. $\vec{F} = q\left[\vec{E} + \left(\vec{v} \times \vec{B}\right)\right]$

$$= q\left[3\hat{i} + \hat{j} + 2\hat{k} + \left(3\hat{i} + 4\hat{j} + \hat{k}\right) \times \left(\hat{i} + \hat{j} - 3\hat{k}\right)\right]$$

$$= q\left[3\hat{i} + \hat{j} + 2\hat{k} + \left(3\hat{i} + 4\hat{j} + \hat{k}\right) \times \left(\hat{i} + \hat{j} - 3\hat{k}\right)\right]e$$

$$\left|\vec{F}_y\right| = 11q$$

32. Magnetic moment of elements ring



$$dM = di \times A = \frac{dq}{T}\pi r^2 = \frac{\sigma dA}{T}\pi r^2$$

$$= \frac{\sigma \times 4\pi r^2 dr}{2\pi}\pi r \times \omega$$

33. $r \propto \frac{\sqrt{2mK}}{qB}$ As K & B are constant

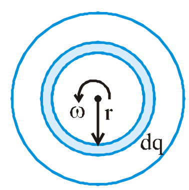
So $r \propto \frac{\sqrt{m}}{q}$

$$r_p : r_d : r_\alpha :: \frac{\sqrt{m_p}}{q_p} : \frac{\sqrt{m_d}}{q_d} : \frac{\sqrt{m_\alpha}}{q_\alpha}$$

$$:: \frac{\sqrt{m_p}}{e} : \frac{\sqrt{2m_p}}{e} : \frac{\sqrt{4m_p}}{2e}$$

$$:: 1 : \sqrt{2} : 1 \Rightarrow \quad r_\alpha = r_p < r_d$$

34. Magnetic field at the centre due to element ring

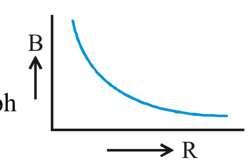


$$dB = \frac{\mu_0 di}{2r} = \frac{\mu_0}{2r}\left(\frac{dq}{T}\right) = \frac{\mu_0 \sigma ds}{2rT}$$

$$= \frac{\mu_0}{2r}\left(\frac{Q}{\pi R^2}\right)\frac{(2\pi r dr)}{2\pi/\omega} = \frac{\mu_0 Q dr \omega}{\pi R^2}$$

$$B = \frac{\mu_0 Q\omega}{\pi R^2}\int_0^R dr = \frac{\mu_0 Q\omega}{\pi R^2}R = \frac{\mu_0 Q\omega}{\pi R} \Rightarrow B \propto \frac{1}{R}$$

So graph



35. 2

36. 1

37. $P = \frac{\text{Work done}}{\text{time}} = \frac{\int F dx}{t} = \frac{\int I l b B.dx}{t}$

$$= \frac{\int_0^2 (10)(3)(3\times10^{-4}e^{-0.2x})dx}{5\times10^{-3}}$$

$$= \frac{9\times10^{-3}}{5\times10^{-3}}\left[\frac{e^{-0.2x}}{-0.2}\right]_0^2 = 9[1-e^{-0.4}] = 2.97\,W$$

38. For equilibrium $\vec{\tau} = 0$

$\vec{\tau} = MB\sin\theta\ \hat{n}$

If, $\sin\theta = 0$; $\vec{\tau} = 0$

If angle between $\vec{M}$ and $\vec{B}$ is zero, then stable equilibrium

If angle between $\vec{M}$ and $\vec{B}$ is π, then unstable equilibrium

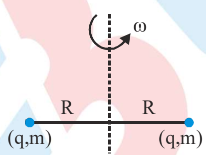
39. 4

40. For electromagnet & transformer hysteresis loss is less.

Part # II : IIT-JEE ADVANCED

1. Current, i = (frequency) (charge)

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



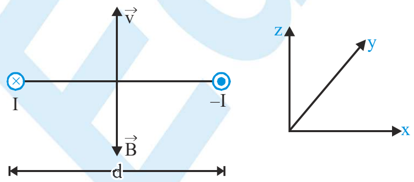
Magnetic moment

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

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

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

2. Net magnetic field due to both the wires will be downwards as shown in the figure.



Since, angle between $\vec{v}$ and $\vec{B}$ is 180°.

Therefore, magnetic force

$\vec{F}_m = q(\vec{v}\times\vec{B}) = 0$

3. The charged particle will be accelerated parallel (if it is a positive charge) or antiparallel (if it is a negative charge) to the electric field, i.e., the charged particle will move parallel or antiparallel to electric and magnetic field. Therefore, net magnetic force on it will be zero and its path will be a straight line.

4. Total magnetic flux passing through whole of the X-Y palne will be zero, because magnetic lines from a closed loop. So, as many lines will move in –Z direction same will return to +Z direction from the X-Y plane.

5. H_1 = Magnetic field at M due to PQ + Magnetic field at M due to QR. But magnetic field at M due to QR = O

$\therefore$ Magnetic field at M due to PQ (or due to current I in PQ) = H_1

Now H_2 = Magnetic field at M due to PQ (current I + magnetic field at M due to QS (current I/2) + magnetic field at M due to QR

$$= H_1 + \frac{H_1}{2} + 0 = \frac{3}{2}H_1$$

$$\Rightarrow \frac{H_1}{H_2} = \frac{2}{3}$$

6. We can write

$\vec{E} = E.\hat{i}$ and $\vec{B} = B\hat{k}$

Velocity of the particle will be along q. $\vec{E}$ direction.

Therefore, we can write $\vec{v} = AqE\hat{i}$

In $\vec{E}, \vec{B}$ and $\vec{v}$, A, E and B are positive constants while q can be positive or negative.

Now, magnetic force on the particle will be

$\vec{F}_m = q(\vec{v}\times\vec{B}) = q\{AqE\hat{i}\}\times\{B\hat{k}\}$

$= q^2 AEB(\hat{i}\times\hat{k})$

$\vec{F}_m = q^2 AEB(-\hat{j})$

Since, $\vec{F}_m$ is along negative y-axis, no matter what is the sign of charge q. Therefore, all ions will deflect towards negative y-direction.

7. Ratio of magnetic moment and angular momentum is given by $\frac{M}{L} = \frac{q}{2m}$

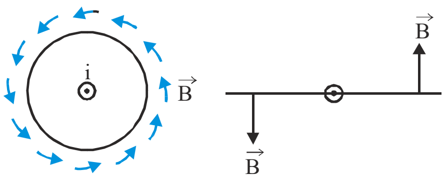
which is a function of q and m only. This can be derived as follows :

$$M = iA = (q\,f).(\pi r)^2 = (q)\left(\frac{\omega}{2\pi}\right)(\pi r^2) = \frac{q\omega r^2}{2}$$

and $\quad L = I\omega = (mr^2\omega)$

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

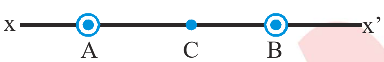
8. If the current flows out of the paper, the magnetic field at points to the right of the wire will be upwards and to the left will be downwards as shown in figure.



Now, let us come to the problem.

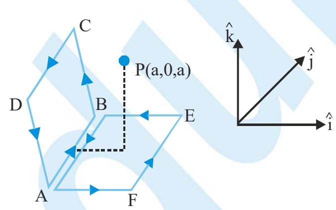
Magnetic field at C = 0

Magnetic field in region BX' will be upwards (+ve) because all points lying in this region are to the right of both the wires.



Magnetic field in region AC will be upwards (+ve), because points are closer to A, compared to B. Similarly magnetic field in region BC will be downwards (–ve). Graph (b) satisfies all these conditions.

9. The magnetic field at P(a,0,a) due to the loop is equal to the vector sum of the magnetic fields produced by loops ABCDA and AFFBA as shown in the figure.

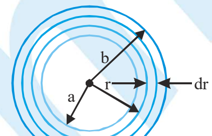


Magnetic field due to loop ABCDA will be along $\hat{i}$ and due to loop AFEBA, along $\hat{k}$. Magnitude of magnetic field due to both the loops will be equal. Therefore direction of resultant magnetic field at P will be $\frac{1}{2}(\hat{i} + \hat{k})$

10. Consider an element of thickness dr at a distance r form the centre. The number of turns in this element,

$$dN = \left(\frac{N}{b-a}\right)dr$$

Magnetic field due to this element at the centre of the coil will be-



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

$$\therefore B = \int_{r=a}^{r=b} dB = \frac{\mu_0 NI}{2(b-a)} \ln\left(\frac{b}{a}\right)$$

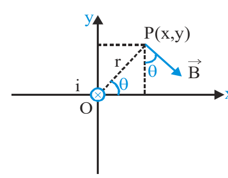
11. Radius of the circle $= \frac{mv}{Bq}$

or radius $\propto$ mv if B and q are same.

