CLASS – 12

WORKSHEET- MOVING CHARGES AND MAGNETISM

A. BIOT-SAVART LAW

(1 Mark Questions)

1. A circular coil of wire consisting of 100 turns each of radius 8.0 cm carries a current of 0.40A, what is the magnitude of magnetic field $\vec{B}$ at the centre of the coil?

Sol. Given N = 100, r = 8cm = 0.08m, I = 0.40A

$\therefore B = \frac{\mu_0 NI}{2r} = \frac{4\pi\times10^{-7}\times100\times0.40}{2\times0.08} = \pi \times 10^{-4} = 3.1 \times 10^{-4}$ T.

2. A long straight wire carries a current of 35A. What is the magnitude of the field $\vec{B}$ at a point 20cm from the wire?

Sol. Here I = 35A, r = 20c = 0.20m, $\mu = 4\pi \times 10^{-7}$ mA^{-1}

$B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi\times10^{-7}\times35}{2\pi\times0.20} = 3.5\times10^{-5}$T.

3. A long straight wire in the horizontal plane carries a current of 50A in the north to south direction. Give the magnitude and direction of $\vec{B}$ at a point 2.5m east of the wire.

Sol. Here I = 50A, r = 2.5m

$B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi\times10^{-7}\times50}{2\pi\times2.5} = 4 \times 10^{-6}$T.

Applying right hand thumb rule, we find that the magnetic field will act in the vertically upward direction at the point 2.5m east of the wire.

4. A horizontal overhead power line carries a current of 90A in an east to west direction. What is the magnitude and direction of magnetic field due to the current 1.5m below the line?

Sol. Here I =- 90A, r = 1.5m, $\mu = 4\pi \times 10^{-7}$ TmA^{-1}

$B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi\times10^{-7}\times90}{2\pi\times2.5}$ T = 1.2×10^{-5} T.

Applying right hand thumb rule, we find that the direction of the field B will be towards south at a point below the power line.

5. State Biot-Savart's law.

Sol. According to Biot-Savart law, the magnetic field due to a current element $I.\vec{dl}$ at the observation point whose position vector is $\vec{r}$ is given by $d.\vec{B} = \frac{\mu_0 I}{4\pi}.\frac{\vec{dl}\times\vec{r}}{r^3}$ where μ_0 is the permeability of free space.

6. What is SI unit of μ_0?

Sol. SI unit of permeability (μ_0) = TmA^{-1} or $WbA^{-1}m^{-1}$.

7. What is the effect of increasing number of turns n magnetic field produced to a circular coil?

Sol. For a circular coil, $B \propto N$. As the number of turns increases, the magnetic field increases.

8. What is force experienced by a stationary charge in a magnetic field?

Sol. For a stationary charge, v = 0. Therefore $F = qvB \sin\theta = q(0) B \sin\theta = 0$.

9. What is the work done by magnetic field on a moving charge?

Sol. Zero, because a magnetic force acts perpendicular to the direction of velocity or the direction of motion fo the charged particle.

10. Biot-Savart Law indicates that the moving electrons (velocity v) produce a magnetic field B such that

(a) $B \perp v$ (b) $B \| v$ (c) it obeys inverse cube law

(d) It is along the line joining the electron and point of observation

Ans. (a)

. By Biot-Savart law, $dB = \frac{Id/\sin\theta}{r^2} = \left(\frac{I \times dl}{r}\right)$

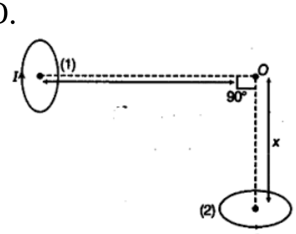
In Biot Savart law, magnetic field **B**||idl × **r** and idl due to flow of electron is in opposite direction of v and by direction of cross product of two vectors

$B \perp V$

So, the magnetic field is $\perp$ to the direction of flow of charge

(2 Marks Questions)

11. Two very small identical circular loops,(1) and (2), carrying equal currents I are placed vertically (with respect to the plane of the paper) with their geometrical axes perpendicular to each other as shown in the magnitude and direction of the net magnetic field produced at the point O.

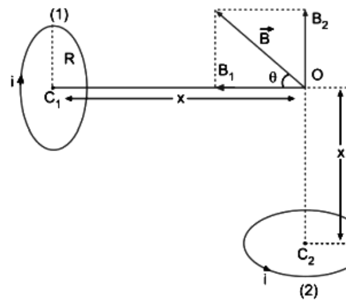


Sol. The magnetic field at an axial point due to a circular loop is given by

$B = \frac{\mu_0}{4\pi} \frac{2\pi I a^2}{(a^2+r^2)^{3/2}}$ where I = current through the loop, a = radius of the loop, r = distance of O from the centre of the loop.

Since I, a and r = x are the same for both the loops, the magnitude of B woill be same and is given by $B_1 - B_2 = \frac{\mu_0}{4\pi}\frac{2\pi I a^2}{(a^2+r^2)^{3/2}}$

The direction of magnetic field due to loop (1) will be away from O and that of loop (2) will be towards O as shown. The direction of the net magnetic field will bas as shown in figure.



The magnitude of the net magnetic field is given by $B_{net} = \sqrt{B_1^2 + B_2^2}$

$B_{net} = \frac{\mu_0}{4\pi}\frac{2\sqrt{2}\pi I a^2}{(a^2+x^2)^{3/2}}$

(3 Marks Questions)

12. (a) State biot-savart law and express this law in the vector form.

(b) Two identical circular coils, P and Q each of radius R, carrying current 1 A and $\sqrt{3}$ A respectively; are placed concentrically and perpendicular to each other lying in the XY and YZ planes. Find the magnitude and direction of the net magnetic field at the Centre of the coils.

