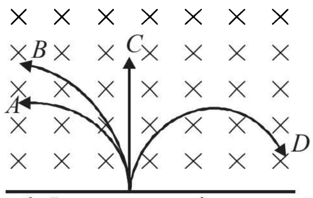
CHAPTER

14 Moving Charges and Magnetism

Section-A JEE Advanced/ IIT-JEE

A Fill in the Blanks

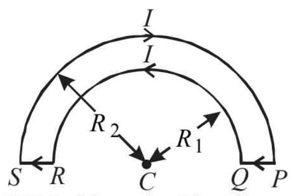
1. A neutron, a proton, and an electron and an alpha particle enter a region of constant magnetic field with equal velocities. The magnetic field is along the inward normal to the plane of the paper. The tracks of the particles are labelled in fig. The electron follows track ...... and the alpha particle follows track ..... *(1984- 2 Marks)*



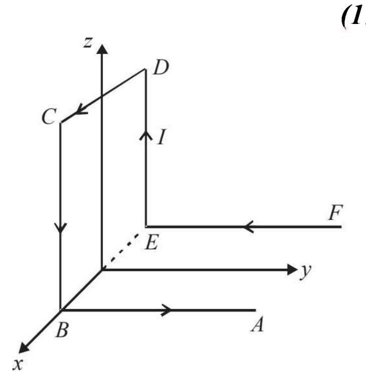
2. A wire of length L metre, carrying a current i ampere is bent in the form of a circle. The magnitude of its magnetic moment is ....in *MKS* units. *(1987 - 2 Marks)*

3. In a hydrogen atom, the electron moves in an orbit of radius 0.5 Å making 10^{16} revolutions per second. The magnetic moment associated with the orbital motion of the electron is .... *(1988 - 2 Marks)*

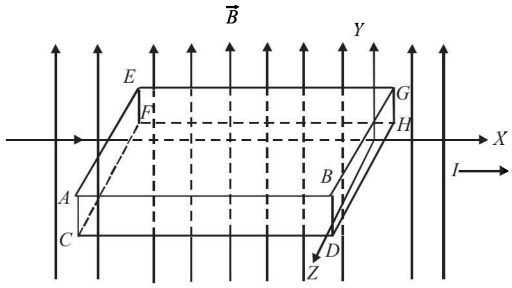
4. The wire loop *PQRSP* formed by joining two semicircular wires of radii R_1 and R_2 carries a current I as shown. The magnitude of the magnetic induction at the centre C is .... *(1988 - 2 Marks)*



5. A wire *ABCDEF* (with each side of length L) bent as shown in figure and carrying a current I is placed in a uniform magnetic induction B parallel to the positive y-direction. The force experienced by the wire is .... in the .... direction. *(1990 - 2 Marks)*



6. A metallic block carrying current I is subjected to a uniform magnetic induction $\vec{B}$ as shown in Figure .



The moving charges experience a force $\vec{F}$ given by .... which results in the lowering of the potential of the face .... Assume the speed of the carriers to be v. *(1996 - 2 Marks)*

B True/False

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

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

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

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

C MCQs with One Correct Answer

1. A conducting circular loop of radius r carries a constant current i. It is placed in a uniform magnetic field $\vec{B}_0$ such that $\vec{B}_0$ is perpendicular to the plane of the loop. The magnetic force acting on the loop is *(1983 - 1 Mark)*

(a) irB_0 (b) $2\pi irB_0$
(c) zero (d) πirB_0

2. A battery is connected between two points A and B on the circumference of a uniform conducting ring of radius r and resistance R. One of the arcs AB of the ring subtends an angle θ at the centre.The value of the magnetic induction at the centre due to the current in the ring is *(1995S)*

(a) proportional to 2 (180° – θ)
(b) inversely proportional to r

(c) zero, only if $\theta = 180°$
(d) zero for all values of θ

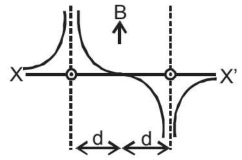
3. A proton, a deuteron and an α - particle having the same kinetic energy are moving in circular trajectories in a constant magnetic field. If r_p, r_d, and r_α denote respectively the radii of the trajectories of these particles, then *(1997 - 1mark)*
(a) $r_\alpha = r_p < r_d$ (b) $r_\alpha > r_d > r_p$
(c) $r_\alpha = r_d > r_p$ (d) $r_p = r_d = r_\alpha$

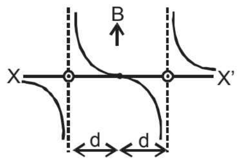
4. A circular loop of radius R, carrying current I, lies in x-y plane with its centre at origin. The total magnetic flux through x-y plane is *(1999S - 2 Marks)*
(a) directly proportional to I
(b) directly proportional to R
(c) inversely proportional to R
(d) zero

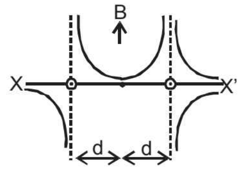
5. A charged particle is released from rest in a region of steady and uniform electric and magnetic fields which are parallel to each other. The particle will move in a *(1999S - 2 Marks)*
(a) straight line (b) circle
(c) helix (d) cycloid

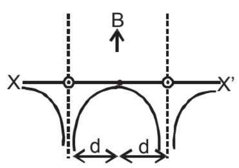
6. A particle of charge q and mass m moves in a circular orbit of radius r with angular speed ω. The ratio of the magnitude of its magnetic moment to that of its angular momentum depends on *(2000S)*
(a) ω and q (b) ω, q and m
(c) q and m (d) ω and m

7. Two long parallel wires are at a distance $2d$ apart. They carry steady equal currents flowing out of the plane of the paper, as shown. The variation of the magnetic field B along the line XX' is given by *(2000S)*

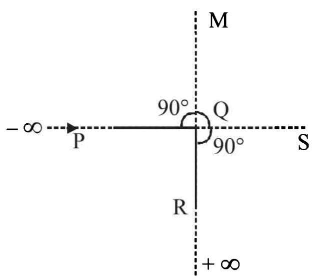
(a) 

(b) 

(c) 

(d) 

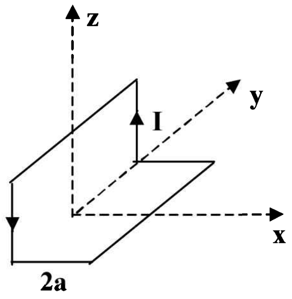
8. An infinitely long conductor PQR is bent to form a right angle as shown in Figure. A current I flows through PQR. The magnetic field due to this current at the point M is H_1. Now, another infinitely long straight conductor QS is connected at Q so that current is $I/2$ in QR as well as in QS, the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



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

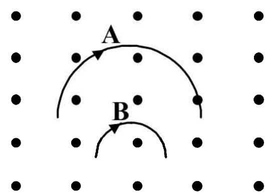
9. An ionized gas contains both positive and negative ions. If it is subjected simultaneously to an electric field along the +x-direction and a magnetic field along the +z-direction, then
(a) positive ions deflect towards +y-direction and negative ions towards -y direction *(2000S)*
(b) all ions deflect towards +y-direction
(c) all ions deflect towards –y-direction
(d) positive ions deflect towards –y-direction and negative ions towards + y-direction.

10. A non-planar loop of conducting wire carrying a current I is placed as shown in the figure. Each of the straight sections of the loop is of length $2a$. The magnetic field due to this loop at the point $P(a, 0, a)$ points in the direction *(2001S)*



(a) $\frac{1}{\sqrt{2}}\left(-\hat{j}+\hat{k}\right)$
(b) $\frac{1}{\sqrt{3}}\left(-\hat{j}+\hat{k}+\hat{i}\right)$
(c) $\frac{1}{\sqrt{3}}\left(\hat{i}+\hat{j}+\hat{k}\right)$
(d) $\frac{1}{\sqrt{2}}\left(\hat{i}+\hat{k}\right)$

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



(a) $m_A v_A < m_B v_B$ (b) $m_A v_A > m_B v_B$
(c) $m_A < m_B$ and $v_A < v_B$ (d) $m_A = m_B$ and $v_A = v_B$

12. A coil having N turns is wound tightly in the form of a spiral with inner and outer radii a and b respectively. When a current I passes through the coil, the magnetic field at the center is *(2001S)*
(a) $\frac{\mu_o NI}{b}$ (b) $\frac{2\mu_o NI}{a}$
(c) $\frac{\mu_o NI}{2(b-a)}\ln\frac{b}{a}$ (d) $\frac{\mu_0 IN}{2(b-a)}\ln\frac{a}{b}$

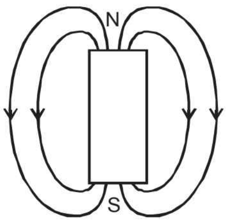
13. A particle of mass m and charge q moves with a constant velocity v along the positive x-direction. It enters a region containing a uniform magnetic field B directed along the negative z-direction, extending from $x = a$ to $x = b$. The minimum value of v required so that the particle can just enter the region $x > b$ is *(2002S)*
(a) $\frac{qbB}{m}$ (b) $\frac{q(b-a)B}{m}$
(c) $\frac{qaB}{m}$ (d) $\frac{q(b+a)B}{2m}$

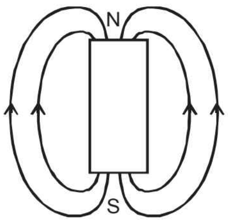
14. A long straight wire along the Z-axis carries a current I in the negative Z-direction. The magnetic vector field $\vec{B}$ at a point having coordinates (x, y) in the $Z = 0$ plane is *(2002S)*

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

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

15. The magnetic field lines due to a bar magnet are correctly shown in *(2002S)*

(a)


(b)


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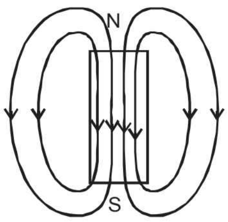
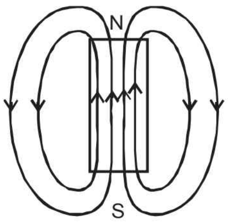
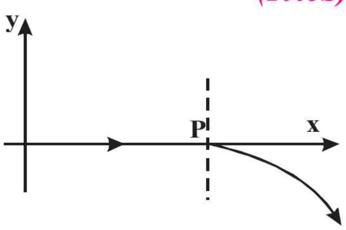


(d)


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



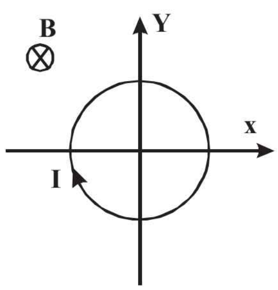
(a) $\vec{E} = 0; \vec{B} = b\hat{i} + c\hat{k}$

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

(c) $\vec{E} = 0; \vec{B} = c\hat{j} + b\hat{k}$

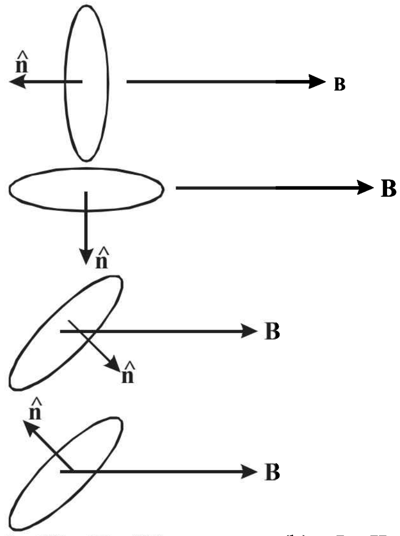
(d) $\vec{E} = a\hat{i}; \vec{B} = c\hat{k} + b\hat{j}$

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



(a) contract (b) expand
(c) move towards +ve x-axis (d) move towards -ve x-axis.

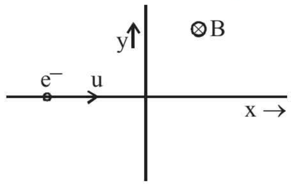
18. A current carrying loop is placed in a uniform magnetic field in four different orientations, I, II, III & IV arrange them in the decreasing order of Potential Energy *(2003S)*

I.
II.
III
IV


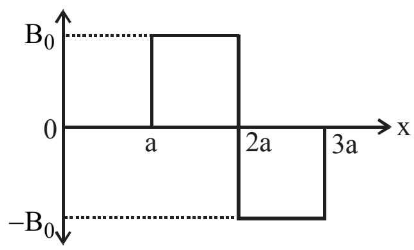
(a) I > III > II > IV (b) I > II > III > IV
(c) I > IV > II > III (d) III > IV > I > II

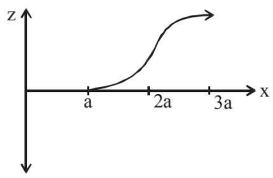
19. An electron travelling with a speed u along the positive x-axis enters into a region of magnetic field where $B = -B_0\hat{k}$ $(x > 0)$. It comes out of the region with speed v then *(2004S)*

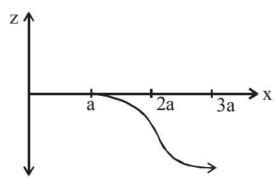
(a) $v = u$ at $y > 0$
(b) $v = u$ at $y < 0$
(c) $v > u$ at $y > 0$
(d) $v > u$ at $y < 0$

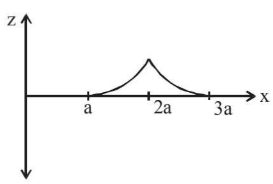


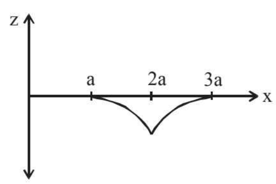
20. A magnetic field $\vec{B} = B_0\hat{J}$, exists in the region $a < x < 2a$, and $\vec{B} = -B_0\hat{j}$, in the region $2a < x < 3a$, where B_0 is a positive constant. A positive point charge moving with a velocity $\vec{v} = v_0\hat{i}$, where v_0 is a positive constant, enters the magnetic field at $x = a$. The trajectory of the charge in this region can be like *(2007)*



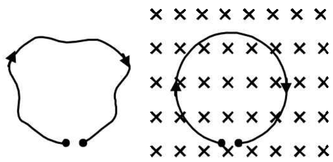
(a)


(b)


(c)


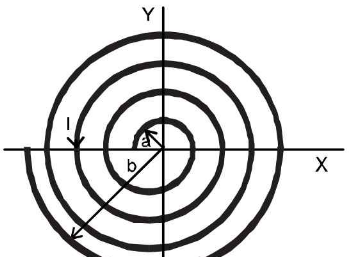
(d)


21. A thin flexible wire of length L is connected to two adjacent fixed points and carries a current I in the clockwise direction, as shown in the figure. When the system is put in a uniform magnetic field of strength B going into the plane of the paper, the wire takes the shape of a circle. The tension in the wire is *(2010)*



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

22. A long insulated copper wire is closely wound as a spiral of 'N' turns. The spiral has inner radius 'a' and outer radius 'b'. The spiral lies in the XY plane and a steady current 'I' flows through the wire. The Z-component of the magnetic field at the centre of the spiral is *(2011)*



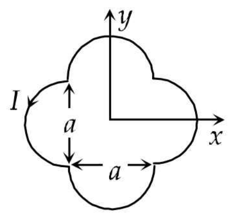
(a) $\frac{\mu_0 NI}{2(b-a)} \ell n\left(\frac{b}{a}\right)$

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

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

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

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



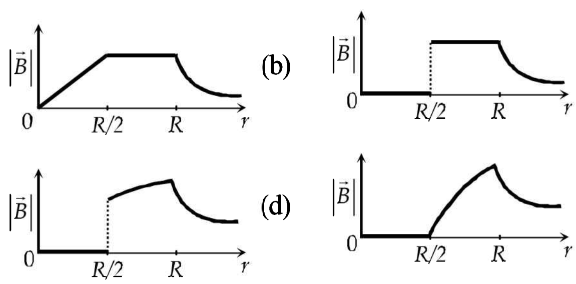
(a) $a^2 I \hat{k}$

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

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

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

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



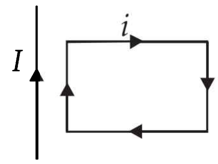
D MCQs with One or More than One Correct

1. A magnetic needle is kept in a non uniform magnetic field. It experiences *(1982 - 3 Marks)*
(a) a force and a torque
(b) a force but not a torque
(c) a torque but not a force
(d) neither a force nor a torque

2. A proton moving with a constant velocity passes through a region of space without any change in its velocity. If E and B represent the electric and magnetic fields respectively, this region of space may have : *(1985 - 2 Marks)*

(a) $E=0, B=0$ (b) $E=0, B\neq 0$
(c) $E\neq 0, B=0$ (d) $E\neq 0, B\neq 0$

3. A rectangular loop carrying a current i is situated near a long straight wire such that the wire is parallel to one of the sides of the loop and is in the plane of the loop. If steady current I is established in the wire as shown in the figure, the loop will : *(1985 - 2 Marks)*



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

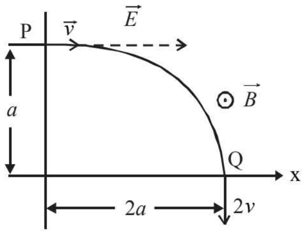
4. Two thin long parallel wires seperated by a distance 'b' are carrying a current 'i' amp each. The magnitude of the force per unit lenght exerted by one wire on the other is *(1986 - 2 Marks)*

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

5. Two particles X and Y having equal charges, after being accelerated through the same potential difference, enter a region of uniform magnetic field and describe circular paths of radii R_1 and R_2 respectively. The ratio of the mass of X to that of Y is *(1988 - 2 Marks)*

(a) $(R_1/R_2)^{1/2}$ (b) R_2/R_1
(c) $(R_1/R_2)^2$ (d) R_1/R_2.

6. A particle of charge $+q$ and mass m moving under the influence of a uniform electric field $E\hat{i}$ and uniform magnetic field $B\hat{k}$ follows a trajectory from P to Q as shown in fig. The velocities at P and Q are $v\hat{i}$ and $-2v\hat{j}$. Which of the following statement (s) is/are correct ? *(1991 - 2 Marks)*



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

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

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

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

7. A microameter has a resistance of $100\,\Omega$ and a full scale range of $50\,\mu A$. It can be used as a voltmeter or as a higher range ammeter provided a resistance is added to it. Pick the correct range and resistance combination (s) *(1991 - 2 Marks)*

(a) 50 V range with $10\,k\Omega$ resistance in series

(b) 10 V range with $200\,k\Omega$ resistance in series

(c) 5 mA range with 1Ω resistance in parallel

(d) 10 mA range with 1Ω resistance in parallel

8. A current I flows along the length of an infinitely long, straight, thin-walled pipe. Then *(1993-2 Marks)*

(a) the magnetic field at all points inside the pipe is the same, but not zero.

(b) the magnetic field at any point inside the pipe is zero

(c) the magnetic field is zero only on the axis of the pipe

(d) the magnetic field is different at different points inside the pipe.