$(\text{Radius})_A > (\text{Radius})_B \quad \therefore m_A v_A > m_B v_B$

12. Magnetic field at P is $\vec{B}$, perpendicular to OP in the direction shown in figure.

So, $\vec{B} = B\sin\theta\,\hat{i} - B\cos\theta\,\hat{j}$;



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

$\sin\theta = \frac{y}{r}$ and $\cos\theta = \frac{x}{r}$

$$\therefore \vec{B} = \frac{\mu_0 I}{2\pi}\frac{1}{r^2}(y\hat{i} - x\hat{j}) = \frac{\mu_0 I(y\hat{i} - x\hat{j})}{2\pi(x^2 + y^2)} \quad (\text{as } r^2 = x^2 + y^2)$$

13. Magnetic lines form closed loop. Inside magnet these are directed from south to north pole.

14. If $(b-a) \geq r$ (r = radius of circular path of particle)

The particle cannot enter the region $x > b$

So, to enter in the region $x > b \quad r > (b-a)$

$$\Rightarrow \frac{mv}{Bq} > (b-a) \Rightarrow v > \frac{q(b-a)B}{m}$$

15. Electric field can deviate the path of the particle in the shown direction only when it is along negative y-direction. In the given options $\vec{E}$ is either zero or along x-direction. Hence, it is the magnetic field which is really responsible for its curved path. Options (a) and (c) cannot be accepted as the path will be helix in that case (when the velocity vector makes an angle other than 0°, 180° or 90° with the magnetic field, path is a helix) option (d) is wrong because in that case component of net force on the particle also comes in $\hat{k}$ direction which is not acceptable as the particle is moving in x-y plane. Only in option (b) the particle can move in x-y plane.

In option (d) : $\vec{F}_{net} = q\vec{E} + q(\vec{v} \times \vec{B})$

Initial velocity is along x-direction. So, let $\vec{v} = v\hat{i}$

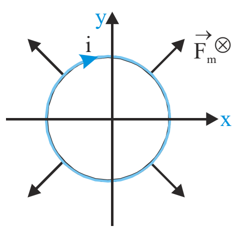
$\therefore \vec{F}_{net} = qa\hat{i} + q[(v\hat{i}) \times (c\hat{k} + b\hat{j})]$

$= qa\hat{i} - qvc\hat{j} + qvb\hat{k}$

In option (b) :

$\vec{F}_{net} = q(a\hat{i}) + q[(v\hat{i}) \times (c\hat{k} + a\hat{i})] = qa\hat{i} - qvc\hat{j}$

16. Net force on a current carrying loop in uniform magnetic field is zero. Hence, the loop cannot translate. So, options (c) and (d) are wrong. From Fleming's left hand rule we can see that if magnetic field is perpendicular to paper inwards and current in the loop is closkwise (as shown) the magnetic force $\vec{F}_m$ on each element of the loop is radially outwards, or the loops will have a tendency to expand.



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

Here, $\vec{M}$ = magnetic moment of the loop

θ = angle between $\vec{M}$ and $\vec{B}$

U is maximum when $\theta = 180°$ and minimum when $\theta = 0°$. So, as θ decrease from 180° to 0° its PE also decreases.

18. Magnetic force does not change the speed of charged particle. Hence, v=u. Further magnetic field on the electron in the given condition is along negative y-axis in the starting Or it describes a circular path in clockwise direction. Hence, when it exits from the field, y < 0.

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

20. $\vec{F}_{BA} = 0$,

because magnetic lines are parallel to this wire.

$\vec{F}_{CD} = 0$,

because magnetic lines are antiparallel to this wire.

$\vec{F}_{CB}$ is perpendicular to paper outwards and $\vec{F}_{AD}$ is perpendicular to paper inwards. These two forces (although calculated by integration) cancel each other but produce a torque which tend to rotate the loop in clockwise direction about an axis OO'.

21. Radius of circular path of charged particle $R = \dfrac{mV}{qB}$

❖ Particle enters region III if R > ● $\Rightarrow \dfrac{mV}{qB} > 1$

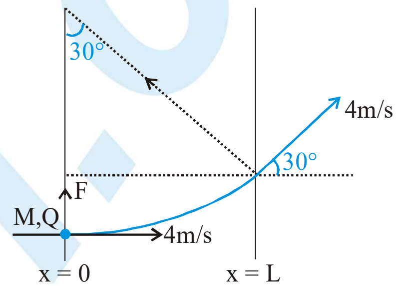
❖ Path length in region II is maximum is

$R = ● \Rightarrow V = \dfrac{ql B}{m}$

❖ Time spent in region II $t = \dfrac{T}{2} = \dfrac{\pi m}{qB}$

22. **(C)**

23. By direction of $\vec{F}$ from equation $\vec{F} = q(\vec{v} \times \vec{B})$ Magnetic field is in –z direction

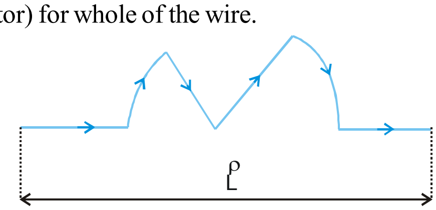


$\text{Time} = \dfrac{\theta}{\omega} = \dfrac{\pi/6}{QB/M} = \dfrac{M\pi}{6QB}$

$\Rightarrow B = \dfrac{M\pi}{6Q(10\times10^{-3})} = \dfrac{50\pi M}{3Q}$

24. **AD**

25. If magnetic field is uniform, then we can define $\vec{L}$ (length vector) for whole of the wire.



$|\vec{L}| = 2(L+R)$

Net force on wire will be $\vec{F} = i(\vec{L} \times \vec{B})$

if $\vec{L} \perp \vec{B}$, then $\vec{F} = i|\vec{L}|\,|\vec{B}| = 2i(L+R)B$

if $\vec{L} \parallel \vec{B}$, then $\vec{F} = 0$

Comprehension#1

1. If $B_2 > B_1$, critical temperature, (at which resistance of semiconductors abrupt becomes zero) in case 2 will be less than compared to case 1.

2. With increase in temperature, T_C is decreasing.

$T_C(0) = 100$ K

$T_C = 75$ K at $B = 7.5$ T

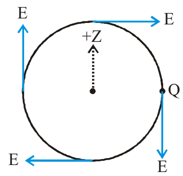
Hence, at B = 5T, T_C should line between 75 K and 100 K.

Comprehension#2

1. induce electric field $= \frac{R}{2}\frac{dB}{dt} = \frac{BR}{2}$

torque on charge $= \frac{QBR^2}{2}(-\hat{k})$

by $\vec{\tau} = \frac{d\vec{L}}{dt} \Rightarrow \int d\vec{L} = \int_0^t \vec{\tau}dt$



$\Delta\vec{L} = \frac{QBR^2}{2}(-\hat{k})$

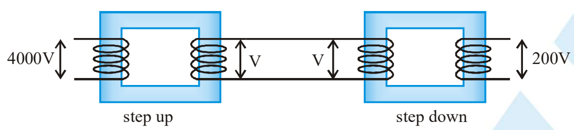
Change magnetic dipole moment $= \gamma\Delta\vec{L}$

$\frac{\gamma QBR^2}{2}(-\hat{k})$

2. Magnitude of induced electric field $= \frac{R}{2}\frac{dB}{dt} = \frac{BR}{2}$

Comprehension#3

1.



for step up transformer $\frac{V}{4000} = \frac{10}{1}$

$\Rightarrow$ V = 40,000 Volt

for step down transformere

$$\frac{N_1}{N_2} = \frac{V}{200} = \frac{4000}{200} = 200$$

2. Current in transmission line

$$= \frac{\text{Power}}{\text{Voltage}} = \frac{600\times10^3}{40,000} = 150\text{A}$$