Sol. (a) A current carrying wire produces a magnetic field around it. Biot-Savart law states that magnitude of intensity of small magnetic field $d\vec{B}$ due to current I carrying element $d\vec{l}$ at any point P at distance r fro it is given by

$|d\vec{B}| = \frac{\mu_0 I dl \sin\theta}{4\pi r^2}$ where θ is the angle between $\vec{r}$ and $d\vec{l}$ and $\mu_0 = 4\pi \times 10^{-7}$ TmA^{-1} is called permittivity of free space.

In vectorial form, $d\vec{B} = \frac{\mu_0 I}{4\pi}\frac{d\vec{l} \times r}{r^3}$

So, the direction of $d\vec{B}$ is perpendicular to the plane containing $\vec{r}$ and $d\vec{l}$.

SI unit of magnetic field strength is tesla denoted by "T" and cgs unit is gauss determined by 'G', where 1T = 10^4G.

(b) Field due to current in coil P is

$\vec{B}_1 = \frac{\mu_0 I_1}{2R}.\hat{k}$

Current in coil Q is $\vec{B}_2 = \frac{\mu_0 I_2}{2R}.\hat{i}$

∴ Net field $\vec{B} = \vec{B}_1 + \vec{B}_2$

∴ $\vec{B} = \left(\frac{\mu_0 I_1}{2R}\right)\hat{k} + \left(\frac{\mu_0 I_2}{2R}\right)\hat{i}$

$= \left(\frac{\mu_0}{2R}\right)^2 + \left(\frac{\sqrt{3}\mu_0}{2R}\right)^2$ ($\because$ I_1= 1A, $I_2 = \sqrt{3}$A)

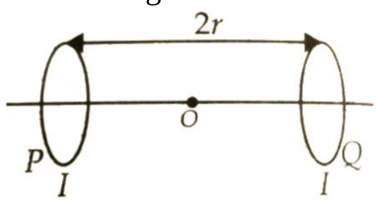
$\therefore \vec{B} = \sqrt{\left(\frac{\mu_0}{2R}\right)^2 + \left(\frac{\sqrt{3}\mu_0}{2R}\right)^2}$

$= \frac{\mu_0}{2R}\sqrt{1+3} = \frac{\mu_0}{2R} \times 2$

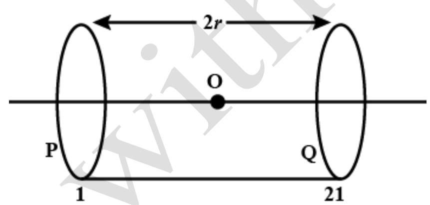
$\therefore \vec{B} = \frac{\mu_0}{2R}$

The resultant magnetic field is directed to XZ plane.

13. Two identical circular loops P and Q each of radius r and carrying equal currents I are kept in the parallel planes having a common axis passing through O. the direction of current in P is clockwise and in Q is anti- clockwise as seen from O which is equidistant from the loops P and Q . find the magnitude of the net magnetic field at O.



Sol. The magnetic field at a point on the axis of a circular point on the axis from the centre of the loop:



A magnetic field at O due to loop P is $B_P = \frac{\mu_0 I r^2}{2(r^2+r^2)^{3/2}} = \frac{\mu_0 I r^2}{2(2r^2)^{3/2}} = \frac{\mu_0 I}{2(2)^{3/2} r}$

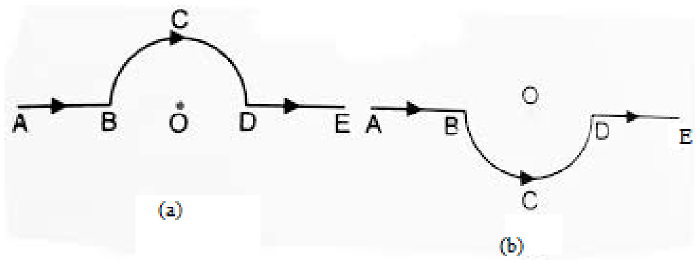
By the right hand thumb's rule, the dimension of magnetic field will be towards left.

Magnetic field at O due to loop Q is $B_Q = \frac{\mu_0 I r^2}{2(r^2+r^2)^{3/2}} = \frac{\mu_0 I r^2}{2(2r^2)^{3/2}} = \frac{\mu_0 I}{2(2)^{3/2} r}$

By the right hand thumb's rule, the direction of the magnetic field will be toward left.

Since B_P and B_Q are equal in magnitude and in same direction. Therefore, net magnetic field at O is $\vec{B} = \vec{B}_P + \vec{B}_Q = \frac{\mu_0 I}{2^{3/2} r}$

14. A straight wire carrying a current of 12A is bent into a semicircular arc of radius 2.0 as shown in the figure (a). What is the direction and magnitude of **B** at the centre of the arc? Would your answer change if the wore were bent into a semicircular arc of same radius but in the opposite way as shown in the figure (b)?



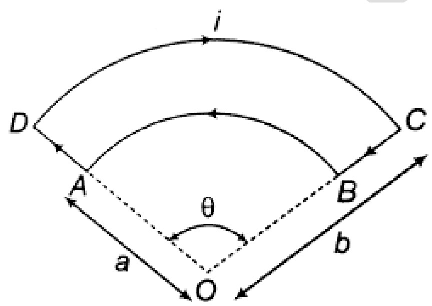
Sol. (a) magnetic field at the center of the arc is $B = \frac{\mu_0 I}{4r}$. Here I = 12A, r = 3.0cm = 0.02m, $\mu_0 = 4\pi \times 10^{-7}$ TmA^{-1}.