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

(a) H^+ will be deflected most

(b) O^{2+} will be deflected most

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

(d) all will be deflected equally

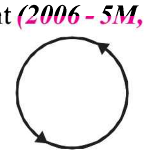
10. Two particles, each of mass m and charge q, are attached to the two ends of a light rigid rod of length $2R$. The rod is rotated at constant angular speed about a pependicular axis passing through its centre. The ratio of the magnitudes of the magnetic moment of the system and its angular momentum about the centre of the rod is *(1998S - 2 Marks)*

(a) $\frac{q}{2m}$ (b) $\frac{q}{m}$ (c) $\frac{2q}{m}$ (d) $\frac{q}{\pi m}$

11. Two very long, straight, parallel wires carry steady currents I & -I respectively. The distance between the wires is d. At a certain instant of time, a point charge q is at a point equidistant from the two wires, in the plane of the wires. Its instantaneous velocity **v** is perpendicular to this plane. The magnitude of the force due to the magnetic field acting on the charge at this instant is *(1998S - 2 Marks)*

(a) $\frac{\mu_0 Iqv}{2\pi d}$ (b) $\frac{\mu_0 Iqv}{\pi d}$ (c) $\frac{2\mu_0 Iqv}{\pi d}$ (d) 0

12. The following field line can never represent *(2006 - 5M, –1)*



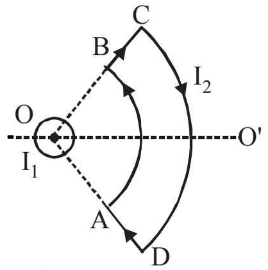
(a) induced electric field

(b) magnetostatic field

(c) gravitational field of a mass at rest

(d) electrostatic field

13. A long current carrying wire, carrying current I_1 such that I_1 is flowing out from the plane of paper is placed at O. A steady state current I_2 is flowing in the loop $ABCD$ *(2006 - 5M, –1)*



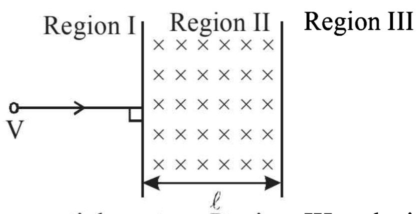
(a) the net force is zero

(b) the net torque is zero

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

(d) as seen from O, the loop will rotate in anticlockwise direction along OO' axis

14. A particle of mass m and charge q, moving with velocity v enters Region II normal to the boundary as shown in the figure. Region II has a uniform magnetic field B perpendicular to the plane of the paper. The length of the Region II is ℓ Choose the correct choice(s). *(2008)*



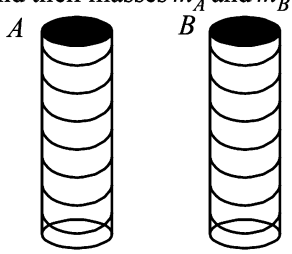
(a) The particle enters Region III only if its velocity $v > \frac{q\ell B}{m}$

(b) The particle enters Region III only if its velocity $v < \frac{q\ell B}{m}$

(c) Path length of the particle in Region II is maximum when velocity $v = \frac{q\ell B}{m}$

(d) Time spent in Region II is same for any velocity v as long as the particle returns to Region I

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



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

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

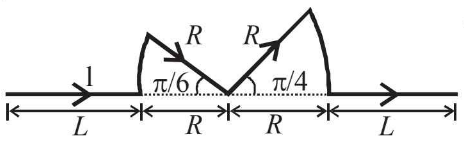
16. An electron and a proton are moving on straight parallel paths with same velocity. They enter a semi infinite region of uniform magnetic field perpendicular to the velocity. Which of the following statement(s) is / are true? ***(2011)***
(a) They will never come out of the magnetic field region.
(b) They will come out travelling along parallel paths.
(c) They will come out at the same time.
(d) They will come out at different times.

17. Consider the motion of a positive point charge in a region where there are simultaneous uniform electric and magnetic fields $\vec{E} = E_0\hat{j}$ and $\vec{B} = B_0\hat{j}$. At time $t = 0$, this charge has velocity $\vec{v}$ in the in the x-y plane, making an angle θ with the x-axis. Which of the following option(s) is (are) correct for time $t > 0$? ***(2012)***
(a) If $\theta = 0°$, the charge moves in a circular path in the x-z plane.
(b) If $\theta = 0°$, the charge undergoes helical motion with constant pitch along the y-axis.
(c) If $\theta = 10°$, the charge undergoes helical motion with its pitch increasing with time, along the y-axis.
(d) If $\theta = 90°$, the charge undergoes linear but accelerated motion along the y-axis.

18. A particle of mass M and positive charge Q, moving with a constant velocity $\vec{u}_1 = 4\hat{i}\ \text{ms}^{-1}$, enters a region of uniform static magnetic field, normal to the x-y plane. The region of the magnetic field extends from $x = 0$ to $x = L$ for all values of y. After passing through this region, the particle emerges on the other side after 10 milliseconds with a velocity $\vec{u}_2 = 2(\sqrt{3}\hat{i} + \hat{j})\ \text{ms}^{-1}$. The correct statement(s) is (are) ***(JEE Adv. 2013)***
(a) The direction of the magnetic field is $-z$ direction
(b) The direction of the magnetic field is $+z$ direction
(c) The magnitude of the magnetic field $\frac{50\pi M}{3Q}$ units
(d) The magnitude of the magnetic field is $\frac{100\pi M}{3Q}$ units

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

20. A conductor (shown in the figure) carrying constant current I is kept in the x-y plane in a uniform magnetic field $\vec{B}$. If F is the magnitude of the total magnetic force acting on the conductor, then the correct statement(s) is(are) ***(JEE Adv. 2015)***



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

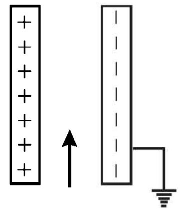
21. Consider two identical galvanometers and two identical resistors with resistance R. If the internal resistance of the galvanometers $R_C < R/2$, which of the following statement(s) about any one of the galvanometers is (are) true? ***(JEE Adv. 2016)***
(a) The maximum voltage range is obtained when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

E Subjective Problems

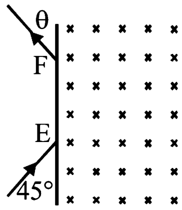
1. A bar magnet with poles 25 cm apart and of strength 14.4 amp-m rests with centre on a frictionless pivot. It is held in equilibrium at an angle of 60° with respect to a uniform magnetic field of induction 0.25 Wb/m^2, by applying a force F at right angles to its axis at a point 12 cm from pivot. Calculate F. What will happen if the force F is removed? ***(1978)***

2. A bar magnet is placed with its north pole pointing north and its south pole pointing south. Draw a figure to show the location of neutral points. ***(1979)***

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



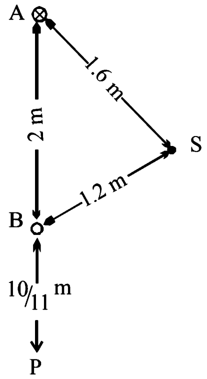
4. A particle of mass $m = 1.6 \times 10^{-27}$ kg and charge $q = 1.6 \times 10^{-19}$ C enters a region of uniform magnetic field of strength 1 tesla along the direction shown in fig. The speed of the particle is 10^7 m/s. (i) The magnetic field is directed along the inward normal to the plane of the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



(1984- 8 Marks)

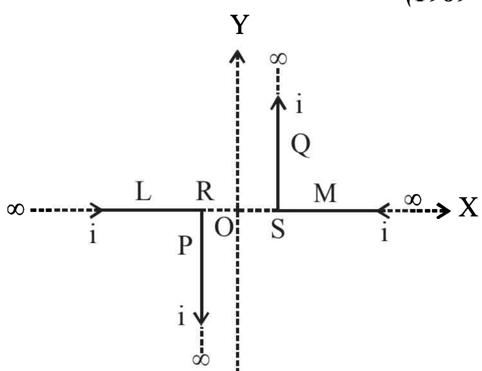
5. A beam of protons with a velocity 4×10^5 m/sec enters a uniform magnetic field of 0.3 tesla at an angle of 60° to the magnetic field. Find the radius of the helical path taken by the proton beam. Also find the pitch of the helix (which is the distance travelled by a proton in the beam parallel to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

6. Two long straight parallel wires are 2 metres apart, perpendicular to the plane of the paper (see figure). The wire *A* carries a current of 9.6 amps, directed into the plane of the paper. The wire *B* carries a current such that the magnetic field of induction at the point *P*, at a distance of $\frac{10}{11}$ metre from the wire *B*, is zero.

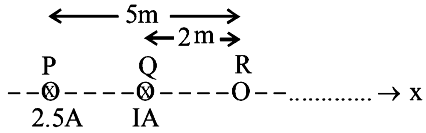


Find : *(1987 - 7 Marks)*
(i) The magnitude and direction of the current in *B*.
(ii) The magnitude of the magnetic field of induction at the point *S*.
(iii) The force per unit length on the wire *B*.

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

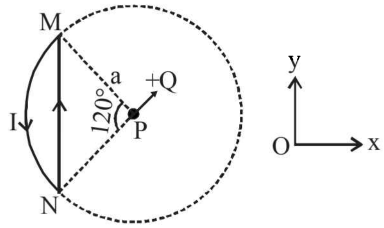


8. Two long parallel wires carrying current 2.5 amperes and I ampere in the same direction (directed into the plane of the paper) are held at *P* and *Q* respectively such that they are perpendicular to the plane of paper. The points *P* and *Q* are located at a distance of 5 metres and 2 metres respectively from a collinear point R (see figure) *(1990 - 8 Marks)*



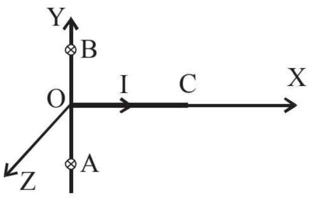
(i) An electron moving with a velocity of 4×10^5 m/s along the positive x - direction experiences a force of magnitude 3.2×10^{-20} N at the point *R*. Find the value of I.
(ii) Find all the positions at which a third long parallel wire carrying a current of magnitude 2.5 amperes may be placed so that the magnetic induction at *R* is zero.

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



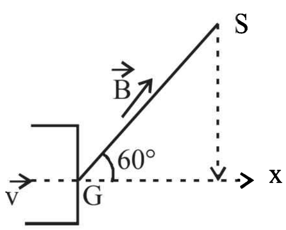
(a) If a particle with charge +*Q* and mass m is placed at the centre P and given a velocity $\vec{v}$ along *NP* (see figure), find its instantaneous acceleration.
(b) If an external uniform magnetic induction field $\vec{B} = B\hat{i}$ is applied, find the force and the torque acting on the loop due to this field.

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



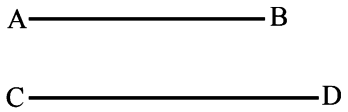
If the wires *A* and *B* each carry a current *I* amp into the plane of the paper, obtain the expression for the force acting on the segment *OC*. What will be the force on *OC* if the current in the wire *B* is reversed ? *(1992 - 10 Marks)*

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



(1993-7 Marks)

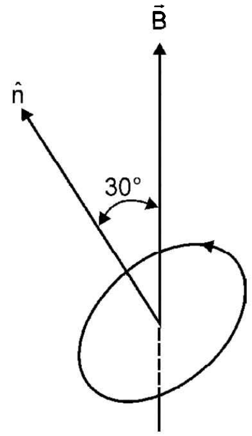
12. A long horizontal wire AB, which is free to move in a vertical plane and carries a steady current of $20A$, is in equilibrium at a height of 0.01 m over another parallel long wire CD which is fixed in a horizontal plane and carries a steady current of $30A$, as shown in figure . Show that when AB is slightly depressed, it executes simple harmonic motion. Find the period of oscillations. ***(1994 - 6 Marks)***



13. An electron in the ground state of hydrogen atom is revolving in anticlock-wise direction in a circular orbit of radius R. ***(1996 - 5 Marks)***

(i) Obtain an expression for the orbital magnetic dipole moment of the electron.

(ii) The atom is placed in a uniform magnetic induction $\vec{B}$ such that the plane-normal of the electron-orbit makes an angle of 30° with the magnetic induction. Find the torque experienced by the orbiting electron.

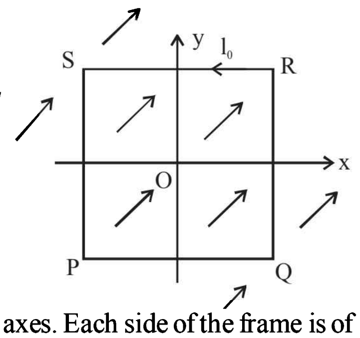


14. Three infinitely long thin wires, each carrying current i in the same direction, are in the x-y plane of a gravity free space. The central wire is along the y-axis while the other two are along $x = \pm d$.

(i) Find the locus of the points for which the magnetic field B is zero. ***(1997 - 5 Marks)***

(ii) If the central wire is displaced along the Z-direction by a small amount and released, show that it will execute simple harmonic motion. If the linear density of the wires is λ, find the frequency of oscillation.

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



(a) What is the torque τ about O acting on the frame due to the magnetic field?

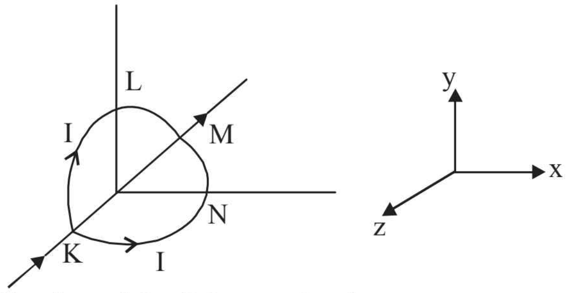
(b) Find the angle by which the frame rotates under the action of this torque in a short interval of time Δt, and the axis about this rotation occurs. (Δt is so short that any variation in the torque during this interval may be neglected.) Given : the moment of inertia of the frame about an axis through its centre perpendicular to its plane is $\frac{4}{3}ML^2$. ***(1998 - 8 Marks)***

16. The region between $x = 0$ and $x = L$ is filled with uniform, steady magnetic field $B_0\hat{k}$. A particle of mass m, positive charge q and velocity $v_0\hat{i}$ travels along x-axis and enters the region of the magnetic field. Neglect gravity throughout the question. ***(1999 - 10 Marks)***

(a) Find the value of L if the particle emerges from the region of magnetic field with its final velocity at angle 30° to its initial velocity.

(b) Find the final velocity of the particle and the time spent by it in the magnetic field, if the magnetic field now extends up to $2.1L$.

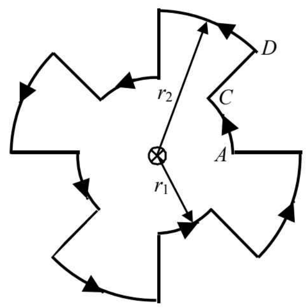
17. A circular loop of radius R is bent along a diameter and given a shape as shown in the figure. One of the semicircles (KNM) lies in the x-z plane and the other one (KLM) in the y-z plane with their centres at the origin. Current I is flowing through each of the semi circles as shown in figure.



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

(b) If an external uniform magnetic field $B_o\hat{j}$ is applied, determine the force $\vec{F_1}$ and $\vec{F_2}$ on the semicircles KLM and KNM due to the field and the net force $\vec{F}$ on the loop. ***(2000 - 10 Marks)***

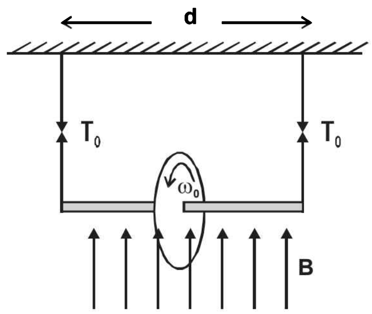
18. A current of 10 A flows around a closed path in a circuit which is in the horizontal plane as shown in the figure. The circuit consists of eight alternating arcs of radii $r_1 = 0.08$ m and $r_1 = 0.12$ m. Each arc subtends the same angle at the center.



(a) Find the magnetic field produced by this circuit at the center. ***(2001-10 Marks)***

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

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



20. A proton and an α-particle are accelerated with same potential difference and they enter in the region of constant magnetic field B perpendicular to the velocity of particles. Find the ratio of radius of curvature of proton to the radius of curvature of α - particle. *(2004 - 2 Marks)*

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

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

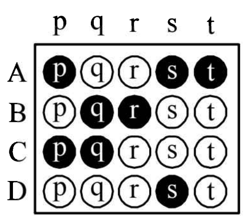
(b) the torsion constant of the spring, if a current i_0 produces a deflection of $\pi/2$ in the coil.

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

F Match the Following

DIRECTIONS (Qs. 1-3) : *Each question contains statements given in two columns, which have to be matched. The statements in Column-I are labelled A, B, C and D, while the statements in Column-II are labelled p, q, r and s. Any given statement in Column-I can have correct matching with ONE OR MORE statement(s) in Column-II. The appropriate bubbles corresponding to the answers to these questions have to be darkened as illustrated in the following example :*

If the correct matches are A-p, s and t; B-q and r; C-p and q; and D-s then the correct darkening of bubbles will look like the given.



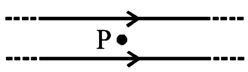
1. Match the following columns : *(2006, 6M)*

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

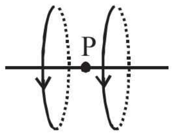
2. Column I gives certain situations in which a straight metallic wire of resistance R is used and Column II gives some resulting effects. Match the statements in Column I with the statements in Column II and indicate your answer by darkening appropriate bubbles in the 4 × 4 matrix given in the ORS.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

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

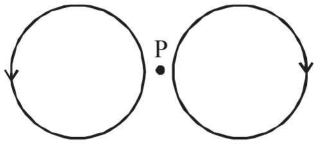
3. Two wires each carrying a steady current I are shown in four configurations in Column I. Some of the resulting effects are described in Column II. Match the statements in Column I with the statements in column II and indicate your answer by darkening appropriate bubbles in the 4 × 4 matrix given in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

Column I	Column II
(A) Point P is situated midway between the wires. 	(p) The magnetic fields (B) at P due to the currents in the wires are in the same direction.

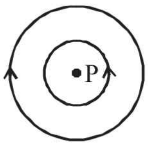
(B) Point P is situated at the mid-point of the line joining the centers of the circular wires, which have same radii.



(C) Point P is situated at the mid-point of the line joining the centers of the circular wires, which have same radii.



(D) Point P is situated at the common center of the wires.



(q) The magnetic fields (B) at P due to the currents in the wires are in opposite directions.

(r) There is no magnetic field at P.

(s) The wires repel each other.