Resistance of line = 0.4 × 20 = 8Ω

Power loss in line = $i^2R = (150)^2 8 = 180$ KW

percentage of power dissipation in during transmission

$$= \frac{180\times10^3}{600\times10^3}\times100 = 30\%$$

Comprehension#4

1. $qE = qV_dB \Rightarrow V_d = \frac{E}{B} = \frac{V}{wB}$

$I = neAV_d$

Now, $I_1 = I_2 \Rightarrow A_1 v_{d_1} = A_2 v_{d_2}$

$\Rightarrow w_1 d_2 \frac{V_1}{w_1 B} = w_2 d_2 \frac{V_2}{w_2 B}$

$\Rightarrow d_1V_1 = d_2V_2\ d_1 = 2d_2 \Rightarrow V_2 = 2V_1\ d_1 = d_2$

$\Rightarrow V_1 = V_2$

2. $I_1 = I_2$

$n_1 eA_1 v_{d_1} = n_2 eA_2 v_{d_2}$

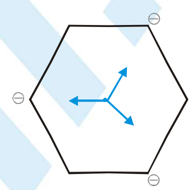
$\Rightarrow n_1 v_{d_1} = n_2 v_{d_2}$

$n_1\frac{V_1}{w_1B_1} = n_2\frac{V_2}{w_2B_2}$

If $B_1 = B_2$ then $n_1V_1 = n_2V_2$

Match the column

4. (P)



(A) All electric field vector at an angle of 120°

∴ electric field at centre is zero.

Individually due to +ve and (–ve) charge

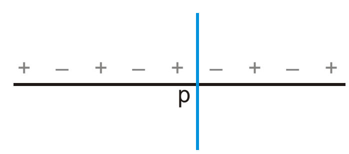
(B) Electric potential due to negative charges and positive charges is equal therefore it is zero

(C) On rotating the hexagon current in the loop becomes zero

∴ magnetic field at the centre is zero

(D) As current in the whole loop iz zero therefore magnetic moment is zero

(Q)

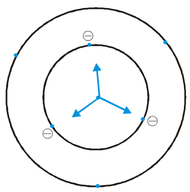


(A) Electric field will be non zero due combination of two charge electric field is additive in nature

(B) Electric potential due to negative charges and positive charges is equal therefore its potential is zero

(C) On rotating about the axis current is zero magnetic field is zero [∵ total charge is zero]

(D) Magnetic moment due to rod is zero

(R) 

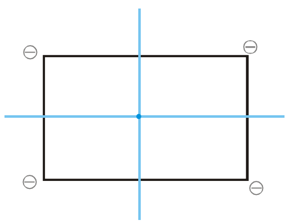
$\vec{E} = \frac{Kq}{a^2} + \frac{k^2}{b^2}$

(A) Same charges are spread at an Angle of 120° therefore electric field at centre is zero

(B) Electric potential due to negative charges and positive charges is not equal therefore it is non-zero

(C) Current in the individual loop is non zero therefore magnetic field is non zero

(D) As current is non zero magnetic moment will be non zero

(S) 

(A) Electric field at the centre due to symmetrical distribution is zero

(B) Electric potential due to negative charges and positive charges is not equal therefore its potential is non-zero

(C) Current non-zero $\therefore$ Magnetic field is non-zero

(D) As current is non-zero magnetic moment is also non-zero

(T)

(A) Electric field at M is additive therefore it is non-zero

(B) Electric potential due to negative charges and positive charges is equal therefore its potential is zero

(C) Current is zero because summation of charge is zero

$\therefore$ Magnetic field is zero

(D) As current is zero magnetic moment is also zero

Subjective

1. Magnetic moment of the loop,

$$\vec{M} = (iA)\hat{k} = (I_0L^2)\hat{k}$$

Magnetic field,

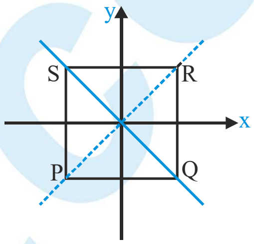
$$\vec{B} = (B\cos 45°)\hat{i} + (B\sin 45°)\hat{j} = \frac{B}{\sqrt{2}}(\hat{i}+\hat{j})$$

(i) Torque acting on the loop,

$$\vec{\tau} = \vec{M}\times\vec{B} = (I_0L^2\hat{k})\times\left[\frac{B}{\sqrt{2}}(\hat{i}+\hat{j})\right]$$

$$\therefore \vec{\tau} = \frac{I_0L^2B}{\sqrt{2}}(\hat{j}-\hat{i}) \Rightarrow |\vec{\tau}| = I_0L^2B$$

(ii) Axis of rotating coincides with the torque and since torque is in $\hat{j}-\hat{i}$ direction or parallel to QS. Therefore, the loop will rotate about an axis passing through Q and S as shown in the figure.



Angular acceleration, $a = \frac{|\vec{\tau}|}{I}$

where I = moment of inertia of loop about QS.

$I_{QS} + I_{PR} = I_{ZZ}$ (From theorem of perpendicular axis)

But $I_{QS} = I_{PR}$

$$\therefore\ 2I_{QS} = I_{ZZ} = \frac{4}{3}ML^2 \Rightarrow I_{QS} = \frac{2}{3}ML^2$$

$$\therefore\ \alpha = \frac{|\vec{\tau}|}{I} = \frac{I_0L^2B}{2/3ML^2} = \frac{3}{2}\frac{I_0B}{M}$$

$\therefore$ Angle by which the frame roates in time Δt is

$$\theta = \frac{1}{2}\alpha(\Delta t)^2 \Rightarrow \theta = \frac{3}{4}\frac{I_0B}{M}.(\Delta t)^2$$

2. **(i)** $\theta = 30° \Rightarrow \sin\theta = \frac{L}{R}$

Here, $R = \frac{mv_0}{B_0q}$

$$\therefore \sin 30° = \frac{L}{\frac{mv_0}{B_0q}}$$

$$\Rightarrow \frac{1}{2} = \frac{B_0qL}{mv_0} \qquad \therefore L = \frac{mv_0}{2B_0q}$$

(ii) In part (i)

$$\sin 30^\circ = \frac{L}{R} \Rightarrow \frac{1}{2} = \frac{L}{R} \Rightarrow L = R/2$$

Now when $L' = 2.1\,L \Rightarrow \frac{2.1}{2}R \Rightarrow L' > R$

Therefore, deviation of the particle is $\theta = 180^\circ$ is as shown

$$\therefore\ \vec{v}_f = -v_0\hat{i} = \vec{v}_B \text{ and } t_{AB} = T/2 = \frac{\pi m}{B_0 q}$$

3. **(i)** Magnetic field $(\vec{B})$ at the origin = magnetic field due to semicircle KLM + Magnetic field due to other semicircle

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

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

$\therefore$ Magnetic force acting on the particle

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

$$\vec{F} = -\frac{\mu_0 q v_0 I}{4R}\hat{k}$$

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

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

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

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

Then, $\vec{F}_{ADC} = \vec{F}_{AC}$ or $|\vec{F}_{ADC}| = \hat{i}(AC)B$

4. **(i)** Given : $i = 10A$, $r_1 = 0.08m$ and $r_2 = 0.12m$. Straight portions i.e., CD etc., will produce zero magnetic field at the centre. Rest eight arcs will produce the magnetic field at the centre in the same direction i.e., perpendicular to the paper outwards or vertically upwards and its magnitude is

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

$$= \frac{1}{2}\left\{\frac{\mu_0 i}{2r_1}\right\} + \frac{1}{2}\left\{\frac{\mu_0 i}{2r_2}\right\} = \left(\frac{\mu_0}{4\pi}\right)(\pi i)\left(\frac{r_1 + r_2}{r_1 r_2}\right)$$

Substituting the values, we have

$$B = \frac{(10^{-7})(3.14)(10)(0.08 + 0.12)}{(0.08 \times 0.12)}T$$

$B = 6.54 \times 10^{-5}$ T (Vertically upward or outward normal to the paper)

(ii) Force on AC

Force on circular portions of the circuit i.e., AC etc., due to the wire at the centre will be zero because magnetic field due to the central wire at these arcs will be tangential ($\theta = 180^\circ$) as shown.