Therefore, $B = \frac{4\pi\times10^{-7}\times12}{4\times0.02} = 1.9\times10^{-4}T$

According to right hand rule, the direction of the field is normally into the plane of paper.

(b) The magnetic field will be of same magnitude, $B = 1.9 \times 10^{-4}T$. The direction of the field is normally out of the plane of paper.

15. Figure shows a current loop having two circular segments and joined by two radial lines. Find the magnetic field at the centre O.



Sol. Since the point O lies on lines SP and QR, so, the magnetic field at O due to these straight portions is zero.

The magnetic field at O due to the circular segment PQ is $B_1 = \frac{\mu_0}{4\pi}\frac{I}{a^2} l$, Here l is the length of arc PQQ = αa.

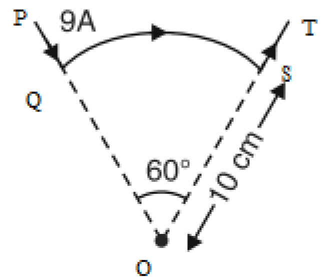
$\therefore B_1 = \frac{\mu_0}{4\pi}\frac{I\alpha}{a}$, directed normally upward.

Similarly the magnetic field at O due to circular segments SR is, $B_2 = \frac{\mu_0}{4\pi}\frac{I\alpha}{b}$ directed normally downward.

The resultant field at O is, $B = B_1 - B_2 = \frac{\mu_0 I\alpha}{4\pi}\left[\frac{1}{a} - \frac{1}{b}\right]$

Or $B = \frac{\mu_0 I\alpha(b-a)}{4\pi ab}$

16. A circular segment of radius10cm subtends an angle of 60° at its centre. A current of 9A is flowing through it. Find the magnitude and direction of the magnetic field produced at the centre. [Ans. 9.42×10^{-6} T]



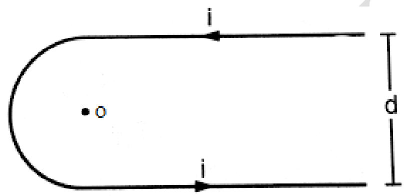
Sol. Here $\theta = 60° = \pi/3$ rad

As θ (rad) = l/r, $\therefore \pi/3 = l/r$ or $l = \pi r/3$

According to Biot-Savart law, magnetic field at centre O is

$$B = \frac{\mu_0}{4\pi}.\frac{Il}{r^2} = \frac{\mu_0}{4\pi}.\frac{I}{r^2}.\frac{\pi r}{3} = \frac{\mu_0}{4\pi}.\frac{\pi}{3}.\frac{I}{r} = \frac{10^{-7}\times 3.14\times 9}{3\times 0.10} = 9.42\times 10^{-6}\text{T}$$

17. In the figure, the curved portion is a semicircle and the straight wires are long. Find the magnetic field at the point O.



Sol. Magnetic field at point O due to any current element is perpendicular to and points out of the plane of paper.

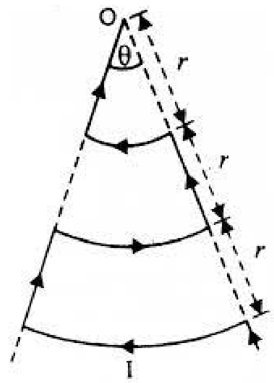
Magnetic field at O due to upper straight wire is $B_1 = \frac{1}{2}\times\frac{\mu_0 I}{2\pi(\frac{d}{2})} = \frac{\mu_0 I}{2\pi d}$

Similarly field at O due to lower straight wire is $B_2 = \frac{\mu_0 I}{2\pi d}$

Field at O due to the semicircle of radius d/2 is $B_3 = \frac{1}{2}\times\frac{\mu_0 I}{2(\frac{d}{2})} = \frac{\mu_0 I}{2d}$

Resultant field at O, $B = B_1 + B_2 + B_3 = \frac{\mu_0 I}{2d}\left[1 + \frac{2}{\pi}\right]$

18. A metallic wire is bent into the shape shown in the figure and carries a current I. If O is the common centre of all the three circular arcs of radii r, 2r and 3r, find the magnetic field at the point O.



Sol. Magnetic field at O due to straight parts of the wire will be zero. Magnetic fields at O due to the three circular arcs of radii r, 2r and 3r are

$B_1 = \frac{\mu_o I}{4\pi}.\frac{\theta}{r}$, acting normally inward

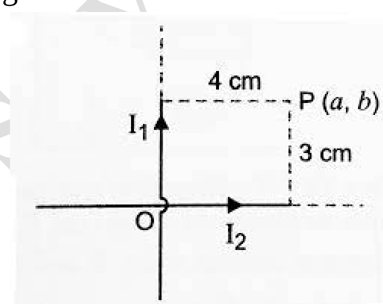
$B_2 = \frac{\mu_o I}{4\pi}.\frac{\theta}{2r}$, acting normally outward

$B_3 = \frac{\mu_o I}{4\pi}.\frac{\theta}{3r}$, acting normally inward

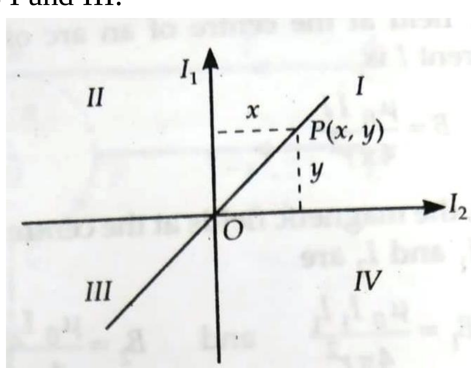
Thus the total magnetic field at the centre O is

$B = B_1 - B_2 + B_3 = \frac{\mu_o I}{4\pi}\left(\frac{\theta}{r} - \frac{\theta}{2r} + \frac{\theta}{3r}\right) = \frac{5\mu_o I}{24\pi r}\theta$, acting normally inward.