G Comprehension Based Questions

PASSAGE-1

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

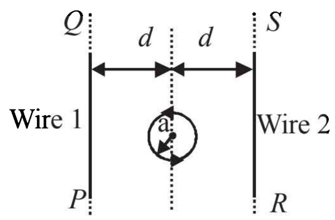
Instead of using a engine based on fossil fuels, they make use of magnetic field forces. The magnetized coils are arranged in the guide way which repels the strong magnets placed in the train's under carriage. This helps train move over the guideway, a technic called electro-dynamic suspension. When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

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

1. The levitation of the train is due to *(2006 - 5M, –2)*
   (a) Mechanical force (b) Electrostatic attraction
   (c) Electrostatic repulsion (d) Magnetic repulsion
2. The disadvantage of maglev trains is that *(2006 - 5M, –2)*
   (a) More friction (b) Less pollution
   (c) Less wear & tear (d) High initial cost
3. The force which makes maglev move *(2006 - 5M, –2)*
   (a) Gravitational field (b) Magnetic field
   (c) Nuclear forces (d) Air drag

PASSAGE-2

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

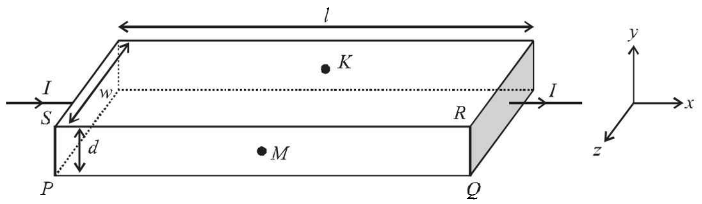


4. When $d \approx a$ but wires are not touching the loop, it is found that the net magnetic field on the axis of the loop is zero at a height h above the loop. In that case *(JEE Adv. 2014)*
   (a) current in wire 1 and wire 2 in the direction PQ and RS, respectively and $h \approx a$
   (b) current in wire 1 and wire 2 in the direction PQ and SR, respectively and $h \approx a$
   (c) current in wire 1 and wire 2 in the direction PQ and SR, respectively and $h \approx 1.2a$
   (d) current in wire 1 and wire 2 in the direction PQ and RS, respectively and $h \approx 1.2a$
5. Consider $d >> a$, and the loop is rotated about its diameter parallel to the wires by 30° from the position shown in the figure. If the currents in the wires are in the opposite directions, the torque on the loop at its new position will be (assume that the net field due to the wires is constant over the loop). *(JEE Adv. 2014)*
   (a) $\frac{\mu_0 I^2 a^2}{d}$ (b) $\frac{\mu_0 I^2 a^2}{2d}$
   (c) $\frac{\sqrt{3}\mu_0 I^2 a^2}{d}$ (d) $\frac{\sqrt{3}\mu_0 I^2 a^2}{2d}$

PASSAGE-3

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

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



6. Consider two different metallic strips (1 and 2) of the same material. Their lengths are the same, widths are w_1 and w_2 and thicknesses are d_1 and d_2 respectively. Two points K and *M* are symmetrically located on the opposite faces parallel to the x-y plane (see figure). V_1 and V_2 are the potential differences between *K* and *M* in strips 1 and 2, respectively. Then, for a given current I flowing through them in a given magnetic field strength B, the correct statement(s) is(are) ***(JEE Adv. 2015)***
   (a) If $w_1 = w_2$ and $d_1 = 2d_2$, then $V_2 = 2V_1$
   (b) If $w_1 = w_2$ and $d_1 = 2d_2$, then $V_2 = V_1$
   (c) If $w_1 = 2w_2$ and $d_1 = d_2$, then $V_2 = 2V_1$
   (d) If $w_1 = 2w_2$ and $d_1 = d_2$, then $V_2 = V_1$

7. Consider two different metallic strips (1 and 2) of same dimensions (length *l*, width *w* and thickness *d*) with carrier densities n_1 and n_2, respectively. Strip 1 is placed in magnetic field B_1 and strip 2 is placed in magnetic field B_2, both along positive y-directions. Then V_1 and V_2 are the potential differences developed between *K* and *M* in strips 1 and 2, respectively. Assuming that the current *I* is the same for both the strips, the correct option(s) is(are) ***(JEE Adv. 2015)***
   (a) If $B_1 = B_2$ and $n_1 = 2n_2$, then $V_2 = 2V_1$
   (b) If $B_1 = B_2$ and $n_1 = 2n_2$, then $V_2 = V_1$
   (c) If $B_1 = 2B_2$ and $n_1 = n_2$, then $V_2 = 0.5V_1$
   (d) If $B_1 = 2B_2$ and $n_1 = n_2$, then $V_2 = V_1$

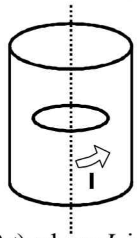
H Assertion & Reason Type Questions

1. **Statement-1 :** The sensitivity of a moving coil galvanometer is increased by placing a suitable magnetic material as a core inside the coil.
   and
   Statement-2 : Soft iron has a high magnetic permeability and cannot be easily magnetized or demagnetized. ***(2008)***
   (a) **Statement**-1 is True, **Statement**-2 is True; **Statement**-2 is a correct explanation for **Statement**-1
   (b) **Statement**-1 is True, **Statement**-2 is True; **Statement**-2 is NOT a correct explanation for **Statement**-1
   (c) **Statement** -1 is True, **Statement**-2 is False
   (d) **Statement** -1 is False, **Statement**-2 is True

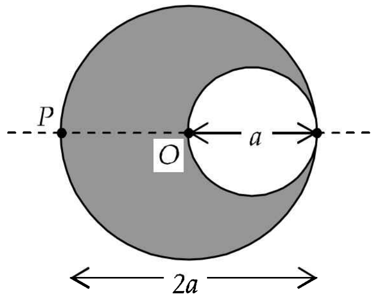
I Integer Value Correct Type

1. A steady current *I* goes through a wire loop PQR having shape of a right angle triangle with PQ = 3x, PR = 4x and QR = 5x. If the magnitude of the magnetic field at P due to this loop is $k\left(\frac{\mu_0 I}{48\pi x}\right)$, find the value of *k*. ***(2009)***

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



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



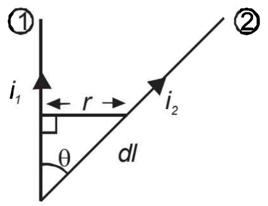
4. Two parallel wires in the plane of the paper are distance X_0 apart. *A* point charge is moving with speed *u* between the wires in the same plane at a distance X_1 from one of the wires. When the wires carry current of magnitude *I* in the same direction, the radius of curvature of the path of the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

Section-B JEE Main / AIEEE

1. If in a circular coil A of radius R, current I is flowing and in another coil B of radius $2R$ a current $2I$ is flowing, then the ratio of the magnetic fields B_A and B_B, produced by them will be **[2002]**
(a) 1 (b) 2 (c) 1/2 (d) 4

2. If an electron and a proton having same momenta enter perpendicular to a magnetic field, then **[2002]**
(a) curved path of electron and proton will be same (ignoring the sense of revolution)
(b) they will move undeflected
(c) curved path of electron is more curved than that of the proton
(d) path of proton is more curved.

3. Wires 1 and 2 carrying currents i_1 and i_2 respectively are inclined at an angle θ to each other. What is the force on a small element dl of wire 2 at a distance of r from wire 1 (as shown in figure) due to the magnetic field of wire 1? **[2002]**



(a) $\frac{\mu_0}{2\pi r} i_1 i_2\, dl \tan\theta$ (b) $\frac{\mu_0}{2\pi r} i_1 i_2\, dl \sin\theta$

(c) $\frac{\mu_0}{2\pi r} i_1 i_2\, dl \cos\theta$ (d) $\frac{\mu_0}{4\pi r} i_1 i_2\, dl \sin\theta$

4. The time period of a charged particle undergoing a circular motion in a uniform magnetic field is independent of its
(a) speed (b) mass **[2002]**
(c) charge (d) magnetic induction

5. A particle of mass M and charge Q moving with velocity $\vec{v}$ describe a circular path of radius R when subjected to a uniform transverse magnetic field of induction B. The work done by the field when the particle completes one full circle is **[2003]**

(a) $\left(\frac{Mv^2}{R}\right)2\pi R$ (b) zero

(c) $BQ2\pi R$ (d) $BQv2\pi R$

6. A particle of charge -16×10^{-18} coulomb moving with velocity 10ms^{-1} along the x-axis enters a region where a magnetic field of induction B is along the y-axis, and an electric field of magnitude 10^4 V/m is along the negative z-axis. If the charged particle continues moving along the x-axis, the magnitude of B is **[2003]**
(a) $10^3 Wb/m^2$ (b) $10^5 Wb/m^2$
(c) $10^{16} Wb/m^2$ (d) $10^{-3} Wb/m^2$

7. A thin rectangular magnet suspended freely has a period of oscillation equal to T. Now it is broken into two equal halves (each having half of the original length) and one piece is made to oscillate freely in the same field. If its period of oscillation is T', the ratio $\frac{T'}{T}$ is **[2003]**

(a) $\frac{1}{2\sqrt{2}}$ (b) $\frac{1}{2}$ (c) 2 (d) $\frac{1}{4}$

8. A magnetic needle lying parallel to a magnetic field requiers W units of work to turn it through 60^0. The torque needed to maintain the needle in this position will be **[2003]**

(a) $\sqrt{3}$W (b) W (c) $\frac{\sqrt{3}}{2}$W (d) 2W

9. The magnetic lines of force inside a bar magnet **[2003]**
(a) are from north-pole to south-pole of the magnet
(b) do not exist
(c) depend upon the area of cross-section of the bar magnet
(d) are from south-pole to north-pole of the Magnet

10. Curie temperature is the temperature above which **[2003]**
(a) a ferromagnetic material becomes paramagnetic
(b) a paramagnetic material becomes diamagnetic
(c) a ferromagnetic material becomes diamagnetic
(d) a paramagnetic material becomes ferromagnetic

11. A current i ampere flows along an infinitely long straight thin walled tube, then the magnetic induction at any point inside the tube is **[2004]**

(a) $\frac{\mu_0}{4\pi}.\frac{2i}{r}$ tesla (b) zero

(c) infinite (d) $\frac{2i}{r}$ tesla

12. A long wire carries a steady current. It is bent into a circle of one turn and the magnetic field at the centre of the coil is B. It is then bent into a circular loop of n turns. The magnetic field at the centre of the coil will be **[2004]**
(a) $2nB$ (b) $n^2 B$ (c) nB (d) $2n^2 B$

13. The magnetic field due to a current carrying circular loop of radius 3 cm at a point on the axis at a distance of 4 cm from the centre is 54 μT. What will be its value at the centre of loop? **[2004]**
(a) 125 μT (b) 150 μT (c) 250 μT (d) 75 μT

14. Two long conductors, separated by a distance d carry current I_1 and I_2 in the same direction. They exert a force F on each other. Now the current in one of them is increased to two times and its direction is reversed. The distance is also increased to $3d$. The new value of the force between them is **[2004]**

(a) $-\frac{2F}{3}$ (b) $\frac{F}{3}$ (c) $-2F$ (d) $-\frac{F}{3}$

15. The length of a magnet is large compared to its width and breadth. The time period of its oscillation in a vibration magnetometer is 2s. The magnet is cut along its length into three equal parts and these parts are then placed on each other with their like poles together. The time period of this combination will be [2004]

(a) $2\sqrt{3}$ s (b) $\frac{2}{3}$s (c) 2 s (d) $\frac{2}{\sqrt{3}}$s

16. The materials suitable for making electromagnets should have [2004]
(a) high retentivity and low coercivity
(b) low retentivity and low coercivity
(c) high retentivity and high coercivity
(d) low retentivity and high coercivity

17. Two concentric coils each of radius equal to 2 π cm are placed at right angles to each other. 3 ampere and 4 ampere are the currents flowing in each coil respectively. The magnetic induction in $Weber/m^2$ at the centre of the coils will be $\left(\mu_0 = 4\pi \times 10^{-7} Wb/A.m\right)$ [2005]

(a) 10^{-5} (b) 12×10^{-5} (c) 7×10^{-5} (d) 5×10^{-5}

18. A charged particle of mass *m* and charge *q* travels on a circular path of radius *r* that is perpendicular to a magnetic field *B*. The time taken by the particle to complete one revolution is [2005]

(a) $\frac{2\pi q^2 B}{m}$ (b) $\frac{2\pi mq}{B}$ (c) $\frac{2\pi m}{qB}$ (d) $\frac{2\pi qB}{m}$

19. A magnetic needle is kept in a non-uniform magnetic field. It experiences [2005]
(a) neither a force nor a torque
(b) a torque but not a force
(c) a force but not a torque
(d) a force and a torque

20. A uniform electric field and a uniform magnetic field are acting along the same direction in a certain region. If an electron is projected along the direction of the fields with a certain velocity then [2005]
(a) its velocity will increase
(b) Its velocity will decrease
(c) it will turn towards left of direction of motion
(d) it will turn towards right of direction of motion

21. Needles N_1, N_2 and N_3 are made of a ferromagnetic, a paramagnetic and a diamagnetic substance respectively. A magnet when brought close to them will [2006]
(a) attract N_1 and N_2 strongly but repel N_3
(b) attract N_1 strongly, N_2 weakly and repel N_3 weakly
(c) attract N_1 strongly, but repel N_2 and N_3 weakly
(d) attract all three of them

22. In a region, steady and uniform electric and magnetic fields are present. These two fields are parallel to each other. A charged particle is released from rest in this region. The path of the particle will be a [2006]
(a) helix (b) straight line
(c) ellipse (d) circle

23. A long solenoid has 200 turns per cm and carries a current *i*. The magnetic field at its centre is 6.28 × 10^{-2} Weber/m². Another long solenoid has 100 turns per cm and it carries a current $\frac{i}{3}$. The value of the magnetic field at its centre is [2006]
(a) 1.05 × 10^{-2} Weber/m² (b) 1.05 × 10^{-5} Weber/m²
(c) 1.05 × 10^{-3} Weber/m² (d) 1.05 × 10^{-4} Weber/m²

24. A long straight wire of radius *a* carries a steady current *i*. The current is uniformly distributed across its cross section. The ratio of the magnetic field at *a*/2 and 2*a* is [2007]
(a) 1/2 (b) 1/4 (c) 4 (d) 1

25. A current *I* flows along the length of an infinitely long, straight, thin walled pipe. Then [2007]
(a) the magnetic field at all points inside the pipe is the same, but not zero
(b) the magnetic field is zero only on the axis of the pipe
(c) the magnetic field is different at different points inside the pipe
(d) the magnetic field at any point inside the pipe is zero

26. A charged particle with charge *q* enters a region of constant, uniform and mutually orthogonal fields $\vec{E}$ and $\vec{B}$ with a velocity $\vec{v}$ perpendicular to both $\vec{E}$ and $\vec{B}$, and comes out without any change in magnitude or direction of $\vec{v}$. Then [2007]
(a) $\vec{v} = \vec{B}\times\vec{E}/E^2$ (b) $\vec{v} = \vec{E}\times\vec{B}/B^2$
(c) $\vec{v} = \vec{B}\times\vec{E}/B^2$ (d) $\vec{v} = \vec{E}\times\vec{B}/E^2$

27. A charged particle moves through a magnetic field perpendicular to its direction. Then [2007]
(a) kinetic energy changes but the momentum is constant
(b) the momentum changes but the kinetic energy is constant
(c) both momentum and kinetic energy of the particle are not constant
(d) both momentum and kinetic energy of the particle are constant

28. Two identical conducting wires *AOB* and *COD* are placed at right angles to each other. The wire *AOB* carries an electric current I_1 and *COD* carries a current I_2. The magnetic field on a point lying at a distance d from *O*, in a direction perpendicular to the plane of the wires *AOB* and *COD*, will be given by [2007]

(a) $\frac{\mu_0}{2\pi d}(I_1^2 + I_2^2)$ (b) $\frac{\mu_0}{2\pi}\left(\frac{I_1+I_2}{d}\right)^{\frac{1}{2}}$

(c) $\frac{\mu_0}{2\pi d}\left(I_1^2 + I_2^2\right)^{\frac{1}{2}}$ (d) $\frac{\mu_0}{2\pi d}(I_1 + I_2)$

29. A horizontal overhead powerline is at height of 4m from the ground and carries a current of 100A from east to west. The magnetic field directly below it on the ground is ($\mu_0 = 4\pi\times10^{-7}$ Tm A^{-1}) [2008]
(a) 2.5 × 10^{-7} *T* southward
(b) 5 × 10^{-6} *T* northward
(c) 5 × 10^{-6} *T* southward
(d) 2.5 × 10^{-7} *T* northward

30. Relative permittivity and permeability of a material ε_r and μ_r, respectively. Which of the following values of these quantities are allowed for a diamagnetic material? **[2008]**

(a) $\varepsilon_r = 0.5, \mu_r = 1.5$ (b) $\varepsilon_r = 1.5, \mu_r = 0.5$

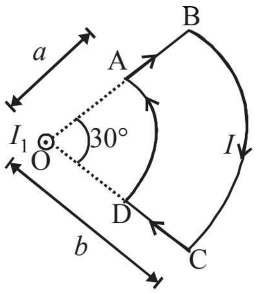
(c) $\varepsilon_r = 0.5, \mu_r = 0.5$ (d) $\varepsilon_r = 1.5, \mu_r = 1.5$

DIRECTIONS : *Question numbers 31 and 32 are based on the following paragraph.*

PASSAGE

A current loop *ABCD* is held fixed on the plane of the paper as shown in the figure. The arcs *BC* (radius = *b*) and *DA* (radius = *a*) of the loop are joined by two straight wires *AB* and *CD*. A steady current *I* is flowing in the loop. Angle made by *AB* and *CD* at the origin *O* is 30°. Another straight thin wire with steady current I_1 flowing out of the plane of the paper is kept at the origin.

|2009|



31. The magnitude of the magnetic field (*B*) due to the loop *ABCD* at the origin (*O*) is :

(a) $\frac{\mu_o I(b-a)}{24ab}$ (b) $\frac{\mu_o I}{4\pi}\left[\frac{b-a}{ab}\right]$

(c) $\frac{\mu_o I}{4\pi}[2(b-a)+\pi/3\,(a+b)]$ (d) zero

32. Due to the presence of the current I_1 at the origin:

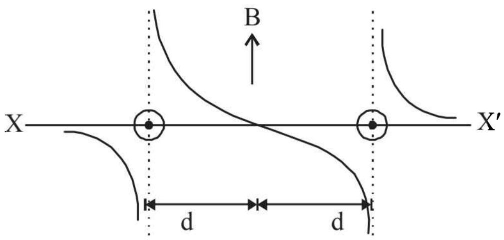
(a) The forces on *AD* and *BC* are zero.

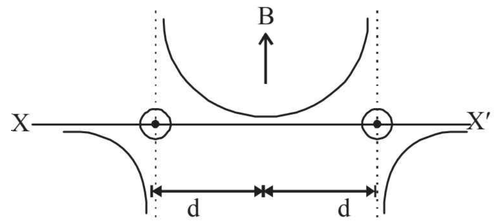
(b) The magnitude of the net force on the loop is given by $\frac{I_1 I}{4\pi}\mu_o[2(b-a)+\pi/3\,(a+b)]$.

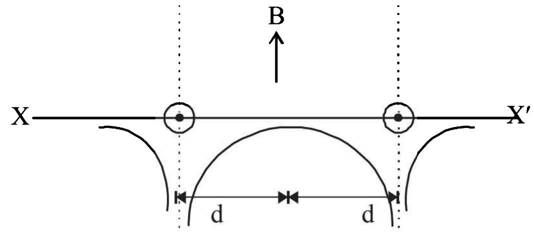
(c) The magnitude of the net force on the loop is given by $\frac{\mu_o I I_1}{24ab}(b-a)$.

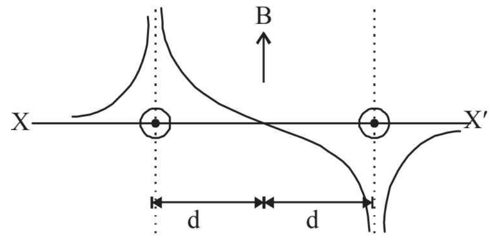
(d) The forces on *AB* and *DC* are zero.