Force on CD

Current in central wire is also i=10A. Magnetic field at P due to central wire, $B = \frac{\mu_0}{2\pi}.\frac{i}{x}$

$\therefore$ Magnetic force on element dx due to this magnetic field

$$dF = (i)\left(\frac{\mu_0}{2\pi}.\frac{i}{x}\right).dx = \left(\frac{\mu_0}{2\pi}\right)i^2\frac{dx}{x}$$

$$(F = i\,\bullet B \sin 90^\circ)$$

Therefore, net force on CD is-

$$F = \int_{x=r_1}^{x=r_2} dF = \frac{\mu_0 i^2}{2\pi}\int_{0.08}^{0.12}\frac{dx}{x} = \frac{\mu_0}{2\pi}i^2 \ln\left(\frac{3}{2}\right)$$

Substituting the values,

$F = (2\times10^{-7})(10)^2 \bullet n(1.5)$ or

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

Force on wire at the centre

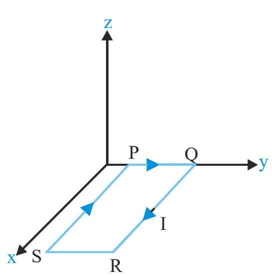
Net magnetic field at the centre due to the circuit is in vertical direction and current in the wire in centre is also in vertical direciton. Therefore, net force on the wire at the centre will be zero. ($\theta = 180^\circ$). Hence,

(i) Force acting on the wire at the centre is zero.

(ii) Force on arc AC = 0

(iii) Force on segment CD is 8.1×10^{-6} N (inwards).

5. Let the direction of current in wire PQ is from P to Q and its magnitude be I.



The magnetic moment of the given loop is :

$$\vec{M} = -Iab\hat{k}$$

Torque on the loop due to magnetic forces is :

$$\vec{\tau}_1 = \vec{M} \times \vec{B}$$

$$= (-Iab\hat{k}) \times (3\hat{i} \times 4\hat{k})B_0\hat{i} = -3IabB_0\hat{j}$$

Torque of weight of the loop about axis PQ is :

$$\vec{\tau}_2 = \vec{r} \times \vec{F} = \left(\frac{a}{2}\hat{i}\right) \times (-mg\hat{k}) = \frac{mga}{2}\hat{j}$$

We see that when the current in the wire PQ is from P to Q, $\vec{\tau}_1$ and $\vec{\tau}_2$ are in opposite direction, so they can cancel each other and the loop may remain in equilibrium. So, the direction of current I in wire PQ is from P to Q. Further for equilibrium of the loop: $|\vec{\tau}_1| = |\vec{\tau}_2| \Rightarrow 3IabB_0$

$$= \frac{mga}{2} \Rightarrow I = \frac{mg}{6bB_0}$$

(ii) Magnetic force on wire RS is :

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

$$\vec{F} = IbB_0\left(3\hat{k} - 4\hat{j}\right)$$

6. In equilibrium, $2T_0 = mg \Rightarrow T_0 = \frac{mg}{2}$ ....**(i)**

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

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

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

For translational equilibrium of ring is vertical direction, $T_1 + T_2 = mg$ ....**(ii)**

For rotational equilibrium,

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

$$\Rightarrow T_1 - T_2 = \frac{\omega BQR^2}{2} \quad ....\textbf{(iii)}$$

Solving equations **(ii)** and **(iii)**, we have

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

As $T_1 > T_2$ and maximum values of T_1 can be

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

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

7. $r = \frac{\sqrt{2qvm}}{Bq} \Rightarrow r \propto \sqrt{\frac{m}{q}}$

$$\frac{r_p}{r_\alpha} = \sqrt{\frac{m_p}{m_\alpha}}\sqrt{\frac{q_\alpha}{q_p}} = \sqrt{\frac{1}{4}}\sqrt{\frac{2}{1}} = \frac{1}{\sqrt{2}}$$

8. **(i)** $\tau = MB = ki\ (\theta = 90°)$

$$\therefore k = \frac{MB}{i} = \frac{(NiA)B}{i} = NBA$$

(ii) $\tau = k.\theta = BiNA$ (k = Torsional constant)

$$\therefore k = \frac{2BiNA}{\pi} \qquad (\text{as } \theta = \pi/2)$$

(iii) $\tau = BiNA \Rightarrow \int_0^t \tau dt = BNA\int_0^t i dt$

$$\Rightarrow I\omega = BNAQ \Rightarrow \omega = \frac{BNAQ}{I}$$

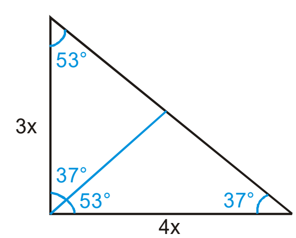
At maximum deflection whole kinetic energy (rotational) will be converted into potential energy of spring. Hence,

$$\frac{1}{2}I\omega^2 = \frac{1}{2}k\theta^2_{max}$$

Substituting the values, we get $\theta_{max} = Q\sqrt{\frac{BN\pi A}{2I}}$

9. $B = \frac{\mu_0 i}{4\pi d}(\sin 37 + \sin 53)$

$$= \frac{\mu_0 i}{4\pi\left(\frac{12}{5}\pi\right)}\left[\frac{7}{5}\right]$$

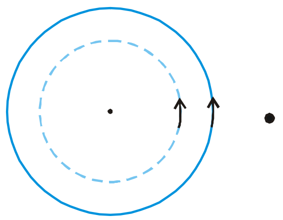


$$\Rightarrow \frac{7\mu_0 i}{48\pi x} \Rightarrow k = 7$$

10. 2

11.

MOCK TEST

1. 

Disc behaves like made up of coils arranged in a plane in which current is flowing in anti-clockwise direction.
Hence, the field at A is directed into the page. Hence (A).

2. $\vec{B} = \frac{\mu_0}{4\pi} q \frac{\vec{v} \times \vec{r}}{r^3}$ and $\vec{E} = \frac{1}{4\pi \epsilon_0} \frac{q\vec{r}}{r^3}$

$\therefore \quad \vec{B} = \mu_0 \epsilon_0 (\vec{v} \times \vec{E}) = \frac{\vec{v} \times \vec{E}}{c^2}$

3. Since

$\vec{B} = \frac{\mu_0}{4\pi} q \frac{\vec{v} \times \vec{r}}{r^3}$, $\vec{v} \times \vec{r}$ must be same

where $\vec{v}$ = velocity of charge with respect to observer
Let A and B are the observers

then $(\vec{v}_C - \vec{v}_A) \times \vec{r} = (\vec{v}_C - \vec{v}_B) \times \vec{r}$

or $(\vec{v}_A - \vec{v}_B) \times \vec{r} = 0$ or $(\vec{v}_A - \vec{v}_B) \parallel \vec{r}$

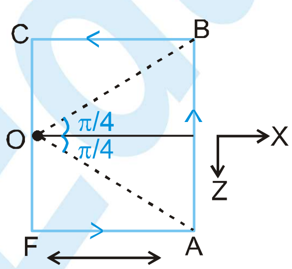
4. Due to FABC the magnetic field at O is along y – axis and due to CDEF the magnetic field is along x–axis.

Hence the field will be of the form $A\left[\hat{i} + \hat{j}\right]$

Calculating field due to FABC :

due to AB :

$$\vec{B}_{AB} = \frac{\mu_0 i}{4\pi\left(\frac{1}{2}\right)} (\sin 45^\circ + \sin 45^\circ)\ \hat{j} = \sqrt{2}\frac{\mu_0 i}{2\pi l}\hat{j}$$



Due to BC :

$$\vec{B}_{BC} = \frac{\mu_0 i}{4\pi l\left(\frac{1}{2}\right)}(\sin 0^\circ + \sin 45^\circ)\hat{j} = \frac{\mu_0 i}{2\sqrt{2}\pi l}\hat{j}$$

Similarly due to FA :

$$\vec{B}_{FA} = \frac{\mu_0 i}{2\sqrt{2}\pi l}\hat{i}$$

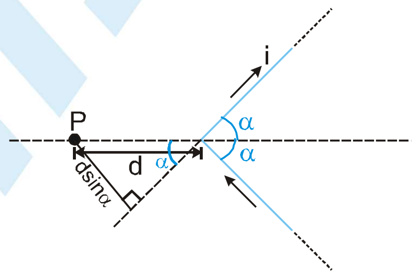
Hence $\vec{B}_{PABC} = \frac{\mu_0 i}{\pi l}\left[\frac{1}{2\sqrt{2}} + \frac{1}{2\sqrt{2}} + \frac{\sqrt{2}}{2}\right]\hat{i}$

$$\vec{B}_{FABC} = \frac{\sqrt{2}\mu_0 i}{\pi l}\left(\hat{j}\right)$$

Similarly due to CDEF:

$$\vec{B}_{CDEF} = \frac{\sqrt{2}\mu_0 i}{\pi l}\left(\hat{i}\right) \Rightarrow \vec{B}_{net} = \frac{\sqrt{2}\mu_0 i}{\pi l}\left(\hat{i} + \hat{j}\right)$$