19. Two insulating infinitely long conductors carrying currents I_1 and I_2 lie mutually perpendicular to each other in the same plane as shown in figure. Find the locus of the point at which the net magnetic field is zero.



Sol. According to right hand thumb rule, the magnetic fields due to the two conductors can vanish only in regions I and III.



Let the magnetic field be zero at point P(x, y)

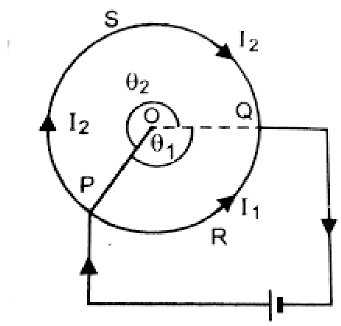
Magnetic field at P due to current I_1, $B_1 = \frac{\mu_0 I_1}{2\pi x}$ (directed inwards)

Magnetic field at P due to current I_2, $B_2 = \frac{\mu_0 I_2}{2\pi y}$ (directed outwards)

As the net magnetic field at P is zero, so $B_1 = B_2$

$\frac{\mu_0 I_1}{2\pi x} = \frac{\mu_0 I_2}{2\pi y}$ or $y = \frac{I_1}{I_2}.x$.

20. As shown in the figure, a cell is connected across two points A and B of a uniform circular conductor. Prove that the magnetic field at its centre O will be zero.



Sol. Let the lengths of the two circular segments ACB and ADB be l_1 and l_2, and ρ be the resistance per unit length. Then

Resistance of segment ACB , $R_1 = l_1\rho$

Resistance of segment ADB, $R_2 = l_2\rho$

Suppose I_1 and I_2 are the currents in segments ACB and ADB respectively. As the two segments are connected in parallel, so the potential differences across them must be equal.

$\therefore I_1R_1 = I_2R_2$

Or $O_1l_1\rho = I_2l_2\rho$ or $I_1l_1 = I_2l_2$

Magnetic field at the centre of an arc of length l carrying current I is, $B = \frac{\mu_0 Il}{4\pi r^2}$

Therefore, the magnetic fields at the centre O due to the current I_1 and I_2 are

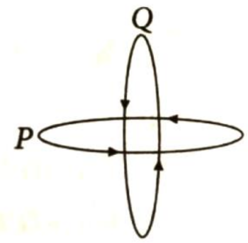
$B_1 = \frac{\mu_0 I_1 l_1}{4\pi r^2}$ and $B_2 = \frac{\mu_0 I_2 l_2}{4\pi r^2}$ where r is the radius of the circular conductor. As $I_1l_1 = I_2l_2$, so, $B_1 = B_2$.

As the currents I_1 and $_2$ are oppositely directed, their magnetic fields B_1 and B_2 will be opposite to each other. Hence the resultant field at the center O is zero.

(5 Marks Questions)

21. Two identical coils P and Q each of radius R are lying in perpendicular planes such that they have a common center. Find the magnitude and direction of the magnitude and

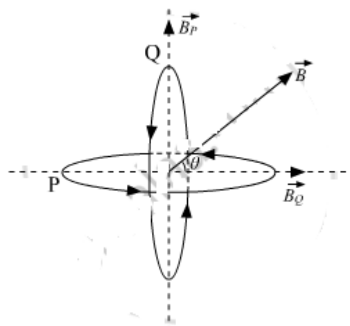
direction of the magnetic field at the common center of the two coils, if they carry currents equal to I $\sqrt{3}$ I respectively.



Sol. Magnetic field at the center of the coils due to the coil P, having current I is $B_P = \frac{\mu_0 I}{2R}$

And magnetic field due to coil Q having current $\sqrt{3}I$ is $B_Q = \frac{\mu_0\sqrt{3}I}{2R}$

Since both coils are inclined to each other at an angle of 90°, the magnitude fo their resultant magnetic field at the common centre will be $B = \sqrt{B_P^2 + B_Q^2} = \frac{\mu_0 I}{2R}\sqrt{1+3} = \frac{\mu_0 I}{R}$

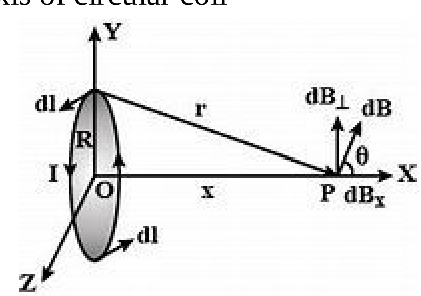


The directions of B_P and B_Q are as indicated in the figure. The direction of their resultant field is at an angle θ given by $\theta = \tan^{-1}\left(\frac{B_P}{B_Q}\right) = \tan^{-1}\left(\frac{1}{\sqrt{3}}\right) = 30°$

Hence the direction of the magnetic field will be at an angle 30° to the plane of loop P.

22. A circular loop of radius R carries a current I. obtain an expression for the magnetic field at a point on its axis at a distance x from its center.