33. Two long parallel wires are at a distance 2d apart. They carry steady equal currents flowing out of the plane of the paper as shown. The variation of the magnetic field B along the line XX' is given by **[2010]**

(a)


(b)


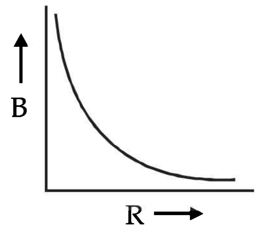
(c)


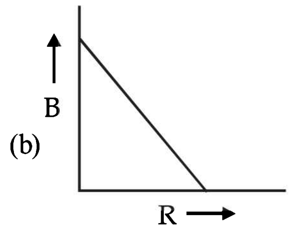
(d)


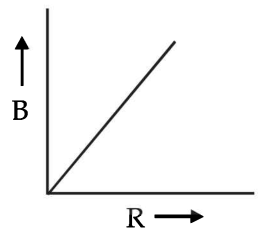
34. A current *I* flows in an infinitely long wire with cross section in the form of a semi-circular ring of radius *R*. The magnitude of the magnetic induction along its axis is: **[2011]**

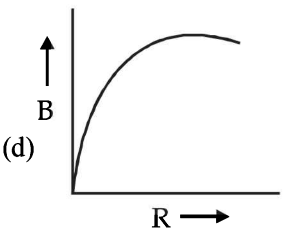
(a) $\frac{\mu_0 I}{2\pi^2 R}$ (b) $\frac{\mu_0 I}{2\pi R}$ (c) $\frac{\mu_0 I}{4\pi R}$ (d) $\frac{\mu_0 I}{\pi^2 R}$

35. A charge *Q* is uniformly distributed over the surface of non-conducting disc of radius *R*. The disc rotates about an axis perpendicular to its plane and passing through its centre with an angular velocity ω. As a result of this rotation a magnetic field of induction B is obtained at the centre of the disc. If we keep both the amount of charge placed on the disc and its angular velocity to be constant and vary the radius of the disc then the variation of the magnetic induction at the centre of the disc will be represented by the figure : **[2012]**

(a)


(b)


(c)


(d)


36. Proton, deuteron and alpha particle of same kinetic energy are moving in circular trajectories in a constant magnetic field. The radii of proton, deuteron and alpha particle are respectively r_p, r_d and r_α. Which one of the following relation is correct? **[2012]**

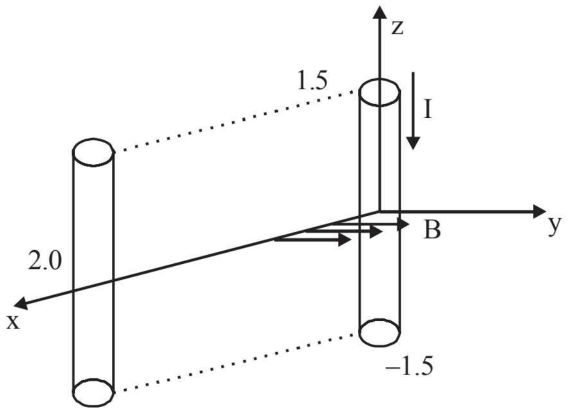
(a) $r_\alpha = r_p = r_d$ (b) $r_\alpha = r_p < r_d$

(c) $r_\alpha > r_d > r_p$ (d) $r_\alpha = r_d > r_p$

37. Two short bar magnets of length 1 cm each have magnetic moments 1.20 Am^2 and 1.00 Am^2 respectively. They are placed on a horizontal table parallel to each other with their N poles pointing towards the South. They have a common magnetic equator and are separated by a distance of 20.0 cm. The value of the resultand horizontal magnetic induction at the mid-point O of the line joining their centres is close to (Horizontal component of earth.s magnetic induction is 3.6× 10.5Wh/m^2) **[JEE Main 2013]**

(a) 3.6 × 10.5 Wh/m^2 (b) 2.56 × 10.4 Wh/m^2
(c) 3.50 × 10.4 Wb/m^2 (d) 5.80 × 10.4 Wh/m^2

38. A conductor lies along the z-axis at $-1.5 \le z < 1.5$ m and carries a fixed current of 10.0 A in $-\hat{a}_z$ direction (see figure). For a field $\vec{B} = 3.0\times10^{-4}e^{-0.2x}\,\hat{a}_y$ T, find the power required to move the conductor at constant speed to x = 2.0 m, y = 0 m in 5×10^{-3} s. Assume parallel motion along the x-axis. **[JEE Main 2014]**



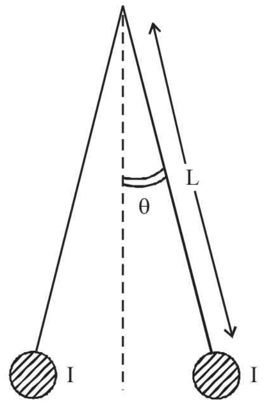
(a) 1.57 W (b) 2.97 W
(c) 14.85 W (d) 29.7 W

39. The coercivity of a small magnet where the ferromagnet gets demagnetized is $3\times10^3\,\text{Am}^{-1}$. The current required to be passed in a solenoid of length 10 cm and number of turns 100, so that the magnet gets demagnetized when inside the solenoid, is: **[JEE Main 2014]**

(a) 30 mA (b) 60 mA
(c) 3 A (d) 6 A

40. Two long current carrying thin wires, both with current I, are held by insulating threads of length L and are in equilibrium as shown in the figure, with threads making an angle 'θ' with the vertical. If wires have mass λ per unit length then the value of I is : **[JEE Main 2015]**

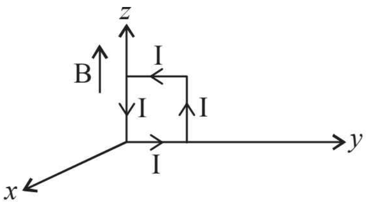
(*g = gravitational acceleration*)

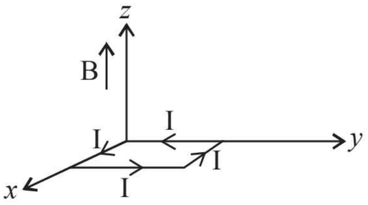


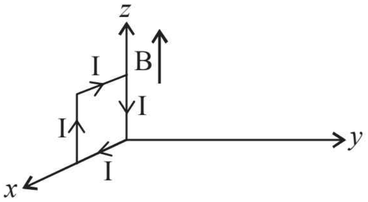
(a) $2\sqrt{\frac{\pi g L}{\mu_0}}\tan\theta$ (b) $\sqrt{\frac{\pi \lambda g L}{\mu_0}}\tan\theta$

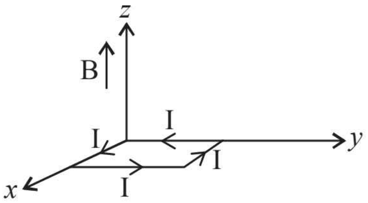
(c) $\sin\theta\sqrt{\frac{\pi \lambda g L}{\mu_0 \cos\theta}}$ (d) $2\sin\theta\sqrt{\frac{\pi \lambda g L}{\mu_0 \cos\theta}}$

41. A rectangular loop of sides 10 cm and 5 cm carrying a current 1 of 12 A is placed in different orientations as shown in the figures below : **[JEE Main 2015]**

(A)


(B)


(C)


(D)


If there is a uniform magnetic field of 0.3 T in the positive z direction, in which orientations the loop would be in (i) stable equilibrium and (ii) unstable equilibrium ? **[JEE Main 2015[**

(a) (B) and (D), respectively
(b) (B) and (C), respectively
(c) (A) and (B), respectively
(d) (A) and (C), respectively

42. Two identical wires A and B, each of length 'l', carry the same current I. Wire A is bent into a circle of radius R and wire B is bent to form a square of side 'a'. If B_A and B_B are the values of magnetic field at the centres of the circle and square respectively, then the ratio $\frac{B_A}{B_B}$ is: **[JEE Main 2016]**

(a) $\frac{\pi^2}{16}$ (b) $\frac{\pi^2}{8\sqrt{2}}$

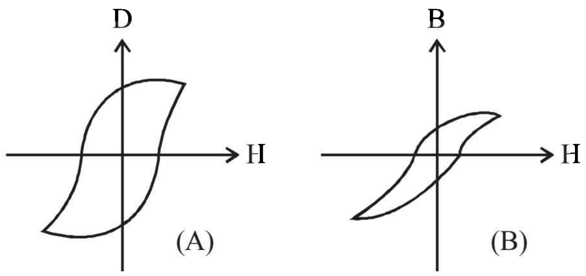
(c) $\frac{\pi^2}{8}$ (d) $\frac{\pi^2}{16\sqrt{2}}$

43. A galvanometer having a coil resistance of 100 Ω gives a full scale deflection, when a currect of 1 mA is passed through it. The value of the resistance, which can convert this galvanometer into ammeter giving a full scale deflection for a current of 10 A, is : **[JEE Main 2016]**

(a) 0.1 Ω (b) 3Ω

(c) 0.01Ω (d) 2Ω

44. Hysteresis loops for two magnetic materials A and B are given below : **[JEE Main 2016]**



These materials are used to make magnets for elecric generators, transformer core and electromagnet core. Then it is proper to use :

(a) A for transformers and B for electric generators.
(b) B for electromagnets and transformers.
(c) A for electric generators and trasformers.
(d) A for electromagnets and B for electric generators.

GP_3481

14 Moving Charges and Magnetism

Section-A : JEE Advanced/ IIT-JEE

A 1. D, B 2. $\frac{iL^2}{4\pi}$ 3. 1.25×10^{-23} Am^2 4. $\frac{\mu_0 I}{4}\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$

5. IlB; +Z direction 6. evB; $ABCD$

B 1. T 2. T 3. F 4. F

C 1. (c) 2. (d) 3. (a) 4. (d) 5. (a) 6. (c) 7. (b)
8. (c) 9. (c) 10. (d) 11. (b) 12. (c) 13. (b) 14. (a)
15. (d) 16. (b) 17. (b) 18. (a) 19. (b) 20. (a) 21. (c)
22. (a) 23. (b) 24. (d)

D 1. (a) 2. (a,b,d) 3. (c) 4. (b) 5. (c) 6. (a,b,d) 7. (b, c)
8. (b) 9. (a, c) 10. (a) 11. (d) 12. (c, d) 13. (a,c) 14. (a, c, d)
15. (b, d) 16. (b, d) 17. (c, d) 18. (a, c) 19. (a, d) 20. (a, b, c) 21. (a,c)

E 1. 25.98N 3. 0.1T, Directed perpendicular to the plane of paper inwards.

4. **(i)** 0.1414 m, 45° **(ii)** 4.71×10^{-8} sec.

5. 0.012m, 0.044m 6. **(i)** 3A, upward direction **(ii)** 1.3×10^{-6} T **(iii)** 28.8×10^{-7} N

7. 10^{-4} tesla; directed towards the reader perpendicular to the plane of paper.

8. **(i)** 4 A. **(ii)** r = 1m where r is the distance from R

9. **(a)** $\frac{0.11\mu_0 IQv}{ma}$ directed 30° with the negative X-axis **(b)** zero, $0.614\, BIa^2\,\hat{j}$

10. $F = \frac{\mu_0}{4\pi} 2I^2 \left[\log_e \frac{a^2 + L^2}{a^2}\right]$ directed toward $-Z$ direction, zero.

11. $4.737 \times 10^{-3}\, T$ 12. 0.2 sec.

13. **(i)** $M = \frac{he}{4\pi m}$ **(ii)** $\frac{heB}{8\pi m}$ directed perpendicular to the plane containing $\hat{n}$ and $\vec{B}$.

14. **(i)** $\pm\frac{d}{\sqrt{3}}$ **(ii)** $n = \frac{i}{2\pi d}\sqrt{\frac{\mu_0}{\pi\lambda}}$ 15. **(a)** $\frac{I_0 L^2 B}{\sqrt{2}}(\hat{j} - \hat{i})$ **(b)** $\frac{3}{4}\frac{I_0 B}{M}\Delta t^2$ 16. **(a)** $L = \frac{mv_0}{2qB}$ **(b)** $-v_0\hat{i}$, $\frac{\pi m}{qB_0}$

17. **(a)** $\left(\frac{-\mu_0 q v_0 I}{4R}\right)\hat{k}$ **(b)** $\vec{F_1} = 2BIR\hat{i}$, $\vec{F_2} = 2BIR\hat{i}$, $4BIR\hat{i}$

18. **(a)** $6.54 \times 10^{-5} T$ **(b)** 0, Force on arc $AC = 0$, 8.1×10^{-6}N

19. $\omega = \frac{DT_0}{BQr^2}$ 20. $\frac{1}{\sqrt{2}}$ 21. **(a)** $k = NAB$ **(b)** $\frac{2Ni_0 AB}{\pi}$ **(c)** $Q\sqrt{\frac{NAB\pi}{2Ii_0}}$

F 1. A-p; B-q, s; C-q, s; D-q, r, s 2. A-q; B-r, s; C-s; D-p, q, r 3. A-q, r; B-p; C-q, r; D-q, s

G 1. (d) 2. (d) 3. (b) 4. (c) 5. (b) 6. (a, d) 7. (a,c)

H 1. (c)

I 1. 7 2. 6 3. 5 4. 3

Section-B : JEE Main/ AIEEE

1. (a) 2. (a) 3. (c) 4. (a) 5. (b) 6. (a) 7. (b)
8. (a) 9. (d) 10. (a) 11. (b) 12. (b) 13. (c) 14. (a)
15. (b) 16. (b) 17. (d) 18. (c) 19. (d) 20. (b) 21. (b)
22. (b) 23. (a) 24. (d) 25. (d) 26. (b) 27. (b) 28. (c)
29. (c) 30. (b) 31. (a) 32. (a) 33. (a) 34. (d) 35. (a)
36. (b) 37. (b) 38. (b) 39. (c) 40. (d) 41. (a) 42. (b)
43. (c) 44. (b)

Section-A JEE Advanced/ IIT-JEE

A. Fill in the Blanks

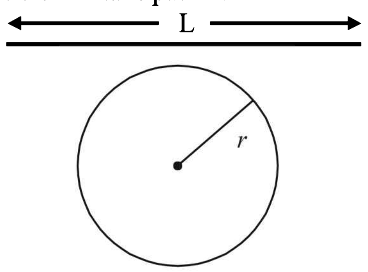
1. According to Fleming's left hand rule, the force on electrons will be towards right (*D*).
Also, by the same rule we find that the force on proton and α-particle is towards left. Now since the magnetic force will behave as centripetal force, therefore

$\therefore \dfrac{mv^2}{r} = qvB$

$\therefore \dfrac{mv}{qB} = r$ or $r \propto \dfrac{m}{q}$

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

∴ radius will be more for α-particle
∴ α-particle will take path *B*.

2. 

Wire of length *L* is bent in the form of a circle. Then the perimeter of the circle

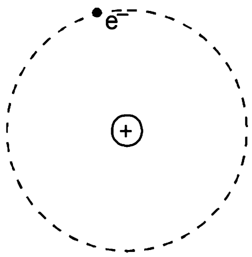
$2\pi r = L \Rightarrow r = \dfrac{L}{2\pi}$

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

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

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

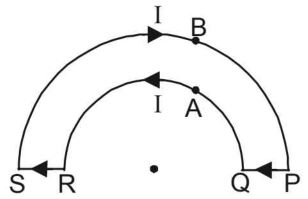
3. $i = \dfrac{q}{t} = \dfrac{ne}{t} = \dfrac{10^{16}}{1} \times 1.6 \times 10^{-19} = 1.6 \times 10^{-3}$ A.
$M = i \times A = i \times \pi r^2$
$= 1.6 \times 10^{-3} \times 3.14 \times 0.5 \times 10^{-10} \times 0.5 \times 10^{-10}$
$= 1.25 \times 10^{-23}$ Am^2



4. The magnetic field at *C* due to current in *PQ* and *RS* is zero. Magnetic field due to current in semi-circular arc *QAR*

$= \dfrac{1}{2}\left[\dfrac{\mu_0}{2}\dfrac{I}{R_1}\right]$

directed towards reader perpendicular to the plane of paper.



Magnetic field due to current in semi-circular arc

$SBP = \dfrac{1}{2}\left[\dfrac{\mu_0}{2}\dfrac{I}{R_2}\right]$

directed away from reader perpendicular to the plane of paper.

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

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

$= \dfrac{\mu_0 I}{4}\left[\dfrac{1}{R_1} - \dfrac{1}{R_2}\right]$.

5. We may assume current to be flowing in segment *EB* in both directions.
Net force on the loop *EDCBE* will be zero. Also force due to segment *FE* and *BA* will be zero. Force due to segment *EB*

$\vec{F} = I[L\hat{i} \times B\hat{j}] = ILB\hat{k}$

6. $\vec{F} = q(\vec{v} \times \vec{B}) = (-e)(-v\hat{i} \times B\hat{j}) = evB\,\hat{k}$

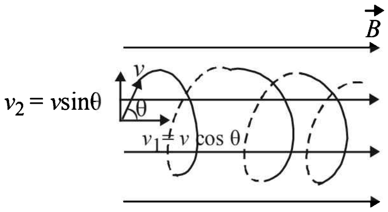
NOTE : The direction of flow of electrons is opposite to that of current.

B. True/ False

1. A current carrying coil is a magnetic dipole. The net force on a magnetic dipole placed in uniform magnetic field is zero.
2. **NOTE :** The magnetic force acts in a direction perpendicular to the direction of velocity and hence it cannot change the speed of the charged particle.

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

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



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

4. When a charged particle passes through a uniform magnetic field perpendicular to the direction of motion, a force acts on the particle perpendicular to the velocity. This force acts as a centripetal force

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

$r = \frac{\sqrt{2mK}}{qB} \qquad \left[\text{Where } K = \frac{p^2}{2m}\right]$

$\therefore \quad r \propto \frac{\sqrt{m}}{q} \qquad$ [for const. K.E. and B]

Here, q is same for electron and proton

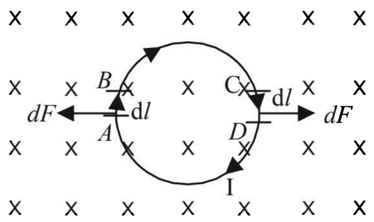
$\therefore \quad r \propto \sqrt{m}$

Radius of proton will be more.

C. MCQs with ONE Correct Answer

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

$dF = I(d\ell)B\sin 90° = I(d\ell)B$



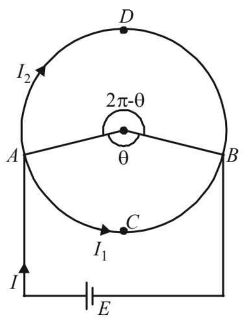
On element CD, the direction of force will be towards right on the plane of the paper and the magnitude will be

$dF = I(d\ell)B.$

These two forces will cancel out.

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

2. **(d)**



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

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

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

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

Therefore net magnetic field at the centre

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

Also, $I_1 = \frac{E}{R_1} = \frac{E}{\rho\ell_1/A} = \frac{EA}{\rho r\theta}$

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

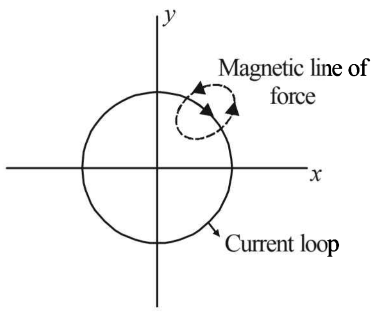
$\therefore \quad B = \frac{\mu_0}{4\pi}\left[\frac{EA}{\rho r\theta}\times\frac{\theta}{r} - \frac{EA}{\rho r(2\pi-\theta)}\times\frac{(2\pi-\theta)}{r}\right] = 0$

3. **(a)** **KEY CONCEPT :** $r \propto \frac{\sqrt{m}}{q}$

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

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

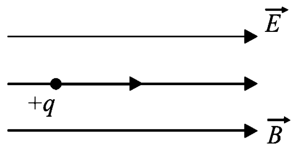
4. **(d)** The magnetic lines of force created due to current will be in such a way that on $x-y$ plane these lines will be perpendicular. Further, these lines will be in circular loops. The number of lines moving downwards in $x-y$ plane will be same in number to that coming upwards of the $x-y$ plane. Therefore, the net flux will be zero. One such magnetic line is shown in the figure.



5. **(a)** $F_E = qE \qquad$ (Force due to electric field)

$F_B = evB\sin\theta = qvB\sin 0 = 0$

(Force due to magnetic field)



Force due to electric field will make the charged particle released from rest to move in the straight line (that of electric field). Since the force due to magnetic field is zero, therefore, the charged particle will move in a straight line.

6. **(c)** The angular momentum L of the particle is given by $L = mr^2\omega$ where $\omega = 2\pi n$.

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

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

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

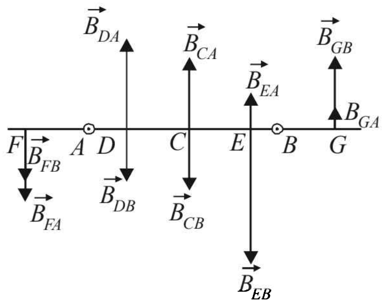
7. (b) The wires at A and B are perpendicular to the plane of paper and current is towards the reader. Let us consider certain points.