5. Let us compute the magnetic field due to any one segment :



$$B = \frac{\mu_0 i}{4\pi(d\sin\alpha)}(\cos 0^0 + \cos(180 - \alpha))$$

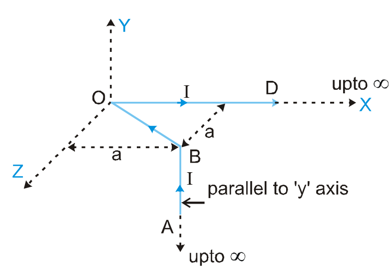
$$= \frac{\mu_0 i}{4\pi(d\sin\alpha)}(1 - \cos\alpha) = \frac{\mu_0 i}{4\pi d}\tan\frac{\alpha}{2}$$

Resultant field will be :

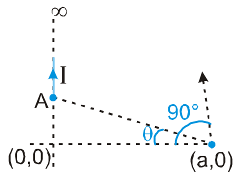
$$B_{net} = 2B = \frac{\mu_0 i}{2\pi d}\tan\frac{\alpha}{2} \Rightarrow k = \frac{\mu_0 i}{2\pi d}$$

6. $B_{OD} = 0 \qquad B_{OB} = 0$

$$B_{AB} = \frac{\mu_0 I}{4\pi a\sqrt{2}}[\cos 45^\circ(-\hat{i}) + \cos 45^\circ \hat{k}] = \frac{\mu_0 I}{8\pi a}(-\hat{i} + \hat{k})$$



7.



$$B = \frac{\mu_0}{4\pi}\frac{i}{a}(\sin 90 + \sin(-\theta)) = \frac{\mu_0}{4\pi}\frac{i}{a}(1 - \sin\theta)$$

$$= \frac{\mu_0}{4\pi}\frac{i}{a}\left(1 - \frac{b}{\sqrt{a^2+b^2}}\right)$$

8. Magnetic field strength at P due to I_1

$$\vec{B}_1 = \frac{\mu_0 I_1}{2\pi(AP)}\hat{k} = \frac{4\pi\times10^{-7}\times 2}{2\pi\times1\times10^{-2}}\hat{k} = (4\times10^{-5}T)\,\hat{k}$$

Magnetic field strength at P due the I_2

$$\vec{B}_2 = \frac{\mu_0 I_2}{2\pi(BP)}\hat{j} = \frac{4\pi\times10^{-7}\times 3}{2\pi\times2\times10^{-2}}\hat{j} = (3\times10^{-5}T)\,\hat{j}$$

Hence, $\vec{B} = (3\times10^{-5}\,T)\,\hat{j} + (4\times10^{-5}T)\,\hat{k}$

9. By symmetry, the magnetic field at the centre P is zero.

10. $\oint_{ABCDA} \vec{B}.\vec{dl} = \mu_0(i_1 + i_3 + i_2 - i_3) = \mu_0(i_1 + i_2)$ [since for the given direction of circumlation i_3 entering at PSTU is positive while i_3 at PQRS is negative]

Alternate solution

$$\oint_{ABCDA} \vec{B}.\vec{dl} = \oint_{ABCA} \vec{B}.\vec{dl} + \oint_{CDAC} \vec{B}.\vec{dl} = \mu_0 i_1 + \mu_0 i_2$$

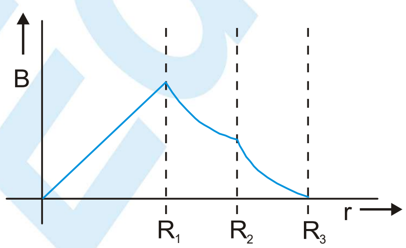
$= \mu_0(i_1 + i_2)$

11. From ampere's law, the field at the axis is zero.

From x = zero to R_1, the field increases linearly as the current enclosed increases.

From x = R_1 to R_2 and from x = R_2 to R_3, the field decreases hyperbolicaly but with different slopes as the media are different.

Hence the required graph is

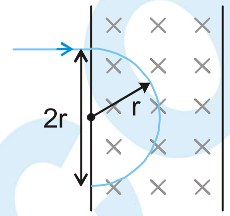


12. $F = q[v(-\hat{i})] \times B(\hat{i})] = 0$

Because B as well as v is are along axis of circular loop.

13. Electromagnetic force will provide the necessary centripetal force.

$$eBv = \frac{mv^2}{r}$$

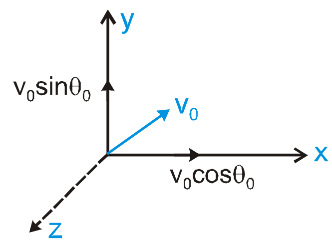


$$\Rightarrow \; r = \frac{mv}{eB} = \frac{v}{B\alpha} = \frac{(2\alpha d)(B)}{(B\alpha)} = 2d$$

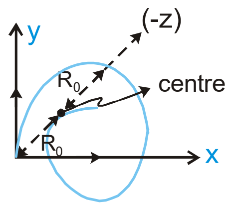
i.e. the electron will move out after travelling on a semicircular path of radius r = 2d.

Hence (B)

14. As the magnetic field is along the x-axis, the magnetic force will be along (–) z-axis from t = 0 to t = T_0 and along (+)ve z-axis from t = T_0 to t = $2T_0$.



For t = 0 to t = T_0 :– At $t = \frac{T_0}{2}$;



$$\text{x-coordinate} = \frac{(V_0\cos\theta)\,T_0}{2}$$

$= \frac{P_0}{2}$ (Since pitch = $P_0 = (V_0\cos\theta)T_0$)

y-coordinate = 0 (from figure)

and z-coordinate = – 2 R_0 (from figure)

Hence (A) is correct.

Similarly at $t = \frac{3T_0}{2}$;

coordinates are $\left(\frac{3P_0}{2}, 0, 2R_0\right)$

Hence (B) is correct.

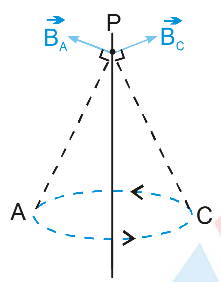
Note : z -coordinate will be + $2R_0$, because from $t = T_0$ to $t = 2T_0$, direction of $\vec{B}$ changes.

As the charge will perform circular motion about x-axis, the two extremes from x-axis are $2R_0$ from each other.

Hence (C) is also correct.

Hence only (D) is incorrect.

15. The point charge moves in circle as shown in figure. The magnetic field vectors at a point P on axis of circle are $\vec{B}_A$ and $\vec{B}_C$ at the instants the point charge is at A and C respectively as shown in the figure.



Hence as the particles rotates in circle, only magnitude of magnetic field remains constant at the point on axis P but its direction changes.

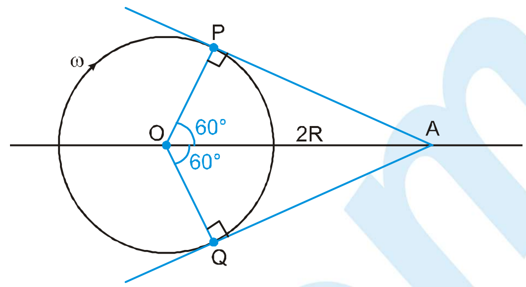
Alternate solution

The magnetic field at point on the axis due to charged particle moving along a circular path is given by

$$\frac{\mu_0}{4\pi}\frac{q\vec{v}\times\vec{r}}{r^3}$$

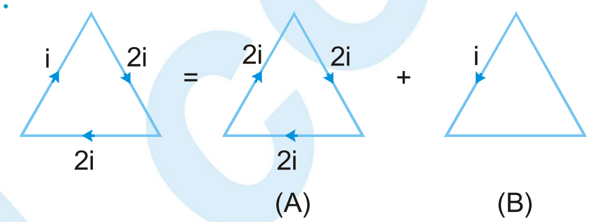
It can be seen that he magnitude of the magnetic field at an point on the axis remains constant. But the direction of the of the field keeps on changing.