Sol. Magnetic field on the axis of circular coil



Small magnetic field due to a current element of circular coil of radius r at point P at distance x from its centre is $dB = \frac{\mu_0}{4\pi}\frac{Idl\sin 90°}{S^2} = \frac{\mu_0}{4\pi}\frac{Idl}{(r^2+x^2)}$

Components dBcosϕ due to current element at point P is canceled by equal and opposite component dBcosϕ of another diametrically opposite current element, where the sine components dBsinϕ add up to give net magnetic field along the axis. So, net magnetic field at point P due to entire loop is B = $\oint dB\sin\emptyset = \int_0^{2\pi r} \frac{\mu_0}{4\pi}\frac{Idl}{(r^2+x^2)}.\frac{r}{(r^2+x^2)^{3/2}}$

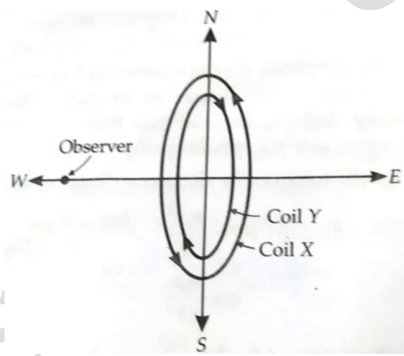
B = $\frac{\mu_0 Ir}{4\pi(r^2+x^2)^{3/2}}\int_0^{2\pi r} dl$

Or B = $\frac{\mu_0 Ir}{4\pi(r^2+x^2)^{3/2}}.2\pi r$

Or B = $\frac{\mu_0 Ir^2}{2(r^2+x^2)^{3/2}}$ directed along the axis (a) towards the coil if current in it is in clockwise direction. (b) away from the coil if current in it is in anticlockwise direction.

23. Two concentric circular coils X and Y of radii 16cm and 10cm respectively lie in the same vertical plane containing the north-south direction. Coil X has 20 turns and carries a current of 16A; coil Y has 25 terms and carries a current of 18A. The sense of current in X is anticlockwise, and in Y clockwise, for an observer looking at the coils facing west. Give the magnitude and direction of the net magnetic field due to the coils at their centre.

Sol.



For coil X, r_x = 16cm = 0.16m, N_x = 20, I_x = 16A

∴ Magnetic field at the centre of coil X is $B_x = \frac{\mu_0 I_x N_x}{2r_x} = \frac{4\pi\times10^{-7}}{2}\times\frac{16\times20}{0.16}T = 4\pi\times10^{-4}T$

As the current in the coil X is anticlockwise, the field is directed towards east.

For coil Y: r_y = 10cm= 0.10m, N_y – 25, I = 18A

∴ Magnetic field at the centre of coil Y is $B_y = \frac{\mu_0 I_y N_y}{2r_y} = \frac{4\pi\times10^{-7}}{2}\times\frac{18\times25}{0.10}T = 9\pi\times10^{-4}T$

As the current in the coil Y is clockwise the field B_y is directed towards west. Since $B_y>B_x$, therefore the net field is directed towards west and its magnitude is

$B = B_y - B_x = 5\pi\times10^{-4}T = 1.6\times10^{-3}$ T.

B. AMPERE’S CIRCUITAL LAW

(1 Mark Question)

1. Show the magnetic lines of force around a straight current carrying conductor.

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2. How does current carrying coil behave like a bar magnet?

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(2 Marks Questions)

3. A closely wound solenoid 80cm long has 5 layers of windings of 400 turns each. The diameter of the solenoid is 1.8cm. If the current carried is 8.0A, estimate the magnitude of $\vec{B}$ inside the solenoid near its centre.

Sol. Number of turns per unit length of the solenoid is

$$n = \frac{\text{Number of turns per layer} \times \text{Number of layers}}{\text{Length of solenoid}} = \frac{400 \times 5}{0.80} = 2500 m^{-1}$$

Magnetic field inside the solenoid is, $B = \mu_0 nI = 4\pi \times 10^{-7} \times 2500 \times 8 = 8\pi \times 10^{-3} T$

$= 2.5 \times 10^{-2} T$

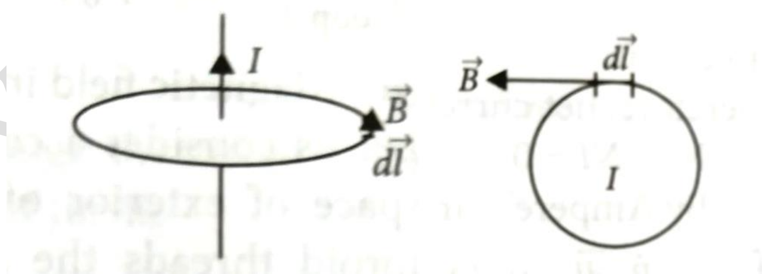
(3 Marks Questions)

4. Explain how biot-savart law enables one to express the Ampere's circuital law in the integral form, viz.

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

where I is the total current passing through the surface.

Sol. Ampere's circuital law states that line integral of magnetic field over a closed loop or circuit is μ_0 times the total; current I threading through the loop i.e., $\oint \vec{B} . d\vec{l} = \mu_0 I$.



Proof: For the small element, $\vec{B} . d\vec{l} = Bdl \cos 0°$

$\int \vec{B} . d\vec{l} = \int B dl = \int \frac{\mu_0 2I}{4\pi r} dl$

$= \int \frac{\mu_0}{4\pi} . \frac{2I}{r} \int dl = \frac{\mu_0}{4\pi} . \frac{2I}{r} \times 2\pi r$

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

5. A toroid has a core (non-ferromagnetic) of inner radius 25cm and outer radius 26cm around which 3500 turns of a wire are wound. If the current is in the wire is 11A, what is the magnetic field (a) outside the toroid (b) inside the core of the toroid (c) in the empty space surrounded by the toroid?