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

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

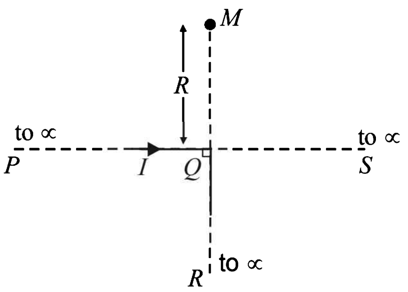
$\therefore$ Net magnetic field is in downward direction.

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



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

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



Case 2 : When wire QS is joined.

H_2 = (Magnetic field at M due to PQ) + (magnetic field at M due to QR) + (Magnetic field at M due to QS)

$$= \frac{1}{2}\left[\frac{\mu_0 I}{2\pi R}\right] + 0 + \frac{1}{2}\left[\frac{\mu_0 I/2}{2\pi R}\right] = \frac{3\mu_0 I}{8\pi R} \quad \therefore \frac{H_1}{H_2} = \frac{2}{3}$$

NOTE : The magnetic field due to an infinitely long wire carrying current at a distance R from the end point is half that at a distance R from the middle point.

9. (c) **Case of positively charged particle :**

Two forces are acting on the positively charged particle

(a) due to electric field in the positive x-direction.

(b) Force due to magnetic field.

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

$$\Rightarrow \vec{F} = q(v\hat{i} \times B\hat{k}) \Rightarrow \vec{F} = qvB(-\hat{j})$$

This forces will move the positively charged particle towards Y-axis.

Case of negatively charged particle.

Two forces are acting on the negatively charged particle

(a) due to electric field in the negative X-direction.

(b) due to magnetic field

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

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

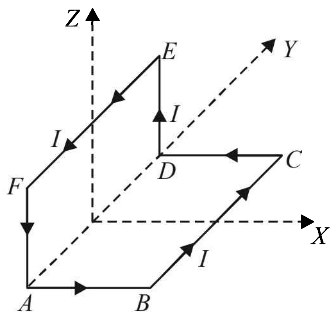
$$\vec{F} = -qvB[\hat{i} \times \hat{k}],\ \vec{F} = qvB(-\hat{j})$$

Same direction as that of positive charge.

(c) is the correct answer.

10. (d) **NOTE :** If we take individual length for the purpose of calculating the magnetic field in a 3-Dimensional figure then it will be difficult.

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



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

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

The magnetic field due to current in $ABCDA$ will be in + ve Z-direction.

NOTE : Due to symmetry the y-components and x-components will cancel out each other.

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

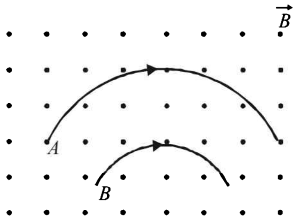
$\therefore$ The resultant magnetic field will be

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

11. (b) **KEY CONCEPT :** When a charged particle is moving at right angles to the magnetic field then a force acts on it which behaves as a centripetal force and moves the particle in circular motion.

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

$$\frac{m_B v_B}{r_B} = qB$$

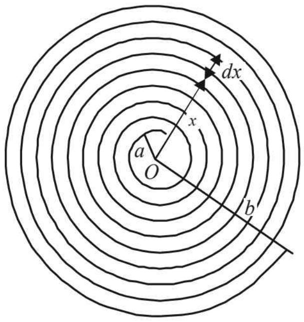


$$\Rightarrow \frac{m_A v_A}{r_A} = \frac{m_B v_B}{r_B}$$

Since $r_A > r_B$

$\Rightarrow m_A v_A > m_B v_B$

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



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

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

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

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

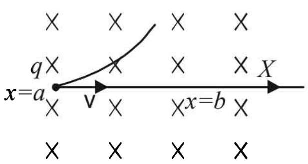
On integrating, we get,

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

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

$$B = \frac{\mu_0}{2}\frac{NI}{(b-a)}\log_e \frac{b}{a}$$

13. (b)



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

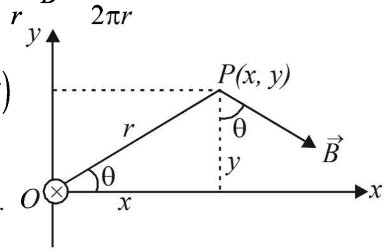
$$\therefore \quad R = \frac{mv}{qB} \ge (b-a) \Rightarrow v_{min} = \frac{(b-a)qB}{m}$$

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

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

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

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



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

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

15. (d) **NOTE :** Magnetic lines of force form closed loops. Inside a magnet, these are directed from south to north pole.

16. (b) The velocity at P is in the X-direction (given).

Let $\vec{v} = k\hat{i}$.

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

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

$\Rightarrow \quad \vec{F} = q[k\hat{i} \times (c\hat{k} + a\hat{i})]$ for option (b)

$= q[kc\hat{i} \times \hat{k} + ka\hat{i} \times \hat{i}] \quad = kcq(-\hat{j})$

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

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

17. (b) **KEY CONCEPT :** Use Fleming's left hand rule. We find that a force is acting in the radially outward direction throughout the circumference of the conducting loop.

18. (a) $U = -\vec{M}.\vec{B} = -MB\cos\theta$

In case I, $\theta = 180°$, $U = +MB$

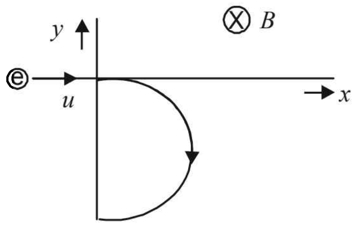
In case II, $\theta = 90°$, $U = 0$

In case III, θ = acute, $U = +$ ve (less than $+MB$)

In case IV, θ = obtuse, $U = -$ ve

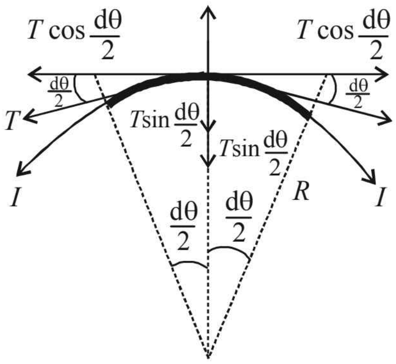
$\therefore \quad$ I > III > II > IV.

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



20. (a) Use the vector form of B and v in the formulae $\vec{F} = q(\vec{v} \times \vec{B})$ to get the instantaneous direction of force at $x = a$ and $x = 2a$.

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



$F_B = BI(dl)$ directed upwards as shown

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

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

Let T be the tension in the wire acting along both ends of the elemental length as shown. On resolving T, we find that the components. $T\cos\left(\dfrac{d\theta}{2}\right)$ cancel out and the components. $T\sin\left(\dfrac{d\theta}{2}\right)$ add up to balance F_B.

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

$\Rightarrow 2T\dfrac{d\theta}{2} = BI\dfrac{L}{2\pi}d\theta$ $\quad \left[\because \dfrac{d\theta}{2} = \text{small}\right]$

$\Rightarrow T = \dfrac{BIL}{2\pi}$

22. (a) same as Q.12 (above)

23. (b) The magnetic moment of a current carrying loop is given by $\vec{M} = NI\vec{A}$

Here $N = 1, A = a^2 + 2\pi\left(\dfrac{a}{2}\right)^2 = a^2\left[1 + \dfrac{\pi}{2}\right]$, the direction is towards positive z-axis.

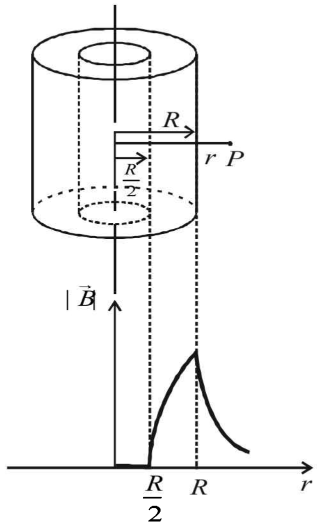
$\therefore \quad \vec{M} = Ia^2\left[1 + \dfrac{\pi}{2}\right]\hat{k}$

24. (d) For $r < \dfrac{R}{2}, \quad B = 0$

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

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

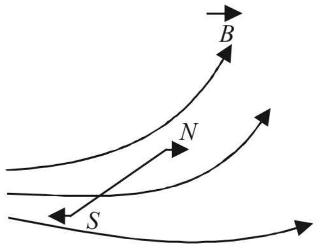
For $r > R, \quad B = \dfrac{\mu_0 i}{2\pi r}$



D. MCQs with ONE or MORE THAN ONE Correct

1. (a) The force on north pole = $m\vec{B}_1$

The force on south pole = $m\vec{B}_2$



Since the forces will be unequal and are not having same line of action therefore, the magnetic needle experiences a force as well as a torque.

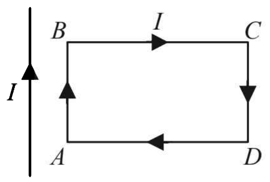
2. (a,b,d)

There is no change in velocity. It can be possible when

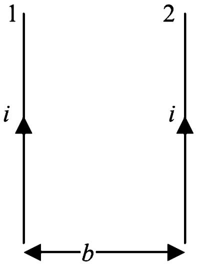
- Electric and magnetic fields are absent, i.e., E = 0, B = 0
- Or when electric and magnetic fields are present but force due to electric field is equal and opposite to the magnetic force, (i.e., $E \neq 0, B \neq 0$).
- Or when E = 0. $B \neq 0$ provided
  $F = qvB\sin\theta = 0$

$\sin\theta = 0$, i.e., $\theta = 0 \Rightarrow v$ and B are in the same direction.

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



4. **(b)** The magnetic field due to current in wire 1 in the region of wire 2 will be



$$B_1 = \frac{\mu_0}{4\pi}\frac{2i}{b}$$

Since wire 2 having current i is placed in a magnetic field B_1, it will experience a force given by

$F = i(\ell B_1 \sin 90°)$

$\therefore$ force per unit length $\frac{F}{\ell} = i \times \frac{\mu_0}{4\pi} \times \frac{2i}{b} = \frac{\mu_0 i^2}{2\pi b}$

$$\left[\because B = \frac{\mu_0}{4\pi} \times \frac{2i}{b}\right]$$

5. **(c)** K.E. of first particle $= \frac{1}{2} m_1 v_1^2 = qV$ ... (i)

K.E. of second particle $= \frac{1}{2} m_2 v_2^2 = qV$ ... (ii)

NOTE : After entering the magnetic field, a magnetic force acts on the charged particle which moves the charged particle in circular path of radius

$$R = \frac{\sqrt{2mK}}{qB}$$

Here, K, q, B are equal

$\therefore \quad R^2 \propto m$

$\Rightarrow \quad \frac{m_1}{m_2} = \frac{R_1^2}{R_2^2}$ From (i) and (ii)

6. **(a, b, d)**

Considering the activity from P to Q (Horizontal)

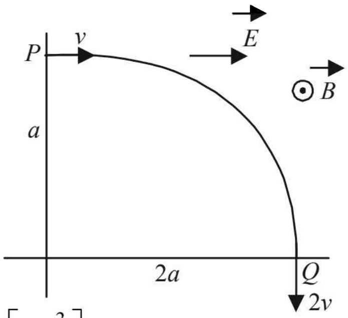
$u_1 = v, v_1 = 2v, s_1 = 2a, \text{Acc} = A$

$\Rightarrow \quad 4v^2 - v^2 = 2A(2a)$

$\Rightarrow \quad A = \frac{3v^2}{4a}$

Force acting in the horizontal direction is

$F = qE = mA$



$\Rightarrow \quad E = \frac{mA}{q} = \frac{3}{4}\left[\frac{mv^2}{qa}\right]$

Rate of doing work at P

Power $= F \times v = mA \times v = \frac{3}{4}\left[\frac{mv^3}{a}\right]$

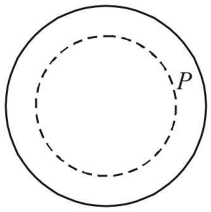
Rate of doing work by the magnetic field is throughout zero. The rate of doing work by electric field is zero at Q. Because at Q, the angle between force due to electric field and displacement is zero.

7. **(b, c)**

For $V = I_g(G + R) = 5 \times 10^{-5}[100 + 200{,}000] = 10\text{V}$

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

8. **(b)** Let us consider any point P inside the thin walled pipe. Let us consider a circular loop and apply Ampere's circuital law,



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

Since current inside the loop is zero.

$\therefore \quad \vec{B} = 0$

9. **(a, c)**

KEY CONCEPT : When the charged particles enter a magnetic field then a force acts on the particle which will act as a centripetal force. We know that when kinetic energy and magnetic field are equal then

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

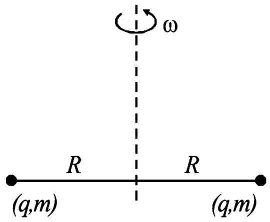
$$r_{H^+} \propto \frac{\sqrt{1}}{1};\ r_{He^+} \propto \frac{\sqrt{4}}{1};\ r_{O^{++}} \propto \frac{\sqrt{16}}{2}$$

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

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

H^+ will be deflected the most since its radius is smallest.

10. **(a)**



Current, $i = \text{(frequency) (charge)} = \left(\frac{\omega}{2\pi}\right)(2q) = \frac{q\omega}{\pi}$

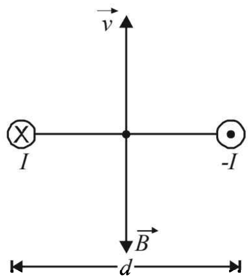
Magnetic moment,

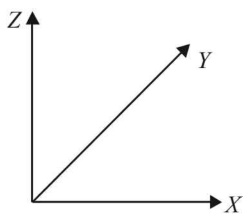
$$M = (i)(A) = \left(\frac{q\omega}{\pi}\right)(\pi R^2) = (q\omega R^2)$$

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

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

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





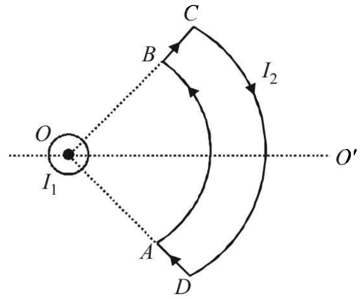
Wires are in X-Y plane and velocity in Z-direction

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

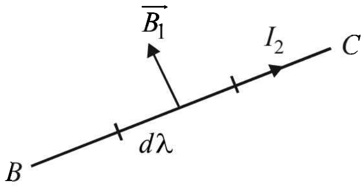
12. (c, d)
Out of the given options only induced electric field and magnetostatic field form closed loops of field lines.

13. (a, c)
Net force on the loop :
Force on *AB* : The magnetic field due to current I_1 is along *AB*.

$$dF = I\,(d\ell \times B \times \sin 0°) = 0$$



Force on *CD* : Similarly the magnetic field due to current I_1 is along *DC*. Because $\theta = 180°$ here, therefore force on *DC* is zero.

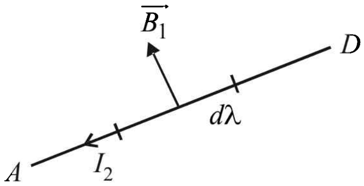


Force on *BC* : Consider a small element $d\ell$.

$$dF = I_2 d\ell B_1 \sin 90° \Rightarrow dF = I_2 d\ell B_1$$

By Fleming's left hand rule, the direction of this force is perpendicular to the plane of the paper directed outwards.

Force on *AD* : $dF = I_2 d\ell B_1 \sin 90° = I_2 d\ell B_1$



By Fleming's left hand rule, the direction of this force is perpendicular to the plane of paper directed inwards. Since the current elements are located symmetrical to current I_1, therefore force on *BC* will cancel out the effect of force on *AD*.

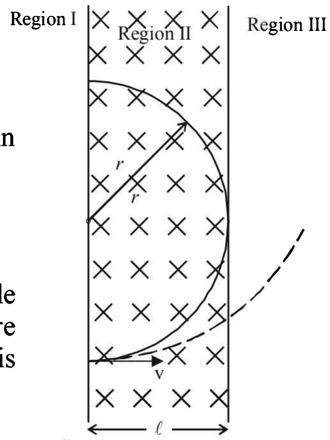
$\Rightarrow$ Net force on loop *ABCD* is zero.

Net Torque on the loop : The force on *BC* and *AD* will create a torque on *ABCD* in clockwise direction about *OO'* as seen by the observer at *O*.

14. (a, c, d)
As the particle enters the magnetic field, a force acts on it due to the magnetic field which moves the particle in a circular path of radius

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

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



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

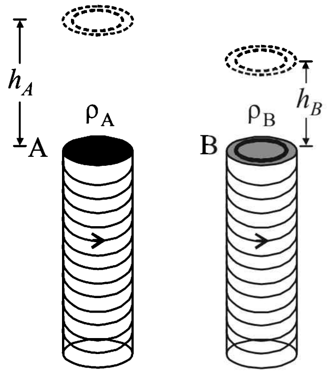
- **For maximum path length** in region II, $r = \ell$

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

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

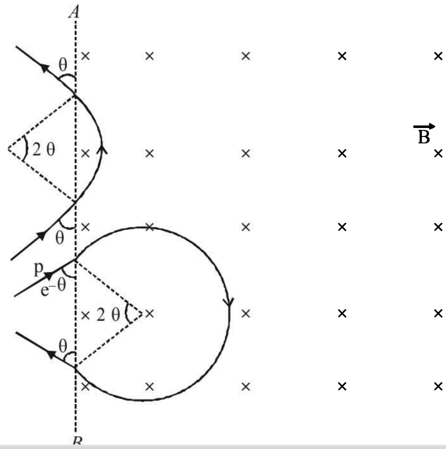
$$t = \frac{\pi m}{qB}$$ which is independent of v.

15. (b, d)
When current *I* is switched on in both the solenoids in identical manner, eddy currents are setup in metallic rings *A* and *B* in such a way that rings *A* and *B* are repelled.



Given $h_A > h_B$. This shows that eddy currents produced in A are greater than in *B*. This is possible when $\rho_A < \rho_B$ (the rate of change of flux is same in both the rings, therefore induced emf is same).

16. (b,d)
Figure shows that the magnetic field $\vec{B}$ is present on the right hand side of *AB*. The electron (*e*) and proton (*p*) moving on straight parallel paths with the same velocity enter the region of uniform magnetic field.
The entry and exit of electron & proton in the magnetic field makes the same angle with AB as shown.
Therefore both will come out travelling in parallel paths.



The time taken by proton

$$t_p = \frac{\text{distance}}{\text{speed}} = \frac{\text{arc}}{\text{speed}} = \frac{\text{angle} \times \text{radius}}{\text{speed}} = \frac{2\theta \times R_p}{v}$$

$$= \frac{2\theta}{v} \times \left(\frac{m_p v}{eB}\right) = \frac{2\theta m_p}{eB}$$

The time taken by electron is

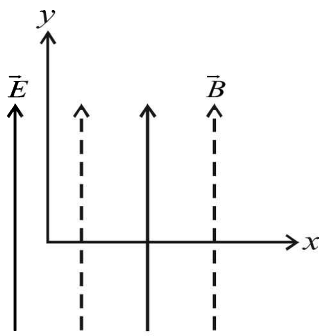
$$t_e = \frac{(2\pi - 2\theta)R_e}{v} = \frac{(2\pi - 2\theta)}{v}\left(\frac{m_e v}{eB}\right) = \frac{(2\pi - 2\theta)m_e}{eB}$$

clearly t_e is not equal to t_p as $m_p >> m_e$

$\therefore$ (b) , (d) are correct options

17. (c, d)

When $\theta = 0°$, the charged particle is projected along x-axis, due to $\vec{B}$ the charged particle will tend to move in a circular path in y-z plane but due to force of electric field, the particle will move in a helical path with increasing pitch. Therefore options (A) and (B) are incorrect.