16. Point A shall record zero magnetic field (due to α-particle) when the α-particle is at position P and Q as shown in figure. The time taken by α-particle to go from P to Q is



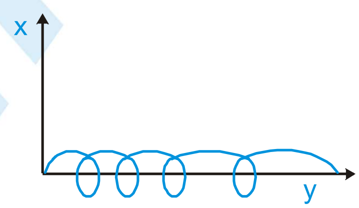
$t = \frac{1}{3}\frac{2\pi}{\omega}$ or $\omega = \frac{2\pi}{3t}$

17.



force in figure (A) is zero, and force in figure (B) = i ● B.

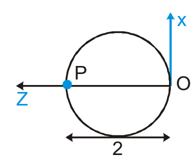
18. The particle will move in a non-uniform helical path with increasing pitch as shown below:



Its time period will be :

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

Changing the view, the particle is seemed to move in a circular path in (x – z) plane as below



After π-seconds the particle will be at point 'P', hence x coordinate will be 0

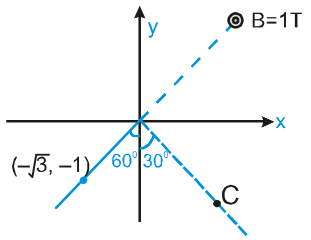
For linear motion along y-direction.

$$y(\pi) = 0(\pi) + \frac{1}{2}\frac{Eq}{m}(\pi)^2$$

$y(\pi) = \frac{\pi^2}{2}$ and OP = 2

Hence the coordinate $\left(0, \frac{\pi^2}{2}, 2\right)$.

19. The centre will be at 'C' as shown :



Coordinates of the centre are $(r\cos60^0, -r\sin60^0)$

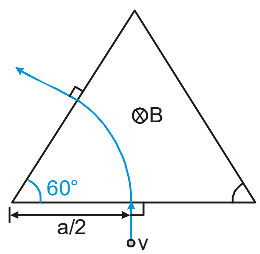
where $r = \text{radius of circle} = \frac{mv}{Bq} = \frac{1\times1}{1\times1} = 1$

i.e. $\left(\frac{1}{2}, -\frac{\sqrt{3}}{2}\right)$

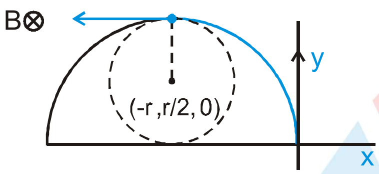
20 The charged particle moves in a circle of radius $\frac{a}{2}$

$\therefore \quad qvB = \frac{mv^2}{a/2}$

or $\quad B = \frac{2mv}{qa}$



21.



Hence (B).

22. After two and half time periods, it is at a distance $2R_0$ on the negative z-axis. y-coordinate will be zero
And the x-coordinate = $2.5\ P_0$.
i.e. it is at a distance $7.5\ P_0$ from the mirror, hence its image will be at $2(7.5\ P_0) + 2.5\ P_0 = 17.5\ P_0$.
Hence (C).

23 $\tau = \vec{m}\times\vec{B}\,S = I_0L^2\hat{k}\times\left(\frac{B}{\sqrt{2}}\hat{i} + \frac{B}{\sqrt{2}}\hat{j}\right) = \frac{I_0L^2B}{\sqrt{2}}(\hat{j}-\hat{i})$

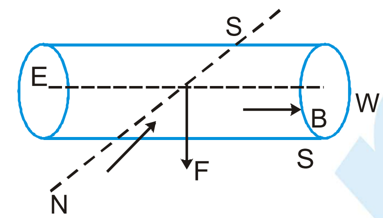
24. $\int E.dl = \frac{-d\phi}{dt} = -\pi r^2\frac{dB}{dt}$

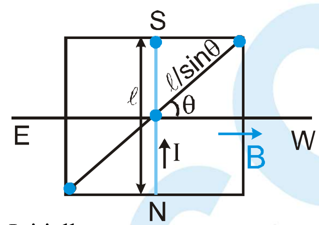
$N = \int \lambda E dl = -R\lambda\pi r^2\frac{dB}{dt}$

$\int N dt = -R\lambda\pi r^2\int dB = R\lambda\pi r^2 B = I\omega$

$\Rightarrow \pi r^2 B\frac{q}{2\pi r} = mr^2\omega \Rightarrow \omega = \frac{qB}{2m}$

25.





Initially

$1.2\,N = \mathbf{I}.(\vec{l}\times\vec{B})\ \downarrow$

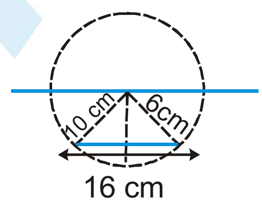
In the given condition –

$F = I\frac{l}{\sin\theta}B\sin\theta = I\lambda B = 1.2\,N\downarrow.$

26. Force on wire is :

$F = I\times16\times B$ ....**(1)**

but $\ 1.2 = I\times20\times B$ ....**(2)**

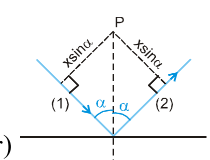


$\frac{F}{1.2} = \frac{16}{20} \Rightarrow F = \frac{4.8}{5}\ \ 0.96\,N\downarrow$ downward

27. Magnetic field at 'P' due to wires (1) and (2) is :

$B_1 = \frac{\mu_0 I}{2\pi(x\sin\alpha)} + \frac{\mu_0 I}{2\pi(x\sin\alpha)}$

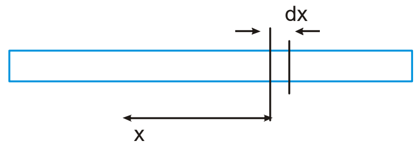
$= \frac{2\mu_0 I}{2\pi(x\sin\alpha)}$ (out of the paper)



Now if a current of $\frac{2I}{\sin\alpha}$ is flowing in the third wire then the magnetic field due to the same will be :

$B_2 = \frac{\mu_0}{2\pi x}\left(\frac{2I}{\sin\alpha}\right)$, which will cancel B_1 if it is out of paper which is possible if the current $\frac{2I}{\sin\alpha}$ in the third wire is from right to left.

28. At a distance x consider small element of width dx. Magnetic moment of the small element is :



$$dm = \frac{\left(\frac{q}{l}dx\right)\omega}{2\pi}.\pi x^2$$

$$M = \int_{-l/2}^{l/2} \frac{q\omega}{2l} x^2 dx, M = \frac{q\omega l^2}{24} = \frac{q\pi f l^2}{12}.$$

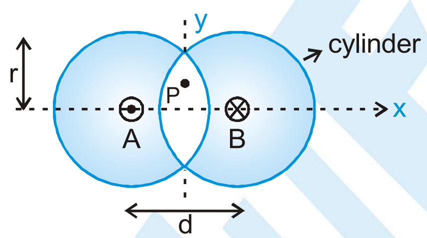
29. (A) $B = \frac{\mu_0 I}{4\pi . \frac{R}{\sqrt{2}}}$ (sin 90° + sin 135°)

$$= \frac{\mu_0 I}{4\pi R}\left(\sqrt{2}-1\right)$$

30. Let the current density in complete left cylinder is $\vec{J}$, then current density in complete right cylinder is $-\vec{J}$. Then magnetic field at any point P in the region of overlap is

$$\vec{B} = \frac{\mu_0}{2} \vec{J}\times\vec{AP} + \frac{\mu_0}{2}(-\vec{J}\times\vec{BP})$$

$$= \frac{\mu_0}{2} \vec{J}\times(\vec{AP}+\vec{PB}) = \frac{\mu_0}{2}(\vec{J}\times\vec{AB})$$



Therefore magnitude of field at any point in region of overlap is $= \frac{\mu_0}{2}Jd$ and its direction is along positive y-direction at any point P in overlap region.