Sol. Here I = 11A, total number of turns = 3500

Mean radius of toroid, $r = \frac{25+26}{2} = 25.5\text{cm} = 25.5 \times 10^{-2}\text{m}$

Length of (circumference) of the toroid = $2\pi r = 2\pi \times 25.5\times10^{-2} = 51.0\times10^{-2}\pi\text{m}$

$\therefore$ Number of turns per unit length, $n = \frac{3500}{51.0\times10^{-2}\pi}$

(a) The field outside the toroid is zero

(b) The field inside the core of the toroid, $B = \mu_0 nI = 4\pi \times 10^{-7} \times \frac{3500}{51.0\times10^{-2}\pi} \times 11$

$= 3.02 \times 10^{-2}\text{T}$

(c) The field in the empty space surrounded by the toroid is zero.

6. State Ampere's circuital law and prove this law for a circular path around a long current carrying conductor.

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7. Using Ampere's circuital law, derive an expression for the magnetic field along the axis of a current carrying toroidal solenoid of N number of turns having radius r.

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8. Using Ampere's circuital theorem, calculate magnetic field due to an infinitely long wire carrying current I.

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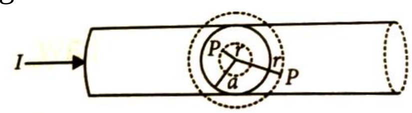
(5 Marks Questions)

9. Figure shows a long straight wire of a circular cross –section of radius 'a' carrying steady current I. the current I is uniformly distributed across the cross-section. Derive the magnetic field in the region $r \leq a$ and $\geq a$.



Sol. (i) Let us consider a circular loop L_1 of radius (r_1 <a) inside the current carrying wire. The current enclosed buy this loop L_1 is $I_1 = \frac{I}{\pi a^2} \times \pi r_1^2 = \frac{I r_1^2}{a^2}$

So, by Ampere's curcuital law, $\oint_{L_1} \vec{B}.d\vec{l} = \mu_0 I_1 = \frac{\mu_0 I_1 r_1^2}{a^2}$ …(i)

Also, $\oint_{L_1} \vec{B}.d\vec{l} = \oint_{L_1} \vec{B}.d\vec{l} \cos 0° = \oint_{L_1} \vec{B}.d\vec{l} = B.2\pi r_1$ …(ii)

So, by equations (i) and (ii)

$B.2\pi r_1 = \frac{\mu_0 I_1 r_1^2}{a^2}$ or $B_{in} = \frac{\mu_0 I r_1}{2\pi a^2}$

(ii) Let us consider a solid metallic wire of cross section 'a' carrying current I. Let us consider a circular loop L of radius r outside the wire, representing a magnetic field line. So, at any point on it magnetic field B is along the tangent to field line at that point.

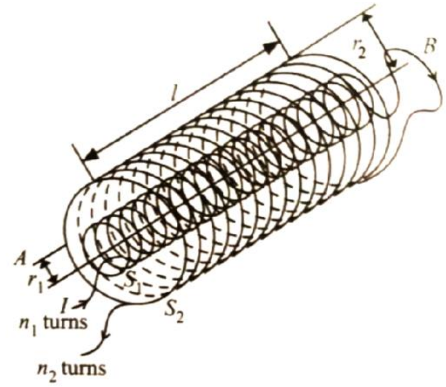
$\oint_L \vec{B}.\vec{dl} = \oint_L B dl \cos 0° = B \oint_L dl = B.2\pi r$ …(i)

But, by Ampere's circuital law, $\oint_L \vec{B}.\vec{dl} = \mu_0 I$ …(ii)

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

$B.2\pi r = \mu_0 I$ or $B_{out} = \frac{\mu_0 I}{2\pi r}$ whereas on the surface of current carrying wire $B_{surface} = \frac{\mu_0 I}{2\pi a}$

10. Two long coaxial insulated solenoid, S_1 and S_2equal length are wound one over the other as shown in the figure. A steady current 'I' flow through the inner solenoid $s_1$to the other end B, which is connected to the outer solenoid S_2through which the same current 'I' flows in the opposite direction so as to come out at end A. if n_1 and $n_2$are the number of turns per unit length, find the magnitude and directions of the net magnetic field at the point (i)inside on the axis and (ii)outside the combined system .



Sol (i) Magnetic field due to a current carrying solenoid, $B = \mu_0 nI$ where n = number fo turns per unit length, I = current flowing in the solenoid

$B_{in} = B_2 - B_1$

$\Rightarrow B_{in} = \mu_0 n_2 I - \mu_0 n_1 I$

$\Rightarrow B_{in} = \mu_0(n_2 - n_1)$.

(ii) Magnetic field at point outside the combined system is zero.

C. LORENTZ FORCE AND MOTION OF A CHARGED PARTICLE INSIDE THE MAGENTIC FIELD

(1 Mark Questions)

1. Write the expression, in a vector form, for the Lorentz magnetic force $\vec{F}$ due to a charge moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$. what is the direction of the magnetic force?

Sol. The magnetic force experienced by the charge of moving velocity v in magnetic field $\vec{B}$ is given by Lorentz, $\vec{F} = q(\vec{v} \times \vec{B})$

The direction of the Lorentz force is perpendicular to the plane containing $\vec{v}$ and $\vec{B}$. The direction is given by right hand screw rule.

2. Define one tesla using the expression for the magnetic force acting on a particle of charge 'q' moving with velocity $\vec{V}$ in a magnetic field B.

Sol. One tesla is defined as the magnitude of magnetic field which produces a force of 1 newton when a charge of 1 coulomb moves perpendicularly in the region of the magnetic field at a velocity of 1 m/s.

$F = qvB \Rightarrow B = \frac{F}{qV}$ or $1T = \frac{1N}{(1C)(\frac{1m}{s})}$.

3. A charge particle after being accelerated through a potential difference 'V' enters in a uniform magnetic field and moves in a circle of radius r. if V is doubled, the radius of the circle will become.