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

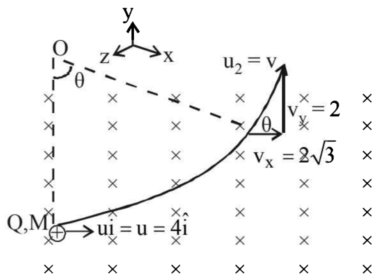
If $\theta = 90°$, the charge is moving along the magnetic field. Therefore the force due to magnetic field is zero. But the force due to electric field will accelerate the particle along y-axis.

18. (a, c)

The magnetic field should be in the –z direction (Fleming's left hand rule)

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

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



$$\text{Angle} = \frac{\text{arc}}{\text{radius}} = \frac{\text{speed} \times \text{time}}{\text{radius}}$$

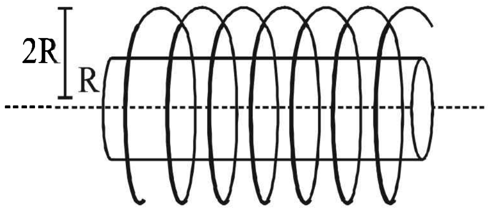
$$\therefore \frac{\pi}{6} = \frac{4 \times 10 \times 10^{-3}}{M \times 4 / QB} \qquad \left[\because \text{radius} = \frac{Mv}{QB}\right]$$

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

(a) and (c) are the correct options

19. (a, d)

In the region $O < r < R$, the magnetic field is present due to current in solenoid.



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

For the region $R < r < 2R$, the magnetic field is neither along the common axis, nor tangential to the circle of radius r. (a) and (d) are correct options.

20. (a, b, c)

$$\vec{F} = I\left[\left(\int \vec{dl}\right) \times \vec{B}\right]$$

If $\vec{B}$ is along $\vec{z}$ then $\vec{F} = I\left[(2L + 2R)\hat{i} \times B\hat{x}\right]$

option [A] is correct

If $\vec{B}$ is along $\vec{x}$ then $\vec{F} = I\left[(2L + 2R)\hat{i} \times B\hat{i}\right] = 0$

If $\vec{B}$ is along $\vec{y}$ then $\vec{F} = I\left[(2L + 2R)\hat{i} \times \hat{j}\right]$

Option (b) and (c) are also correct

21. (a, c)

The range of voltmeter 'V' is given by the expression

$$V = I_g\,[R_c + (R_c + R + R)]$$

V is max in this case as RHS is maximum. Thus (a) is correct.

The range of ammeter I is given by the expression

$$I = \frac{I_g R_c}{R_{eq}} + I_g \qquad \text{Where } \frac{1}{R_{eq}} = \frac{1}{R_c} + \frac{1}{R} + \frac{1}{R}$$

Here R_{eq} is minimum and therefore I is maximum. Thus (c) is the correct option.

E. Subjective Problems

1. $2\ell = 0.25$ m

Also, $m \times 2\ell = 14.4 \Rightarrow m = \frac{14.4}{0.25} = 57.6\ \text{A-m}^2$

Torque due to magnetic field

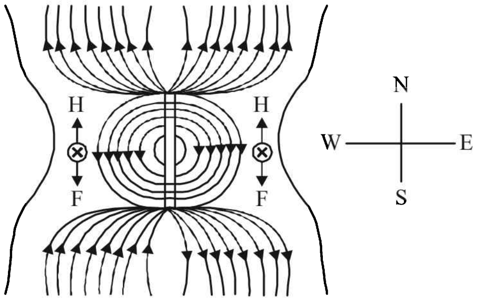
$$= p_m \times B \times \sin 60° = 14.4 \times 0.25 \times \frac{\sqrt{3}}{2}$$

The torque due to the force $= F \times 0.12$

For equilibrium $F \times 0.12 = 14.4 \times 0.25 \times \frac{\sqrt{3}}{2} \Rightarrow F = 25.98$ N

If the force F is removed, the torque due to magnetic field will move the bar magnet. It will start oscillating about the mean position where the angle between $\vec{p}_m$ and $\vec{B}$ is 0.

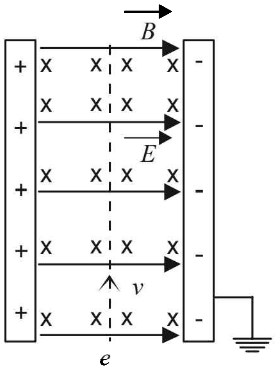
2.



3. The force on electron will be towards the left plate due to electric field and will be equal to

$F_e = eE$

NOTE : For the electron to move undeflected between the plates there should be a force (magnetic) which is equal to the electric force and opposite in direction. The force should be directed towards the right as the electric force is towards the left.



On applying Fleming's left hand rule we find the magnetic field should be directed perpendicular to the plane of paper inwards. Therefore,

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

$eE = evB$

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

where V = p.d. between plates

d = distance between plates

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

$B = 0.1$ tesla

4. $m = 1.6\times10^{-27}$ kg, $q = 1.6\times10^{-19}$ C

$B = 1$ T

$v = 10^7$ m/s

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

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

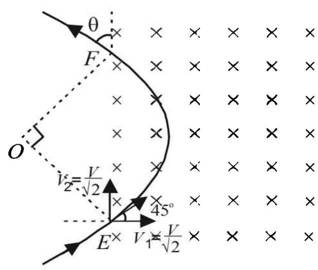
$\Rightarrow \quad F = qvB \qquad [\because \alpha = 90°]$

But $F = ma$

$\therefore qvB = ma \quad \therefore a = \frac{qvB}{m}$

$$= \frac{1.6\times10^{-19}\times10^{7}\times1}{1.6\times10^{-27}}$$

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



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

By symmetry $\angle OFE = 45°$

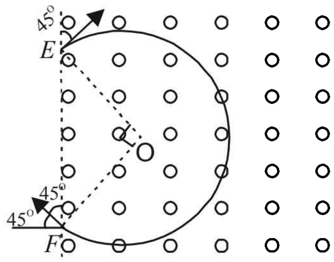
$\therefore \quad \angle EOF = 90°$ $\qquad$ (by Geometry)

This is the centripetal acceleration

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

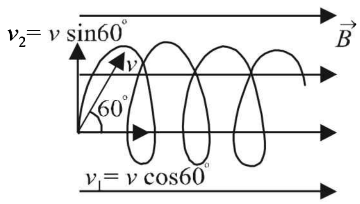
Therefore EF = 0.141 m.

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



$$\therefore \quad \text{Time required} = \frac{3}{4}\times\left[\frac{2\pi r}{v}\right] = 4.71\times10^{-8}\ \text{sec.}$$

5.



v_1 is responsible for horizontal motion of proton

v_2 is responsible for circular motion of proton

$$\therefore \quad \frac{mv_2^2}{r} = qv_2B$$

$$r = \frac{mv_2}{qB} = \frac{1.76\times10^{-27}\times4\times10^{5}\times\sqrt{3}}{1.6\times10^{-19}\times0.3\times2} = 0.012\,\text{m}$$

Pitch of helix $= v_1 \times T$

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

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

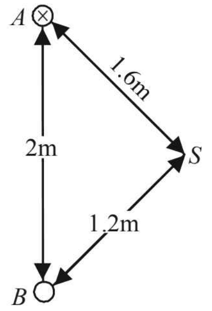
$= 2\pi r\cot\theta = 2\times3.14\times0.012\times\cot60° = 0.044$ m

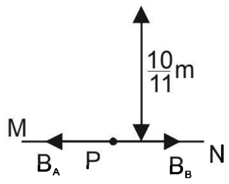
6. (i) The magnetic field at P due to current in wire A.

$$B_A = \frac{\mu_0}{4\pi}\frac{2I_A}{r_{AP}} = \frac{\mu_0}{4\pi}\times\frac{2\times9.6}{\left(2+\frac{10}{11}\right)} \quad \text{(Direction } P \text{ to } M) \ ...(i)$$

NOTE : The current in wire B should be in upward direction so as to cancel the magnetic field due to A at P. (By right hand Thumb rule)

The magnetic field at P due to current in wire B





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

From (i) and (ii)

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

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

(ii) The dimensions given shows that

$SA^2 + SB^2 = AB^2 \Rightarrow \angle ASB = 90°$

Magnetic field due to A at S

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

Magnetic field due to B at S

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

The resultant magnetic field

$$B = \sqrt{B_{SA}^2 + B_{SB}^2} = \frac{\mu_0}{4\pi} \sqrt{\left(\frac{9.6}{0.8}\right)^2 + \left(\frac{3}{0.6}\right)^2}$$

$$= 10^{-7} \times 13 = 1.3 \times 10^{-6}\ \text{T}$$

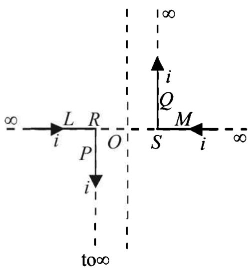
(iii) Force per unit length on wire B

$$= \frac{\mu_0}{4\pi} \frac{2I_A I_B}{r_{AB}}$$

$$= \frac{10^{-7} \times 2 \times 9.6 \times 3}{2} = 28.8 \times 10^{-7}\ \text{N/m}$$

This force will be repulsive in nature.

7.



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

$$B_1 = \frac{\mu_0}{4\pi} \frac{i}{(OR)}$$

directed towards the reader perpendicular to the plane of paper.

Magnetic field due to current carrying conductor Q at point O is directed towards the reader perpendicular to the plane of paper.

$$B_2 = \frac{\mu_0}{4\pi} \frac{i}{(OS)}$$

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

$\therefore$ Resultant magnetic field at O

$B = B_1 + B_2$

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

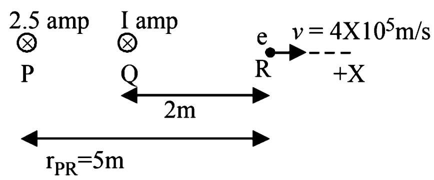
$$\Rightarrow B = \frac{\mu_0}{4\pi} \frac{i}{OR} + \frac{\mu_0}{4\pi} \frac{i}{OS} = \frac{\mu_0}{4\pi} i \left[\frac{1}{OR} + \frac{1}{OS}\right]$$

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

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

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

$$= \frac{\mu_0}{4\pi} \text{ [in the plane of paper downwards]}$$



Similarly, the magnetic field (due to current is wire Q) at R

$$= \frac{\mu_0}{4\pi} \times \frac{2 \times I}{2} = \frac{\mu_0}{4\pi} I$$

[in the plane of paper downwards]

The total magnetic field at R [due to P and Q]

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

[in the plane of paper downwards]

The force experienced by the electron

$F = qvB \sin\theta$

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

But $F = 3.2 \times 10^{-20}$ N (Given)

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

$\Rightarrow$ $I = 4$ amp.

(ii) Let us consider a position between Q and R. The magnetic field produced should be equal to 5×10^{-7} T in the plane of paper acting upwards.

For this let the wire having current 2.5 amp be placed at a distance r from R and current flowing outwards the plane of paper.

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

Let us consider another position beyond R collinear with P, Q and R. Let it be placed at a distance r' from R, having current in the plane of paper.

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

9. **(a)** $\vec{B}_1 = \frac{\mu_0}{4\pi}\frac{2I\sqrt{3}}{a}(-\hat{k}); \quad \vec{B}_2 = \frac{\mu_0}{4\pi}\frac{2\pi I}{3a}\hat{k}$

$$\vec{B} = \vec{B}_1 + \vec{B}_2 = \frac{\mu_0}{4\pi}\frac{I}{a}\left[\frac{2}{3} - 2\sqrt{3}\right]\hat{k} = \frac{-\mu_0}{4\pi}\frac{2I}{a}(1.4)(\hat{k});$$

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

$$\vec{F} = Q(\vec{V} \times \vec{B}) = Q\left[\frac{v}{2}\hat{i} + \frac{\sqrt{3}}{2}v\hat{j}\right] \times \left[\frac{-\mu_0}{4\pi}\frac{2.8I}{a}\hat{k}\right]$$

Now apply $\vec{a} = \frac{\vec{F}}{m}$

(b) **KEY CONCEPT :** The torque acting on the loop in the magnetic field is given by

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

A = (area of $PMQNP$) – (area of triangle PMN)

$$= \frac{1}{3}(\pi a^2) - \frac{1}{2} \times MN \times PS$$

$$= \frac{\pi a^2}{3} - \frac{1}{2} \times \sqrt{3}a \times \frac{a}{2} = a^2\left[\frac{\pi}{3} - \frac{\sqrt{3}}{4}\right]$$

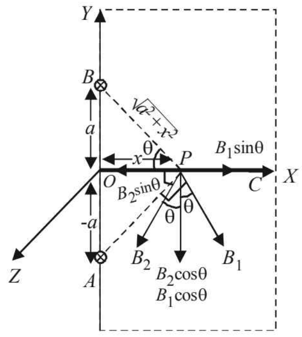
$$\vec{A} = a^2\left[\frac{\pi}{3} - \frac{\sqrt{3}}{4}\right]\hat{k}$$

$$\therefore \quad \vec{\tau} = Ia^2\left[\frac{\pi}{3} - \frac{\sqrt{3}}{4}\right]\hat{k} \times \hat{i}B$$

$$\vec{\tau} = BIa^2\left(\frac{\pi}{3} - \frac{\sqrt{3}}{4}\right)\hat{j} = 0.614\, BIa^2\hat{j}$$

The force acting on the loop is zero.

10. The magnetic field produced at different points on OC will be different. Let us consider an arbitrary point P on OC which is at a distance x from the origin. Let the magnetic field due to currents in A and B at P be B_1 and B_2 respectively, both being in the X-Y plane.



Let $\angle BPO = \angle APO = \theta$

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

On resolving B_1 and B_2 we get that the $\sin\theta$ components cancel out and the $\cos\theta$ components add up. Therefore, the total magnetic field at P is

$B = 2B_1\cos\theta$

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

(towards – Y direction)

Let us consider a small portion of wire OC at P of length dx. The small amount of force acting on that small portion

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

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

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

The total force

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

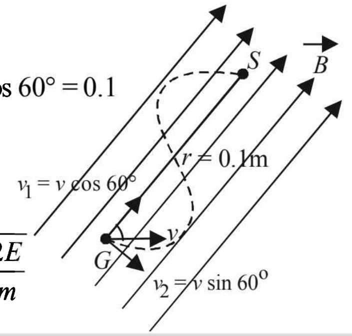
$$= \frac{\mu_0}{4\pi} \times 4I^2\left[\frac{1}{2}\log_e(a^2+x^2)\right]_0^L$$

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

To find the direction of force we can use Fleming's left hand rule. The direction of $\vec{F}$ is towards – Z direction.

When the current in wire B is reversed, the resultant magnetic field at any arbitrary point P on OC will be in the X-direction. Since the current is also in X-direction, therefore force acting will be zero ($F = I\ell B\sin\theta$ and $\theta = 180°$).

11. **(a)** Let us resolve the velocity into two rectangular components v_1 (= vcos 60°) and v_2 (= vsin 60°). v_1 component of velocity is responsible to move the charge particle in the direction of the magnetic field whereas v_2 component is responsible for revolving the charged particle in circular motion. The overall path is helical. The condition for the charged particle to strike S with minimum value of B is that Pitch of Helix = GS



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

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

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

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

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

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

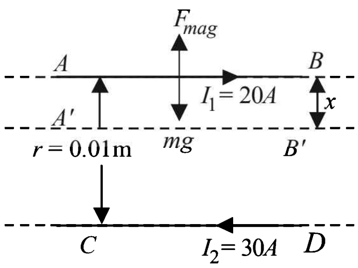
$= \frac{149.8}{10^{-19}} \times 0.316 \times 10^{-23} = 47.37 \times 10^{-4}$

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

12. When AB is steady,
Weight per unit length = Force per unit length

Weight per unit length $= \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r}$ ... (i)

NOTE : When the rod is depressed by a distance x, then the force acting on the upper wire increases and behaves as a restoring force



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

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

$\Rightarrow$ Restoring force/length $= \frac{\mu_0}{4\pi}2I_1I_2\left[\frac{r-(r-x)}{(r-x)r}\right]$

$= \frac{\mu_0}{4\pi}\frac{2I_1I_2x}{r(r-x)}$

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

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

Since, $F \propto x$ and directed to equilibrium position.

$\therefore$ The motion is simple harmonic

$\therefore \quad \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r^2} = \text{(mass per unit length)}\,\omega^2$ ... (ii)

From (i), (Mass per unit length) × g $= \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r}$

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

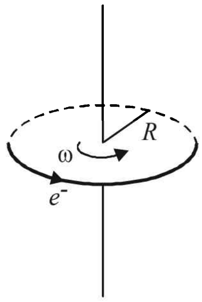
From (ii) and (iii)

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

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

$\Rightarrow T = 2\pi\sqrt{\frac{r}{g}} = 2\pi\sqrt{\frac{0.01}{9.8}} = 0.2\text{sec}$

13. (i) **KEY CONCEPT :** Orbital magnetic dipole moment $M = IA$ where I is the current due to orbital motion of electron and A is the area of loop made by electron.



$\Rightarrow M = \frac{e}{T} \times \pi R^2 \Rightarrow M = \frac{e\omega}{2\pi} \times \pi R^2$

$\Rightarrow M = \frac{1}{2}e\omega R^2$

But according to Bohr's postulate

$mR\omega^2 = \frac{nh}{2\pi} \Rightarrow R\omega^2 = \frac{nh}{2\pi m}$

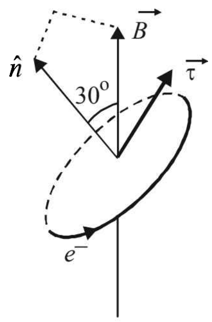
$\Rightarrow M = \frac{e}{2} \times \frac{nh}{2\pi m} = \frac{nhe}{4\pi m} = \frac{eh}{4\pi m}$ ($\because n = 1$ for ground state)

NOTE : The direction of magnetic momentum is same as the direction of area vector, i.e., perpendicular to the plane of orbital motion.

(ii) **KEY CONCEPT :** We know that torque

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

where θ is the angle between M and B



$\Rightarrow \tau = \frac{he}{4\pi m} \times B\sin 30° = \frac{heB}{8\pi m}$

NOTE : The direction of torque can be found by right hand thumb rule.

The direction of torque is perpendicular to the plane containing $\hat{n}$ and $\vec{B}$ as shown.

14. (i) **KEY CONCEPT :** Magnetic field due to an infinitely long current carrying wire at distance r is given by

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

The direction of B is given by right hand palm rule.

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

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

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

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

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

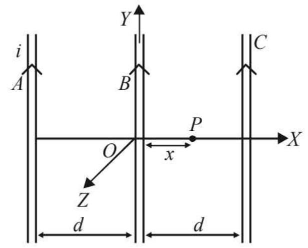
$$\vec{B}_P = \frac{\mu_0}{4\pi}2i\left[\frac{1}{d+x}+\frac{1}{x}-\frac{1}{d-x}\right](-\hat{k}).$$

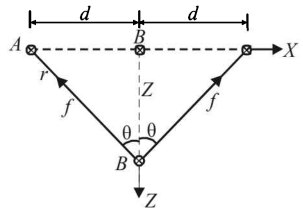
For $\vec{B}_P = 0$, we get $x = \pm d/\sqrt{3}$

(ii) **KEY CONCEPT :** The force per unit length between two parallel current carrying wires is given by

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

and is attractive if currents are in the same direction.