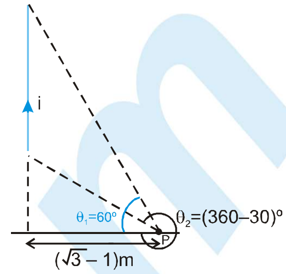
31. $\vec{B}_{\text{due to first loop}} = 4\frac{\mu_0 i}{4\pi\frac{a}{2}}[\cos 45^0 + \cos 45^0] = \frac{2\sqrt{2}\mu_0 i}{\pi a}$

$$\vec{B} = \frac{2\sqrt{2}\mu_0 i}{\pi a}[1 - \frac{1}{2} + ... \infty] = \frac{2\sqrt{2}\mu_0 i}{\pi a} \ln 2$$

32. $B = \frac{\mu_0 . i}{4\pi d}(\sin\theta_1 + \sin\theta_2)$

$$= \frac{10^{-7}\times 100}{\sqrt{3}-1}\left[\frac{\sqrt{3}}{2} - \frac{1}{2}\right]$$

$= 5 \times 10^{-6}$ T



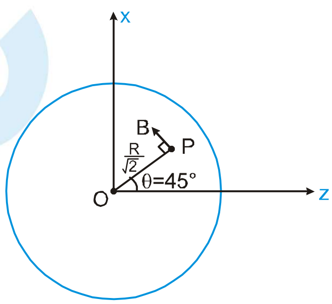
33. The magnitude of magnetic field at P $\left(\frac{R}{2}, y, \frac{R}{2}\right)$ is

$$B = \frac{\mu_0 Jr}{2} = \frac{\mu_0 i}{2\pi R^2} \times \frac{R}{\sqrt{2}} = \frac{\mu_0 i}{2\sqrt{2}\pi R}$$

unit vector in direction of magnetic field is

$$\hat{B} = \frac{\hat{i}-\hat{k}}{\sqrt{2}}$$

$$\therefore \vec{B} = B\hat{B} = \frac{\mu_0 i}{4\pi R}(\hat{i}-\hat{k})$$



Alternate solution

$$\vec{B} = \frac{\mu_0}{2}\vec{J}\times\vec{r} = \frac{\mu_0}{2}\frac{i}{\pi R^2}\hat{j} \times \left(\frac{R}{2}\hat{i} + \frac{R}{2}\hat{k}\right)$$

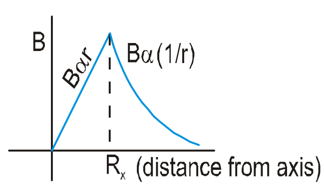
$$= \frac{\mu_0 i}{4\pi R}(\hat{i}-\hat{k})$$

34. (A)

35. The resultant magnetic dipole moment of toroid is zero. $d\vec{\mu}$ of small parts of toroid turn along a circle and hence there resultant is zero.

$\therefore$ Torque acting on it is zero.

36.



$B_{in}\ \alpha\ r \quad B_{out}\ \alpha\ \frac{1}{r}$.

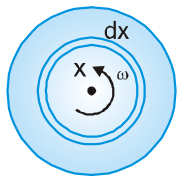
Alternate Solution

B (inside the conductor) $\alpha\, r$

B (outside the conductor) $\alpha\ \frac{1}{r} \quad \therefore u = \frac{B^2}{2\mu_0}\ \alpha\ \frac{1}{r^2}$

37. Consider a ring of radius x and thickness dx.

Equivalent current in this ring $= \frac{\omega}{2\pi} \times$ charge on ring $= \frac{\omega}{2\pi} \times (2\pi x\, dx)\frac{Q}{\pi R^2}$

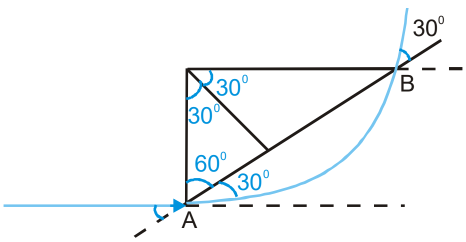


dB (due to this ring) =

$$\frac{\mu_0}{2x}\left(\frac{\omega}{2\pi}\frac{2xQ}{R^2}dx\right)$$

$$\therefore\ B = \int_0^R \frac{\mu_0\omega}{2\pi}\frac{Q}{R^2}dx. = \frac{\mu_0\omega\theta}{2\pi R^2}.R = \frac{\mu_0\omega\theta}{2\pi R}.$$

38.

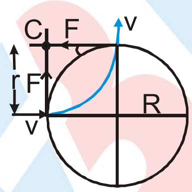


$$\text{Arc AB} = \frac{\pi}{3}r = \frac{\pi mV}{3qB}$$

$$\text{Time 't'} = \left(\frac{I}{2\pi}\right).\left(\frac{\pi}{3}\right) = \frac{T}{6} = \frac{\pi m}{3qB}.$$

39. The particle will move along an arc which is part of a circle of radius

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



From the figure we can see

r = R

$$\therefore\ R = \frac{mv}{Bq};\ T = \frac{\pi r/2}{v} = \frac{\pi r}{2v} \rightarrow r = R = \frac{mv}{Bq}$$

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

40. For cylinder ;

$$B = \frac{\mu_0 ir}{2\pi R^2}\ ;\ r < a = \frac{\mu_0 i}{2\pi r}\ ;\ r \geq a$$

We can consider the given cylinder as a combination of two cylinders. One of radius 'R' carrying current I in one direction and other of radius $\frac{R}{2}$ carrying current $\frac{I}{3}$ in both directions.

$$\text{At point A : } B = \frac{\mu_0 (I/3)}{2\pi (R/2)} + 0 = \frac{\mu_0 I}{3\pi R}$$

$$\text{At point B : } B = \frac{\mu_0}{2}\left(\frac{4I/3}{\pi R^2}\right)\left(\frac{R}{2}\right) + 0 = \frac{\mu_0 I}{3\pi R}$$

41. The magnitude of magnetic force on charged particle undergoing uniform circular motion in uniform magnetic field is

F=qvB

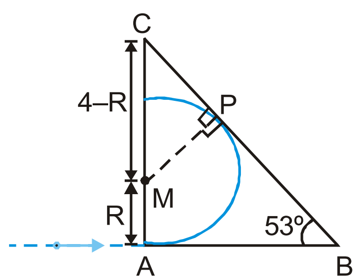
$\therefore$ If v is doubled keeping q and B constant, the force F just doubles. Hence statement 1 is false.

42. Both statements are correct, but statement 2 is not a correct explanation of statement 1.

43. Solenoid tends to contract because the current in all the circular turns is in same direction. Hence all turns(can be assumed as a ring) attract each other.

44. The current through solid metallic cylinder also produces magnetic field inside the cylinder. Hence statement-1 is false

45. In triangle PMC



$$\cos 53^\circ = \frac{MP}{MC}$$

$$\frac{3}{5} = \frac{R}{4-R}$$

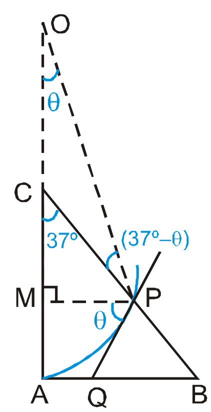
$$12 = 8R$$

$R = \frac{3}{2}$ m (R is the maximum radius of half–circle)

$$R_{max} = \frac{mu_{max}}{qB}$$

$\Rightarrow\ U_{max} = 3$ m/s.

46. $R = \frac{mu}{qB} = 24$ m



Let, $\angle MPQ = \theta$

By geometry,

$\angle CPO = (37 - \theta)$

In ΔCPO

$$\frac{OC}{\sin(\angle CPO)} = \frac{OP}{\sin(\angle PCO)}$$

$$\frac{20}{\sin(37^\circ - \theta)} = \frac{24}{\sin(180^\circ - 37^\circ)}$$

$$\frac{5}{\sin(37^\circ-\theta)}=\frac{5\times 6}{3}$$

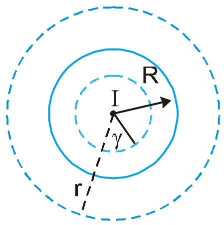
$$\sin(37^\circ-\theta)=\frac{1}{2} \Rightarrow \theta=\frac{7\pi}{180}\text{ rad.}$$

$$\omega=\frac{qB}{m} \Rightarrow \omega=2\text{ rad/sec.} \Rightarrow t=\frac{7\pi}{360}\text{ sec.}$$

47. Inside the cylinder

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

$$B=\frac{\mu_0 I}{2\pi R^2}.r \quad \text{.............(1)}$$



outside the cylinder

$B.2\pi r=\mu_0 I$

$$\therefore \quad B=\frac{\mu_0 I}{2\pi r} \quad \text{.............(2)}$$

Inside cylinder $B \propto r$ and outside $B \propto \frac{1}{r}$

So from surface nature of mag field changes.