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

Sol. (b)

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

Now $qV = ½ mv^2 \Rightarrow v = \sqrt{\frac{2qV}{m}}$ …(ii)

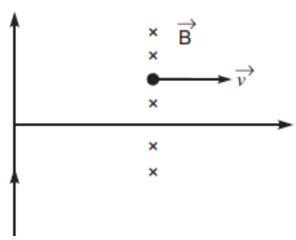
Substituting (ii) in (i)

$r = \frac{m}{qB}\sqrt{\frac{2qV}{m}} = \sqrt{\frac{2mV}{qB^2}}$ …(iii)

Now, V' = 2V, ∴ $r' = \sqrt{\frac{2m(2V)}{qB^2}} = \sqrt{2}\sqrt{\frac{2mV}{qB^2}} = \sqrt{2}\, r$

4. A long straight wire carries a steady current I along the positive y-axis in a coordinate system. A particle of charge +Q is moving with a velocity $\vec{v}$ along the x-axis. In which direction will the particle experience a force?

Sol. From relation $\vec{F} = qVB[\hat{\imath} \times (-\hat{k})] = +qvB(\hat{\jmath})$. Magnetic force $\vec{F}$ will be along +y axis.



5. A narrow beam of protons and deuterons, each having the same momentum, enters a region of momentum. What would be the ratio of the circular paths describe by them?

Sol. Charge on deuteron (q_d) = charge on proton (q_p)

Radius of circular path (r) = $\frac{p}{Bq}$ $\left(\because qvB = \frac{mv^2}{r}\right)$

$r \propto \frac{1}{q}$ [for constant momentum (p)]

So, $\frac{r_p}{r_d} = \frac{q_d}{q_p} = 1$

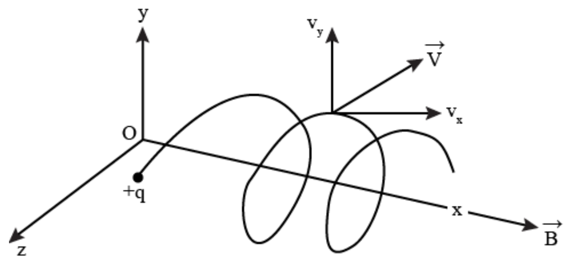
Hence $r_p : r_d = 1 : 1$.

6. Write the condition under which an electron will move undeflected in the presence of crossed electric and magnetic fields.

Sol. The charged particle goes undeflected in the presence of crossed electric and magnetic field only when both these fields are perpendicular to velocity of charged particle. In that case, qE = qvB.

7. A uniform magnetic field B is set up along the positive x-axis. A particle of charge 'q' and mass 'm' moving with a velocity v enter the field at the origin in x-y plane such that it has velocity components both along and a perpendicular to the magnetic field B. trace, giving reason, the trajectory followed by the particle. Find out of expression for the distance moved by the particle along the magnetic field in one rotation.

Sol. Magnetic force an a charged particle $\vec{F} = q(\vec{v} \times \vec{B}) \therefore |\vec{F}| = qvB \sin\theta$



The radius of circular path, $r = \frac{mv\sin\theta}{qB}$

Time period, $T = \frac{2\pi m}{Bq}$

Horizontal distance moved by the particle in one rotation,

Pitch = $v\cos\theta \times T = \frac{2\pi m}{Bq}\cos\theta$

Path of the charged particle will be helical.

8. Answer the following questions: (1 mark each)

(a) A magnetic field that varies in magnitude from point ort point but has a constant direction (east to west) is set up in a chamber. A charged particle enters the chamber and travels undeflected along a straight path with constant speed. What can you say about the initial velocity of the particle?

Sol. The force on a charged particle moving in a magnetic field is given by $F = qvB\sin\theta$. The force on a charged particle will be zero or the particle will remain undeflected if $\sin\theta = 0$ or $\theta = 0°, 180°$

(b) A charged particle enters an environment of a strong and non-uniform magnetic field varying from point to point both in magnitude and direction and comes out of it following a completed trajectory. Would its final speed equal the initial speed if it suffered no collisions with the environment?

Sol. Yes, a magnetic field exerts force on a charged particle in a direction perpendicular to its direction of motion and hence does no work on it. So the charged particle will have its final speed equal to its initial speed.

(c) An electron travelling west to east enters a chamber having a uniform electrostatic field in a north to south direction. Specify the direction in which a uniform magnetic field should be set up to prevent the electron from deflecting from its straight line path.

Sol. The electron travelling west to east experiences a force towards north due to the electrostatic field. It will remain undeflected if it experiences an equal force towards south due the magnetic field. According to Fleming's left hand rule, the magnetic field must act in the vertically downward direction.

9. Two charged particles traverse identical helical paths in a completely opposite sense in a uniform magnetic field $B = B_0\hat{k}$

(a) They have equal z-components of moment a (b) They must have equal charges

(c) They necessarily represent a particle antiparticle pair.

(d) The charge to mass ratio satisfy: $(e/m)_1 + (e/m)_2 = 0$

Ans. (d)

As we know that the uniqueness of helical path is determined by its pitch

P(Pitch) = $\frac{2\pi mv\cos\theta}{Bq}$ where θ is angle of velocity of charge particle with x axis. For the given pitch d correspond to charge particle, we have $\frac{q}{m} = \frac{2\pi v\cos\theta}{BP}$ = constant

If motion is not helical, (θ = 0)

As charged particles traverse identical helical paths in a completely opposite direction in a same magnetic field **B.** LHS for two particles should be same and of opposite sign

Therefore, $\left(\frac{e}{m}\right)_1 + \left(\frac{e}{m}\right)_2 = 0$

10. Show that a force that does not work must be a velocity dependent force.

Sol. dW = **F**.d**I** = 0

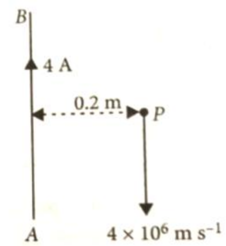
⇒ **F.v**dt = 0

⇒ **F.v** = 0

F must be velocity dependent which implies that angle between **F** and **v** is 90°. If **v** changes (direction) the (directions)**F** should also change so that above condition is satisfied.