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

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

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

or $$\frac{F}{\ell} = -\frac{\mu_0}{4\pi}\left(\frac{2i}{d}\right)^2 z \quad [\text{as } d >> z \text{ and F is opposite to } z] \quad ...(1)$$

Since $F \propto -z$, the motion is simple harmonic.
Comparing eq. (1) with the standard equation of S.H.M. which is

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

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

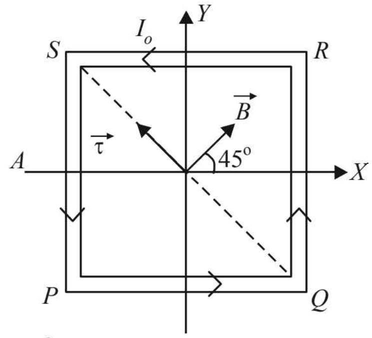
$$\lambda\,\omega^2 = \frac{\mu_0}{4\pi}\times\frac{4i^2}{d^2} \Rightarrow \omega = \sqrt{\frac{\mu_0 i^2}{\pi d^2\lambda}}$$

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

15. (a) As the magnetic field $\vec{B}$ is in $x-y$ plane and subtends an angle of 45° with the x-axis, hence,

$B_x = B\cos 45° = B/\sqrt{2}$ and

$B_y = B\sin 45° = B/\sqrt{2}$



So, in vector from

$$\vec{B} = \hat{i}\left(\frac{B}{\sqrt{2}}\right) + \hat{j}\left(\frac{B}{\sqrt{2}}\right) \text{ and } \vec{M} = I = I_0L^2\hat{k}$$

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

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

(b) According to the theorem of perpendicular axes, moment of inertia of the frame about QS.

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

Also $\tau = I\alpha$,

$$\therefore \quad \alpha = \frac{\tau}{I} = \frac{I_0L^2B\times 3}{2ML^2} = \frac{3}{2}\frac{I_0B}{M}$$

Here α is constant, therefore we can apply

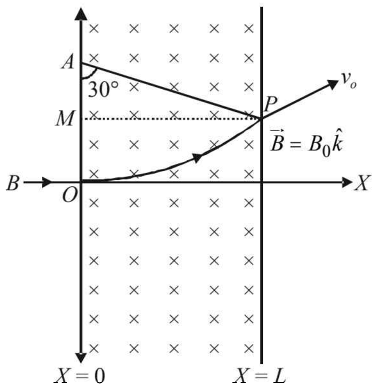
$$\theta = \omega_0 t + \frac{1}{2}\alpha t^2 \text{ with } \omega_0 = 0, \text{ we have}$$

$$\theta = \frac{1}{2}\alpha t^2 = \frac{1}{2}\left(\frac{3I_0B}{2M}\right)(\Delta t)^2$$

or $$\theta = \frac{3}{4}\frac{I_0B}{M}(\Delta t)^2$$

16. **KEY CONCEPT :** This question involves a simple understanding of the motion of charged particle in a magnetic field.

(a)



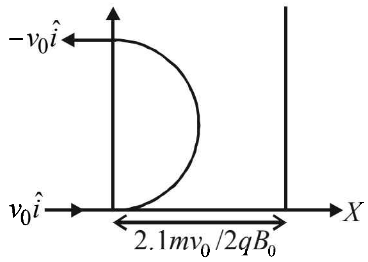
Let the particle emerge out from the region of magnetic field at point P. Then the velocity vector $\vec{v}_0$ makes an angle 30° with x-axis. The normal to circular path at P intersects the negative y-axis at point A.
Hence, $AO = AP = R$ = radius of circular path, which can be found as

$$\frac{mv_0^2}{R} = B_0qv_0 \Rightarrow R = \frac{mv_0}{qB_0} \quad \text{...(i)}$$

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

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

(b)



As the new region of magnetic field is 2.1 L

$= \frac{2.1R}{2}$ which is obviously $> R$.

Thus, the required velocity $= -v_0\hat{i}$.
Since the time period for complete revolution $= 2\pi m/qB_0$.
The time taken by the particle to cross the region of magnetic field $= \pi m/qB_0$.

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

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

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

[**NOTE :** The magnetic field $\vec{B}$ due to a circular current carrying loop is $\frac{\mu_0 I}{2R}$ $\therefore$ For semicircle it is half]

Therefore, magnetic force acting on the particle.

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

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

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

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

Therefore, $\vec{F}_1 = \vec{F}_2 = 2BIR\hat{i}$ or total force on the loop, $\vec{F} = \vec{F}_1 + \vec{F}_2 \Rightarrow \vec{F} = 4BIR\hat{i}$

18. For finding the magnetic field produced by this circuit at the centre we can consider it to contain two semicircles of radii, $r_1 = 0.08$ m and $r_2 = 0.12$ m. Since current is flowing in the same direction, the magnetic field created by circular arcs will be in the same direction and therefore will be added.

$$\therefore \quad B_1 = \frac{\mu_0 i}{4r_1} \text{ and } B_2 = \frac{\mu_0 i}{4r_2} \quad \therefore \quad B = \frac{\mu_0 i}{4}\left[\frac{1}{r_1} + \frac{1}{r_2}\right]$$

$\therefore \quad B = (6.54 \times 10^{-5})\,T$ Directed outwards.
(Right hand thumb rule)

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

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

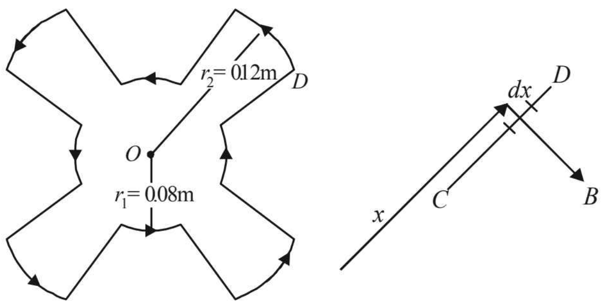
(i) For force acting on the wire at the centre
In this case $\theta = 180°$
$\therefore \quad F = 0$

(ii) On arc AC due to current at the centre

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

The direction of this magnetic field on any small segment of AC will be tangential
$\therefore \quad \theta = 180° \Rightarrow F = 0$

(iii) On segment *CD*.
Force on a small segment dx distant r from O



$dF = I\,dxB$

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

On integrating

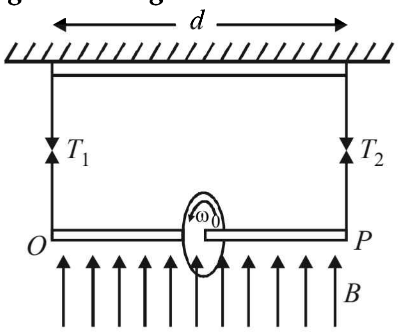
$$\therefore \quad F = \frac{5\mu_0 I}{\pi}\int_{r_1}^{r_2}\frac{dx}{x} \quad \therefore \quad F = \frac{5\mu_0 I}{\pi}[\log_e x]_{r_1}^{r_2}$$

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

$= 8.1 \times 10^{-6}$ N
directed downwards (By Fleming left hand rule).

19. When the ring is not rotating
Wt. of ring = Tension in string
$mg = 2T_0$

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



When the ring is rotating, we can treat it as a current carrying loop. The magnetic moment of this loop

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

This current carrying loop will create its own magnetic field which will interact with the given vertical magnetic field in such a way that the tensions in the strings will become unequal. Let the tensions in the strings be T_1 and T_2.

For translational equilibrium

$$T_1 + T_2 = mg \qquad \text{... (ii)}$$

Torque acting on the ring about the centre of ring

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

$$\tau = M \times B \times \sin 90°$$

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

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

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

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

On solving (ii) and (iii), we get

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

But the maximum tension is $\frac{3T_0}{2}$

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

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

20. KEY CONCEPT :

$$eV = \frac{1}{2}mv_p^2 \text{ and } eV = \frac{1}{2}mv_\alpha^2$$

V is the potential difference
v_p = velocity of proton
v_α = velocity of α-particle
m = mass of proton, mass of α-particle = 4 m

$$\Rightarrow \quad v_p = \sqrt{\frac{2eV}{m}}, v_\alpha = \sqrt{\frac{2eV}{4m}}$$

Now when the particles enter in magnetic field, the force on proton is

$$ev_pB = \frac{mv_p^2}{r_p} \text{ or } r_p = \frac{mv_p}{eB} \Rightarrow r_\alpha = \frac{m}{eB}$$

$$\sqrt{\frac{2eV}{m}} = \frac{1}{B}\sqrt{\frac{2mV}{e}} \quad \text{and } r_\alpha = \frac{1}{B}\sqrt{\frac{4mV}{e}}$$

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

21. **(a)** The torque acting on a rectangular coil placed in a uniform magnetic field is given by,

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

But $M = NiA$ and $\theta = 90°$ (for moving coil galvanometer)

$\therefore \quad \tau = NiAB \sin 90°$

$\Rightarrow \quad \tau = NiAB$

But $\tau = ki$ (given)

$\therefore \quad ki = NiAB$

$\Rightarrow \quad k = NAB$

(b) The torsion constant is given by

$$C = \frac{\tau}{\theta} = \frac{NiAB}{\theta}$$

Here given that when $i = i_0$, $\theta = \pi/2$

$$\therefore \quad C = \frac{2Ni_0AB}{\pi} \qquad \text{... (i)}$$

(c) We know that angular Impulse

$$= \int \tau dt = \int NiAB\, dt = NAB \int i\, dt$$

$$= NABQ \qquad \text{... (ii)}$$

This angular impulse creates an angular momentum

$$\int \tau\, dt = I\omega \qquad \text{... (iii)}$$

From (ii) and (iii)

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

This is the instantaneous angular momentum due to which the coil starts rotating. Let us apply the law of energy conservation to find the angle of rotation.

Rotational kinetic energy of coil

$$= \frac{1}{2}I\omega^2 = \frac{1}{2}\frac{I N^2A^2B^2Q^2}{I^2} = \frac{N^2A^2B^2Q^2}{2I}$$

$$\frac{1}{2}C\theta_{max}^2 = \frac{N^2A^2B^2Q^2}{2I}$$

$$\Rightarrow \quad \theta_{max}^2 = \frac{N^2A^2B^2Q^2}{CI} = \frac{N^2A^2B^2Q^2}{2Ni_0ABI} \times \pi$$

$$\Rightarrow \quad \theta_{max}^2 = \frac{\pi NABQ^2}{2i_0I} \quad \Rightarrow \quad \theta_{max} = Q\sqrt{\frac{NAB\pi}{2Ii_0}}.$$

F. Match the Following

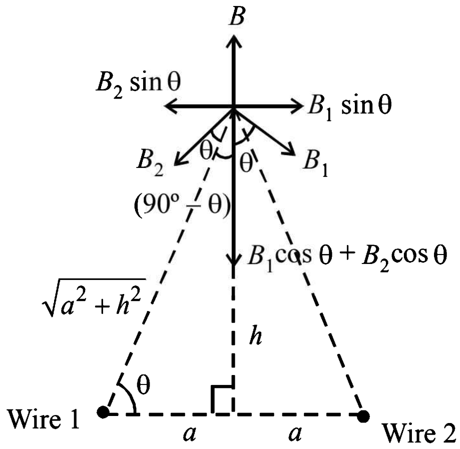
1. (A) Charge on ring will create electric field which is time independent.
   (B) The rotating charge is like a current. This will create a magnetic field and a magnetic moment.
   (C) Since net charge is zero there will be no time independent electric field. The current produces magnetic field and magnetic moment.
   (D) A changing magnetic field will be produced. This will create a induced electric field. Also a changing magnetic moment will be produced.

2. **A : q**
Reason : When a charged capacitor is connected to the ends of the wire, a variable current (decreasing in magnitude with time) passes through the wire (shown as resistor) and thermal energy is generated. The potential difference across the wire also decreases with time. The charge on the capacitor plate also decreases with time.
B : r. s
Reason : $e = B\ell v$
When B, ℓ, v are constant, e is constant
$\Rightarrow$ A constant potential difference develops across the ends of the wire and charges of constant magnitude appear at the ends of the wire.
C : s
Reason : The free electrons move under the influence of electric field opposite to the direction of electric field. This movement of e^- continues till the electric field inside the wire is zero.
$\Rightarrow$ Changes of constant magnitude appear at the ends of the wire.
D : p, q, r
Reason : Since, E, R are constant, a constant current flows in the wire. Due to heating effect of current, thermal energy is generated in the wire. Also a constant potential difference develops between the ends of the wire.

3. **A : q, r**
Reason : The magnetic field at P due to current flowing in AB is perpendicular to the plane of paper acting vertically downward. And the magnetic field at P due to current flowing in CD is perpendicular to the plane of paper acting vertically upwards.
Therefore, q is correct.
As P is the mid point, the two magnetic fields, cancel out each other. Therefore, r is correct.
B : p
Reason : The magnetic field at P due to current in loop A is along the axial line towards right. Similarly, the magnetic field at P due to current in loop B is also along the axial line towards right.
C : q, r
Reason : The magnetic field due to current in loop A at P is equal and opposite to the magnetic field due to current in loop B at P.
D : q, s
Reason : The direction of magnetic field at P due to current in loop A is perpendicular to the plane of paper directed vertically upwards.
The direction of magnetic field at P due to current in loop B is perpendicular to the plane of paper directed vertically downward.
Since the current are in opposite direction the wires repel each other. But net force on each wire is zero.

G. Comprehension Based Questions

1. (d) The magnetised coils running along the track repel large magnets on the train's under carriage.
2. (d) Initial cost will be more.
3. (b) The magnetic force will pull the vehicle.
4. (c)



Magnetic field due to current carrying loop = Magnetic field due to straight wires

$$B = B_1\cos\theta + B_2\cos\theta = 2B_1\cos\theta$$

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

$\Rightarrow h \approx 1.2a$

The current is from P to Q in wire 1 and from R to S in wire 2.

5. (b) We know that torque

$$\vec{\tau} = \vec{M}\times\vec{B}$$
$$\tau = MB\sin\theta$$
$$= (I\times\pi a^2)\times\left[2\times\frac{\mu_0 I}{2\pi d}\right]\sin 30^\circ$$
$$= \frac{\mu_0 I^2 a^2}{2d}$$

6. (a, d) When megnetic force balances electric force

$$F_B = F_E$$
$$q\,v_d B = qE$$

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

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

$\left[v_d = \frac{I}{neA} = \frac{I}{newd}\right]$

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

$\therefore \quad V \propto \frac{1}{d} \quad \Rightarrow \quad V_1 d_1 = V_2 d_2$

when $d_1 = 2d_2$, $V_2 = 2V_1$
and when $d_1 = d_2$, $V_2 = V_1$
(a), (d) are correct options

7. **(a,c)**
Here

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

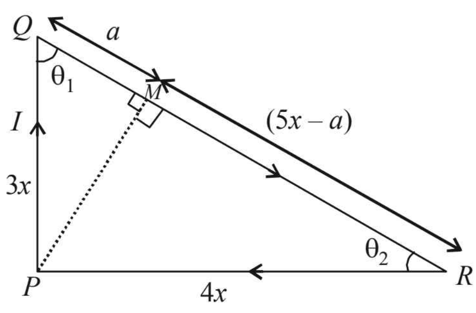
If $B_1 = B_2$ and $n_1 = 2n_2 \Rightarrow V_2 = 2V_1$
and of $B_1 = 2B_2$ and $n_1 = n_2 \Rightarrow V_2 = 0.5V_1$
A and C are the correct options.

H. Assertion & Reason Type Questions

1. **(c)** Statement-1 is true. Sensitivity = $\frac{\theta}{I} = \frac{NBA}{C}$. If B increases, $\frac{\theta}{I}$ increases. Statement-2 is wrong because soft iron can be easily magnetised and de magnetized.

I. Integer Value Correct Type

1. **(7)**
The right angled triangle is shown in the figure. Let us drop a perpendicular from P on QR which cuts QR at M.
The magnatic field due to currents in PQ and RP at P is zero.
The magnetic field due to current in QR at P is



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

In ΔPQM,
$9x^2 = PM^2 + a^2$ ...(ii)

In ΔPRM,

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

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

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

From (ii) & (iv),

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

$\Rightarrow PM = \sqrt{9x^2 - 3.24x^2} = \sqrt{5.76x^2} = 2.4x$ ...(v)

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

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

From (i), (v), (vi) and (vii),

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

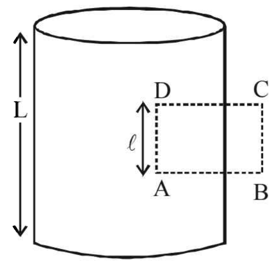
Comparing it with $B = k\left[\frac{\mu_0 I}{48\pi x}\right]$, we get, k = 7.

2. **(6)** Let us consider an amperian loop ABCD which is a rectangle as shown in the figure.
Applying ampere's circuital law we get

$\oint \vec{B}.\vec{d\ell} = \mu_o \times$ (current passing through the loop)

$\therefore \quad \oint \vec{B}.\vec{d\ell} = \mu_o\left(\frac{I}{L}\right) \times \ell$

$\therefore \quad B \times \ell = \mu_o \frac{I}{L} \times \ell$



$\therefore \quad B = \frac{\mu_o I}{L} = \frac{\mu_o}{L} I_o \cos(300t)$

The magnetic moment of the loop
= (current in the loop) × πr^2

$= \frac{1}{R}\left(-\frac{d\phi}{dt}\right) \times \pi r^2$

$= -\frac{1}{R}\left[\frac{d}{dt}(B \times \pi r^2)\right] \times \pi r^2 = -\frac{\pi^2 r^4}{R}\frac{dB}{dt}$

$= \left[\frac{\pi^2 r^4}{R} \times \frac{\mu_o}{L} I_o \sin(300t)\right] \times 300$

Comparing it with the expression given in the question we get

$N = \frac{300\pi^2 r^4}{R} \times \frac{1}{L} = \frac{300(3.14)^2 \times (0.1)^4}{0.005 \times 10} = 6$

3. **(5)** Current density $J = \frac{\text{current}}{\text{area}} = \frac{I}{\pi(2a)^2} = \frac{I'}{(\pi a^2)}$

$\Rightarrow \quad I' = \frac{I}{4}$

Let us consider the cavity to have current I' flowing in both the directions.
The magnetic field at P due to the current flowing through the cylinder

$$B_1 = \frac{\mu_0}{4\pi}\frac{2I}{a}$$

The magnetic field at P due to the current (I') flowing in opposite direction is

$$B_2 = \frac{\mu_0}{4\pi}\frac{3I'}{3a/2} = \frac{\mu_0}{4\pi}\frac{2(I/4)}{3a/2} = \frac{\mu_0}{4\pi}\frac{I}{3a}$$

$\therefore$ The net magnetic field is

$$B = B_1 - B_2 = \frac{\mu_0}{4\pi}\frac{I}{a}\left[2 - \frac{1}{3}\right] = \frac{\mu_0}{4\pi}\frac{I}{a} \times \frac{5}{3}$$

$$\therefore \quad B = \frac{\mu_0}{4\pi}\frac{J\pi a^2}{a} \times \frac{5}{3} = \mu_0 \frac{5Ja}{12}$$

4. **(3)** $R = \frac{mv}{qB}$

$\frac{R_1}{R_2} = \frac{B_2}{B_1}$ $\quad$ [$\because m, q, v$ are the same]

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

$$= \frac{X_0 - X_1 + X_1}{X_0 - X_1 - X_1} = \frac{X_0}{X_0 - 2X_1}$$

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

Section-B JEE Main/ AIEEE

1. **(a)** **KEY CONCEPT :** We know that the magnetic field produced by a current carrying circular coil of radius r at its centre is $B = \frac{\mu_0}{4\pi}\frac{I}{r} \times 2\pi$

Here $B_A = \frac{\mu_0}{4\pi}\frac{I}{R} \times 2\pi$ and $B_B = \frac{\mu_0}{4\pi}\frac{2I}{2R} \times 2\pi$

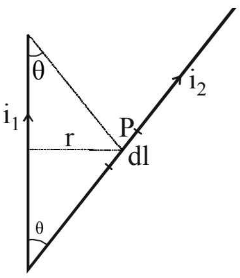
$\Rightarrow \frac{B_A}{B_B} = 1$

2. **(a)** **KEY CONCEPT :** When a charged particle enters perpendicular to a magnetic field, then it moves in a circular path of radius.

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

where q = Charge of the particle
p = Momentum of the particle
B = Magnetic field
Here p, q and B are constant for electron and proton, therefore the radius will be same.