Hence it is clear from the graph that wire 'c' has greatest radius.

48. Magnitude of mag field is maximum at the surface of wire 'a'.

49. Inside the wire

$$B(r)=\frac{\mu_0}{2\pi}.\frac{I}{R^2}.r$$

$$\Rightarrow \frac{dB}{dr}=\frac{\mu_0}{2\pi}.\frac{I}{R^2}$$

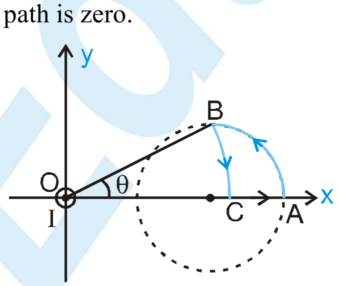
i.e. slope $\propto \frac{I}{\pi R^2}$

$\propto$ current density

It can be seen that slope of curve for wire a is greater than wire c.

50. Since there is no current passing through circular path, the integral $\oint \vec{B}\cdot d\vec{l}$ along the dotted circle is zero.

51. Let segment OB =OC and arc BC is a circular arc with centre at origin. Since the shown closed path ABCA encloses no current, the path integral of magnetic field over this path is zero.



Hence $\int_A^B \vec{B}\cdot d\vec{l}+\int_B^C \vec{B}\cdot d\vec{l}+\int_C^A \vec{B}\cdot d\vec{l}=0.$

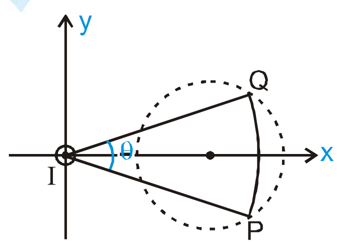
Because $\vec{B}$ is perpendicular to segment AC at all points, therefore $\int_C^A \vec{B}\cdot d\vec{l}=0.$

Hence $\int_A^B \vec{B}\cdot d\vec{l}=\int_C^B \vec{B}\cdot d\vec{l}=\frac{\mu_0 I}{2\pi}\frac{OB(\theta)}{OB}=\frac{\mu_0 I}{2\pi}\tan^{-1}\frac{1}{2}$

52. Consider two points P and Q lying on dotted circle and equidistant from origin O. We draw a circular arc QP with centre at origin O. The path integral of magnetic field, that is, $\int \vec{B}\cdot d\vec{l}$ along the dotted circle between two points P and Q is also equal to path integral $\int \vec{B}\cdot d\vec{l}$ along the arc QP whose centre is at origin.

Therefore the path integral of magnetic field $\int \vec{B}\cdot d\vec{l}$ along the dotted circle between two points P and Q

$$=\frac{\mu_0 I}{2\pi}\frac{OP(\theta)}{OP}=\frac{\mu_0 I}{2\pi}\theta.$$



The value of θ will be maximum when chord OQ and chord OP will be tangent to the dotted circle, that is, $\theta=\frac{\pi}{3}$.

Hence the required maximum value $=\frac{\mu_0 I}{6}$.

53. $R=mv/qB$

$R_B>R_A$

and $R_A=R_C$ (in opposite sense a)

and R_D is smallest

(A) s **(B)** p **(C)** q **(D)** r

54. Work done by magnetic force on the charge = 0 in any part of its motion.

$\therefore$ 'S' is matching for all parts (i), (ii), (iii), (iv)

For loop 1 $\Sigma I_{in}=-i+i-i=-i \quad \therefore \oint \vec{B}.d\vec{l}=\mu_0(-i)$

For loop 2 $\Sigma I_{in}=i-i+i=i \quad \therefore \oint \vec{B}.d\vec{l}=\mu_0(i)$

For loop 3 $\Sigma I_{in} = -i - i + i = -i$ $\quad \oint \vec{B}.\vec{dl} = \mu_0(-i)$

For loop 4 $\Sigma I_{in} = +i + i - i = +i$ $\quad \oint \vec{B}.\vec{dl} = \mu_0(i)$

(Note : That current will be taken as positive which produces lines of magnetic field in the same sense in which $\vec{dl}$ is taken)

55. The magnetic field is along negative y-direction in case A,B and C

Hence z-component of magnetic field is zero in all cases.

The magnetic field at P is $\frac{\mu_0}{4\pi}\frac{i}{d}$ for case (r)

The magnetic field at P is less than $\frac{\mu_0}{2\pi}\frac{i}{d}$ for all cases.

56. (A) Because the magnetic field is parallel to x-axis,the force on wire parallel to x-axis is zero.

The force on each wire parallel to y-axis is $B_o \frac{i}{2}$●.

Hence net force on loop is $B_o i$●. Since force on each wire parallel to y-axis passes through centre of the loop net torque about centre of the loop is zero.

(B) Because the magnetic field is parallel to y-axis, the force on wire parallel to y-axis is zero. The force on each wire parallel to x-axis is $B_o \frac{i}{2}$●. Hence net force on loop is $B_o i$●. Since force on each wire parallel to x-axis passes through centre of the loop, net torque about centre of the loop is zero.

(C) Since net displacement of current from entry point in the loop to exit point in the loop is along the diagonal of the loop.The direction of external uni form magnetic field is also along the same diago nal. Hence net force on the loop is zero. Since force on each wire on the loop passes through centre of the loop net torque about centre of the loop is zero.

(D) The net displacement of current from entry point in the loop to exit point in the loop is along the diagonal (of length $\sqrt{2}$ ●.) of the loop.The diretion of external uniform magnetic field is also perpendicular to the same diagonal. Hence magnitude of net force on the loop is $B_o i(\sqrt{2}$ ●). Since force on each wire on the loop passes through centre of the loop net torque about centre of the loop is zero.

57. $\vec{F} = q\vec{E} + q(\vec{V} \times \vec{B})$

If $\vec{u} = 0$, $\vec{B} = B_x\hat{i}$ and $\vec{E} = E_y\hat{j}$

then charge particle will start to move in y-direction due to electric field and as it aquires velocity it will experience force due to magnetic field and will move in a cycloid path. Similarly, one can find path for other cases.

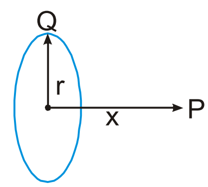
(A) If $B_y = B_z = E_x = E_z = 0$; $u = 0$ then path is cycloid.

(B) If $E = 0$, $u_xB_x + u_yB_y \neq -u_zB_z$ then path is helix with uniform pitch and constant radius or straight line.

(C) If $\vec{u} \times \vec{B} = 0$, $\vec{u} \times \vec{E} = 0$ then path is straight line.

(D) If $\vec{u} \perp \vec{B}$, $\vec{B} \| \vec{E}$ then path is helix with variable pitch and constant radius.

59. Electric field at P is



$$E = \frac{Q\,x}{4\pi\epsilon_0 (x^2 + r^2)^{3/2}}$$

Magnetic field at P is

$$B = \frac{\mu_0}{4\pi}\frac{2\pi i r^2}{(x^2+r^2)^{3/2}} = \frac{\mu_0}{4\pi}\frac{2\pi Q^2 f^2 r^2}{(x^2+r^2)^{3/2}}$$

f = frequency of revolution.

Electric energy density $= \frac{1}{2}\varepsilon_o E^2$; Magnetic energy density $\frac{B^2}{2\mu_0}$

$$\frac{\text{Electric energy density}}{\text{magnetic energy density}} = \frac{\frac{1}{2}\varepsilon_o E^2}{\frac{B^2}{2\mu_0}} = \frac{E^2}{c^2B^2}$$

$$= \frac{x^2 c^2}{4\pi^2 f^2 r^4} = \frac{9}{\pi^2} \times 10^{10} = 9.1 \times 109$$

60. Torque of magnetic force about PQ .... **(1)**

$\tau_m = (ILB)\, L\cos\theta = IL^2 B\cos\theta$ ..... **(2)**

Torque of gravitational force about PQ

$\tau_g = [(\lambda L)\, g\, L\sin\theta + 2(\lambda L)\, g\, (1/2)\, L\sin\theta]$

$= 2\lambda L^2 g \sin\theta$ .... **(1)**

$\tau_m = \tau_g \Rightarrow \tan\theta = \frac{IB}{2\lambda g} = \frac{10\sqrt{3}\times 2}{2\times\sqrt{3}\times 10} = 1$

$\Rightarrow \theta = 45°$