3. **(c)** Magnetic field due to current in wire 1 at point P distant r from the wire is



$$B = \frac{\mu_0}{4\pi}\frac{i_1}{r}[\cos\theta + \cos\theta]$$

$B = \frac{\mu_0}{2\pi}\frac{i_1 \cos\theta}{r}$ (directed perpendicular to the plane of paper, inwards)

The force exerted due to this magnetic field on current element $i_2\, dl$ is
$dF = i_2\, dl\, B \sin 90°$

$$\therefore dF = i_2\, dl\left[\frac{\mu_0}{2\pi}\frac{i_1 \cos\theta}{r}\right] = \frac{\mu_0}{2\pi r} i_1 i_2\, dl \cos\theta$$

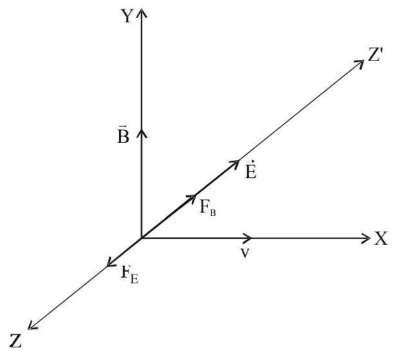
4. **(a)** **KEY CONCEPT :** The time period of a charged particle (m, q) moving in a magnetic field (B) is $T = \frac{2\pi m}{qB}$

The time period does not depend on the speed of the particle.

5. **(b)** The workdone, $dW = Fds\cos\theta$
The angle between force and displacement is 90°.
Therefore work done is zero.

6. (a) The situation is shown in the figure.
F_E = Force due to electric field
F_B = Force due to magnetic field
It is given that the charged particle remains moving along X-axis (i.e. undeviated). Therefore $F_B = F_E$

$$\Rightarrow qvB = qE \Rightarrow B = \frac{E}{v} = \frac{10^4}{10} = 10^3 \text{ weber/m}^2$$



7. (b) **KEY CONCEPT :** The time period of a rectangular magnet oscillating in earth's magnetic field is given by

$$T = 2\pi\sqrt{\frac{I}{\mu B_H}}$$

where I = Moment of inertia of the rectangular magnet
μ = Magnetic moment
B_H = Horizontal component of the earth's magnetic field

Case 1 : $T = 2\pi\sqrt{\frac{I}{\mu B_H}}$ where $I = \frac{1}{12}M\ell^2$

Case 2 : Magnet is cut into two identical pieces such that each piece has half the original length. Then

$$T' = 2\pi\sqrt{\frac{I'}{\mu' B_H}}$$

where $I' = \frac{1}{12}\left(\frac{M}{2}\right)\left(\frac{\ell}{2}\right)^2 = \frac{I}{8}$ and $\mu' = \frac{\mu}{2}$

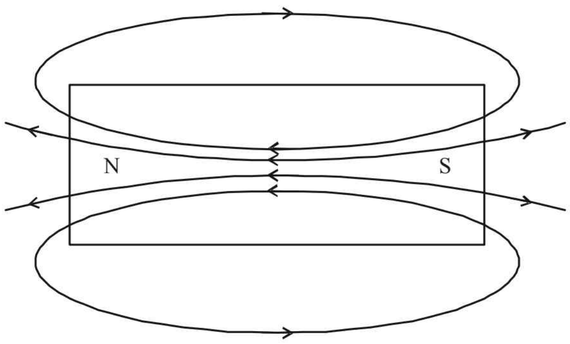
$$\therefore \frac{T'}{T} = \sqrt{\frac{I'}{\mu'} \times \frac{\mu}{I}} = \sqrt{\frac{I/8}{\mu/2} \times \frac{\mu}{I}} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

8. (a) $W = MB(\cos\theta_1 - \cos\theta_2)$

$$= MB(\cos 0° - \cos 60°) = MB(1 - \frac{1}{2}) = \frac{MB}{2}$$

$$\therefore \tau = MB\sin\theta = MB\sin 60° = \sqrt{3}\frac{MB}{2} = \sqrt{3}W$$

9. (d) As shown in the figure, the magnetic lines of force are directed from south to north inside a bar magnet.



10. (a) **KEY CONCEPT :** The temperature above which a ferromagnetic substance becomes paramagnetic is called Curie's temperature.

11. (b) Using Ampere's law at a distance r from axis, B is same from symmetry.

$$\int B.dl = \mu_0 i \quad \text{i.e., } B \times 2\pi r = \mu_0 i$$

Here i is zero, for $r < R$, whereas R is the radius
$\therefore B = 0$

12. (b) **KEY CONCEPT :** Magentic field at the centre of a circular coil of radius R carrying current i is $B = \frac{\mu_0 i}{2R}$

Given : $n \times (2\pi r') = 2\pi R$

$$\Rightarrow nr' = R \quad ...(1)$$

$$B' = \frac{n.\mu_0 i}{2r'} \quad ...(2)$$

from (1) and (2), $B' = \frac{n\mu_0 i.n}{2\pi R} = n^2 B$

13. (c) The magnetic field at a point on the axis of a circular loop at a distance x from centre is,

$$B = \frac{\mu_0 i\, a^2}{2(x^2 + a^2)^{3/2}} \quad B' = \frac{\mu_0 i}{2a}$$

$$\therefore B' = \frac{B.(x^2 + a^2)^{3/2}}{a^3}$$

Put $x = 4$ & $a = 3 \Rightarrow B' = \frac{54(5^3)}{3 \times 3 \times 3} = 250\ \mu T$

14. (a) Force between two long conductor carrying current,

$$F = \frac{\mu_0}{4\pi}\frac{2I_1 I_2}{d} \times \ell$$

$$F' = -\frac{\mu_0}{4\pi}\frac{2(2I_1)I_2}{3d}\ell \quad \therefore \frac{F'}{F} = \frac{-2}{3}$$

15. (b) $T = 2\pi\sqrt{\frac{I}{M \times B}}$ where $I = \frac{1}{12}m\ell^2$

When the magnet is cut into three pieces the pole strength will remain the same and

$$\text{M.I. } (I') = \frac{1}{12}\left(\frac{m}{3}\right)\left(\frac{\ell}{3}\right)^2 \times 3 = \frac{I}{9}$$

We have, Magnetic moment (M)

$= \text{Pole strength } (m) \times \ell$

$\therefore$ New magnetic moment,

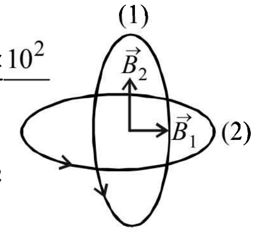
$$M' = m \times \left(\frac{\ell}{3}\right) \times 3 = m\ell = M \quad \therefore T' = \frac{T}{\sqrt{9}} = \frac{2}{3} s.$$

16. (b) **NOTE :** Electro magnet should be amenable to magnetisation & demagnetization.
$\therefore$ retentivity should be low & coercivity should be low

17. (d) The magnetic field due to circular coil 1 and 2 are

$$B_1 = \frac{\mu_0 i_1}{2r} = \frac{\mu_0 i_1}{2(2\pi \times 10^{-2})} = \frac{\mu_0 \times 3 \times 10^2}{4\pi}$$

$$B_2 = \frac{\mu_0 i_2}{2(2\pi \times 10^{-2})} = \frac{\mu_0 \times 4 \times 10^2}{4\pi}$$



$$B = \sqrt{B_1^2 + B_2^2} = \frac{\mu_0}{4\pi} . 5 \times 10^2$$

$$\Rightarrow B = 10^{-7} \times 5 \times 10^2 \Rightarrow B = 5 \times 10^{-5} \text{ Wb/m}^2$$

18. (c) Equating magnetic force to centripetal force,

$$\frac{mv^2}{r} = qvB \sin 90°$$

Time to complete one revolution,

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

19. (d) A magnetic needle kept in non uniform magnetic field experience a force and torque due to unequal forces acting on poles.

20. (b) Due to electric field, it experiences force and decelerates i.e. its velocity decreases.

21. (b) Ferromagnetic substance has magnetic domains whereas paramagnetic substances have magnetic dipoles which get attracted to a magnetic field.
Diamagnetic substances do not have magnetic dipole but in the presence of external magnetic field due to their orbital motion of electrons these substances are repelled.

22. (b) The charged particle will move along the lines of electric field (and magnetic field). Magnetic field will exert no force. The force by electric field will be along the lines of uniform electric field. Hence the particle will move in a straight line.

23. (a) $$\frac{B_2}{B_1} = \frac{\mu_0 n_2 i_2}{\mu_0 n_1 i_1} \Rightarrow \frac{B_2}{6.28 \times 10^{-2}} = \frac{100 \times \frac{i}{3}}{200 \times i}$$

$$\Rightarrow B_2 = \frac{6.28 \times 10^{-2}}{6} = 1.05 \times 10^{-2} \ Wb/m^2$$

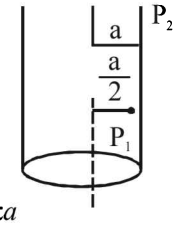
24. (d) Here, current is uniformly distributed across the cross-section of the wire, therefore, current enclosed in the amperean path formed at a distance $r_1 \left(= \frac{a}{2}\right)$

$$= \left(\frac{\pi r_1^2}{\pi a^2}\right) \times I, \text{ where } I \text{ is total current}$$

$\therefore$ Magnetic field at P_1 is

$$B_1 = \frac{\mu_0 \times \text{current enclosed}}{\text{Path}}$$

$$\Rightarrow B_1 = \frac{\mu_0 \times \left(\frac{\pi r_1^2}{\pi a^2}\right) \times I}{2\pi r_1} = \frac{\mu_0 \times I r_1}{2\pi a^2}$$



Now, magnetic field at point P_2,

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

$$\therefore \text{Required ratio} = \frac{B_1}{B_2} = \frac{\mu_0 I r_1}{2\pi a^2} \times \frac{4\pi a}{\mu_0 I}$$

$$= \frac{2r_1}{a} = \frac{2 \times \frac{a}{2}}{a} = 1.$$

25. (d) There is no current inside the pipe. Therefore

$$\oint \vec{B}.\vec{d\ell} = \mu_o I$$

$$I = 0$$

$$\therefore \quad B = 0$$

26. (b) Here, $\vec{E}$ and $\vec{B}$ are perpendicular to each other and the velocity $\vec{v}$ does not change; therefore

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

Also,

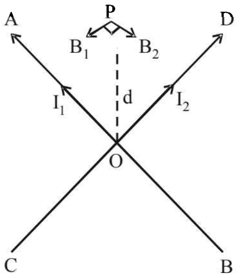
$$\left|\frac{\vec{E} \times \vec{B}}{B^2}\right| = \frac{E\ B \sin\theta}{B^2} = \frac{E\ B\ \sin 90°}{B^2} = \frac{E}{B} = |\vec{v}| = v$$

27. (b) **NOTE :** When a charged particle enters a magnetic field at a direction perpendicular to the direction of motion, the path of the motion is circular. In circular motion the direction of velocity changes at every point (the magnitude remains constant).
Therefore, the tangential momentum will change at every point. But kinetic energy will remain constant as it is given by $\frac{1}{2}mv^2$ and v^2 is the square of the magnitude of velocity which does not change.

28. (c) Clearly, the magnetic fields at a point P, equidistant from AOB and COD will have directions perpendicular to each other, as they are placed normal to each other.

$\therefore$ Resultant field, $B = \sqrt{B_1^2 + B_2^2}$

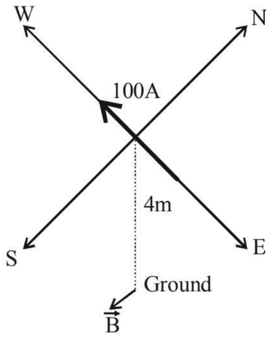
But $B_1 = \frac{\mu_0 I_1}{2\pi d}$ and $B_2 = \frac{\mu_0 I_2}{2\pi d}$



$$\therefore\ B = \sqrt{\left(\frac{\mu_0}{2\pi d}\right)^2 \left(I_1^2 + I_2^2\right)}$$

or, $B = \frac{\mu_0}{2\pi d}\left(I_1^2 + I_2^2\right)^{1/2}$

29. **(c)** The magnetic field is



$$B = \frac{\mu_0}{4\pi}\frac{2I}{r}$$

$$= 10^{-7} \times \frac{2 \times 100}{4}$$

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

According to right hand palm rule, the magnetic field is directed towards south.

30. **(b)** For a diamagnetic material, the value of μ_r is less than one. For any material, the value of ϵ_r is always greater than 1.

31. **(a)** The magnetic field at O due to current in DA is

$$B_1 = \frac{\mu_o}{4\pi}\frac{I}{a} \times \frac{\pi}{6} \qquad \text{(directed vertically upwards)}$$

The magnetic field at O due to current in BC is

$$B_2 = \frac{\mu_o}{4\pi}\frac{I}{b} \times \frac{\pi}{6} \qquad \text{(directed vertically downwards)}$$

The magnetic field due to current AB and CD at O is zero.

Therefore the net magnetic field is

$$B = B_1 - B_2 \qquad \text{(directed vertically upwards)}$$

$$= \frac{\mu_o}{4\pi}\frac{I}{a}\frac{\pi}{6} - \frac{\mu_o}{4\pi}\frac{I}{b} \times \frac{\pi}{6} = \frac{\mu_o I}{24}\left(\frac{1}{a} - \frac{1}{b}\right) = \frac{\mu_o I}{24ab}(b-a)$$

32. **(a)** **KEY CONCEPT :** $\vec{F} = I(\vec{\ell} \times \vec{B})$

The force on AD and BC due to current I_1 is zero. This is because the directions of current element $I\,\vec{d\ell}$ and magnetic field $\vec{B}$ are parallel.

33. **(a)** The magnetic field varies inversely with the distance for a long conductor. That is, $B \propto \frac{1}{d}$. According to the magnitude and direction shown graph (1) is the correct one.

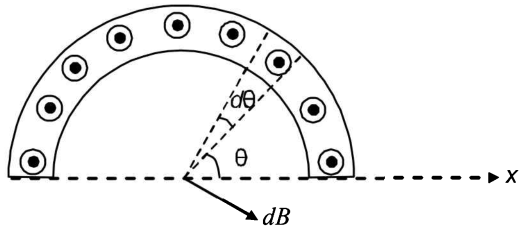
34. **(d)** Current in a small element, $dI = \frac{d\theta}{\pi} I$

Magnetic field due to the element

$$dB = \frac{\mu_0}{4\pi}\frac{2dI}{R}$$

The component $dB \cos\theta$, of the field is cancelled by another opposite component.

Therefore,



$$B_{net} = \int dB \sin\theta = \frac{\mu_0 I}{2\pi^2 R}\int_0^{\pi} \sin\theta d\theta = \frac{\mu_0 I}{\pi^2 R}$$

35. **(a)** The magnetic field due a disc is given as

$$B = \frac{h_0 \omega Q}{2\pi R} \text{ i.e., } B \propto \frac{1}{R}$$

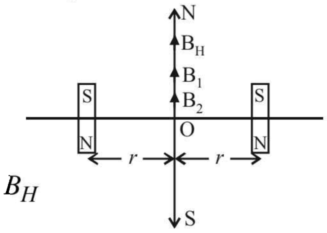
36. **(b)** $r = \frac{\sqrt{2mv}}{qB} \Rightarrow r \times v \frac{\sqrt{m}}{q}$

Thus we have, $r_\alpha = r_p < r_d$

37. **(b)** Given : $M_1 = 1.20 Am^2$ and $M_2 = 1.00 Am^2$

$$r = \frac{20}{2} cm = 0.1\text{m}$$

$$B_{net} = B_1 + B_2 + B_H$$



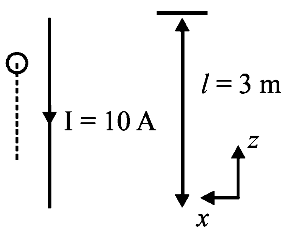
$$B_{net} = \frac{\mu_0}{4\pi}\frac{(M_1 + M_2)}{r^3} + B_H$$

$$= \frac{10^{-7}(1.2+1)}{(0.1)^3} + 3.6 \times 10^{-5} = 2.56 \times 10^{-4}\ \text{wb/m}^2$$

38. **(b)** Work done in moving the conductor is,

$$W = \int_0^2 F dx$$

$$= \int_0^2 3.0 \times 10^{-4} e^{-0.2x} \times 10 \times 3 dx$$



$$= 9 \times 10^{-3}\int_0^2 e^{-0.2x} dx$$

$$= \frac{9 \times 10^{-3}}{0.2}[-e^{-0.2 \times 2} + 1] \quad B = 3.0 \times 10^{-4} e^{-0.2x}$$

(By exponential function)

$$= \frac{9 \times 10^{-3}}{0.2} \times [1 - e^{-0.4}]$$

$= 9 \times 10^{-3} \times (0.33) = 2.97 \times 10^{-3} J$

Power required to move the conductor is,

$$P = \frac{W}{t}$$

$$P = \frac{2.97 \times 10^{-3}}{(0.2) \times 5 \times 10^{-3}} = 2.97\, W$$

39. **(c)** Magnetic field in solenoid $B = \mu_0 n i$

$$\Rightarrow \frac{B}{\mu_0} = ni$$

(Where n = number of turns per unit length)

$$\Rightarrow \frac{B}{\mu_0} = \frac{Ni}{L}$$

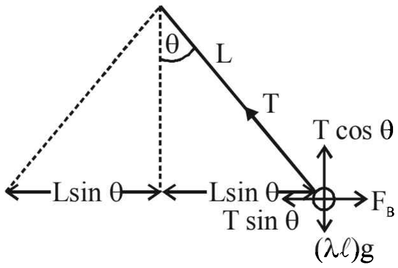
$$\Rightarrow 3 \times 10^3 = \frac{100i}{10 \times 10^{-2}}$$

$$\Rightarrow i = 3A$$

40. **(d)** Let us consider 'ℓ' length of current carrying wire.

At equilibrium

$T \cos\theta = \lambda g \ell$



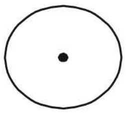
and $T \sin\theta = \frac{\mu_0}{2\pi} \frac{I \times I l}{2L \sin\theta}$ $\left[\because \frac{F_B}{\ell} = \frac{\mu_0}{4\pi} \frac{2I \times I}{2\ell \sin\theta}\right]$

Therefore, $I = 2\sin\theta \sqrt{\frac{\pi \lambda g L}{u_0 \cos\theta}}$

41. **(a)** For stable equilibrium $\vec{M} \parallel \vec{B}$

For unstable equilibrium $\vec{M} \parallel (-\vec{B})$

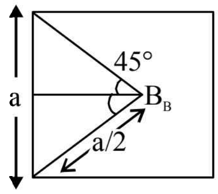
42. **(b)** **Case (a) :**



$$B_A = \frac{\mu_0}{4\pi} \frac{I}{R} \times 2\pi = \frac{\mu_0}{4\pi} \frac{I}{\ell / 2\pi} \times 2\pi \qquad (2\pi R = \ell)$$

$$= \frac{\mu_0}{4\pi} \frac{I}{\ell} \times (2\pi)^2$$

Case (b) :



$$B_B = 4 \times \frac{\mu_0}{4\pi} \frac{I}{a/2} [\sin 45° + \sin 45°]$$

$$= 4 \times \frac{\mu_0}{4\pi} \times \frac{I}{\ell / 8} \times \frac{2}{\sqrt{2}} = \frac{\mu_0}{4\pi} \frac{I}{\ell} \times 32\sqrt{2} \qquad [4a = l]$$

43. **(c)** $I_g G = (I - I_g)s$

$\therefore 10^{-3} \times 100 = (10 - 10^{-3}) \times S$

$\therefore S \approx 0.01\, \Omega$

44. **(b)** Graph [A] is for material used for making permanent magnets (high coercivity)

Graph [B] is for making electromagnets and transformers.