(2 Marks Questions)

11. A long straight wire AB carries a current of 4A. A proton P travels at 4×10^6 M s^{-1}parallel to the wire 0.2 m from it a direction opposite to the current as shown in the current as shown in the figure. Calculate the force which the magnetic field due to the current carrying wire exert on the proton. Also specify its direction.



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(3 Marks Questions)

12. Two particles A and B of masses m and 2m have charges q and 2q respectively. Both these particle moving with velocity v_1 and v_2 respectively in the same direction enter the same magnetic field B acting normally to their direction of motion. If the two forces F_A and F_B acting on them are in the ration of 1:2, find the ratio of their velocities.

Sol. $\frac{F_A}{F_B} = \frac{q_{1|(\vec{v}_1 \times \vec{B}_1)|}}{q_{2|(\vec{v}_2 \times \vec{B}_2)|}}$

$\frac{1}{2} = \frac{qv_1 B\sin 90°}{(2q)v_2 B\sin 90°}$ [∵ $B_1 = B_2$; magnetic field is same]

$1 = \frac{v_1}{v_2}$

∴ $v_1 : v_2 = 1 : 1$.

13. A proton, a deuteron and an alpha particle, are accelerated through the same potential difference and then subjected to a uniform magnetic field B, perpendicular to the direction of their motions. Compare
(i) their kinetic energies, and
(ii) if the radius of the circular path described by proton is 5 cm, determine the radii of the path described by deuteron and alpha particles.

Sol. When a proton, a deuteron and an alpha particles are accelerated through potential difference V, then their energies are

$E_p = eV$, $E_d = eV$, $E_\alpha = 2eV$

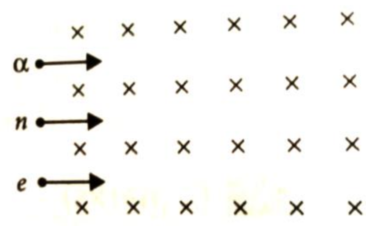
(i) $KE_p = KE_d : KE_\alpha = 1 : 1 : 2$.

(ii) $r = \frac{mv}{qB} = \frac{\sqrt{2mKE}}{qB}$

$r_p : r_d : r_\alpha = \frac{\sqrt{m_p}}{e} : \frac{\sqrt{2m_p}}{e} : \frac{\sqrt{4m_p}}{2e} = 1 : \sqrt{2} : 1$

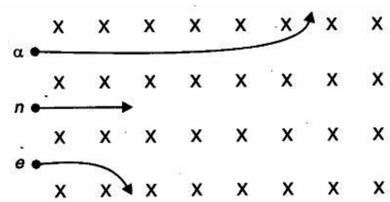
As $r_p = 5$cm, ∴ $r_d = 5\sqrt{2}$ cm, $r_\alpha = 5$ cm.

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



Sol. (a) Magnetic force acting on a charged particle q moving with a velocity v in a uniform magnetic field B is given by, $\vec{F} = q(\vec{v} \times \vec{B})$

(b) Magnetic force on α particle. $F_\alpha = q\vec{v} \times \vec{B}$ =- 2e e B upward



So, curve will bend upward as force is perpendicular to the velocity.

Magnetic force on neutron, F = 0 (as q -= 0). So, neutron will move along straight line.

Magnetic force on electron, $\vec{F}_e = q\vec{v} \times \vec{B}$ = | - q v B| downwards

So, the curve will bend downwards as force is perpendicular to the velocity.

For a charged particle moving in a uniform magnetic field $\vec{B}$ perpendicular to velocity

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

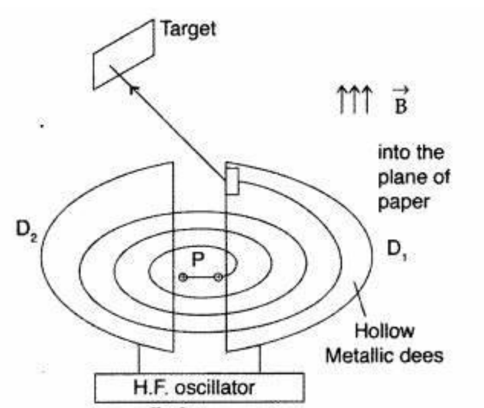
r is the radius of curved path. Here $v_\alpha = v_n = v_e = v$

Radius of path traced by a-particle $r_\alpha = \frac{4m_e v}{2eB} = \frac{2m_e v}{eB}$

Radius of path traced by electron $r_e = \frac{m_e v}{eB}$

15. State the underlying principle of a cyclotron. Write briefly how this machine is used to accelerate charged particle to high energies.

Sol. Cyclotron: It is a device by which positively charged particles like protons, deuterons, etc. can be accelerated.



Cyclotron

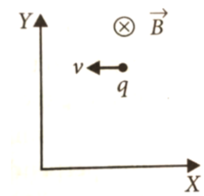
Principle: A positively charged particle can be accelerated by making it to cross the same electric field repeatedly with the help of a magnetic field.

Working and theory: At a certain instant, let D_1 be positive and D_2 be negative. The radius of the circular path is given by $qvB = mv^2/r$ or $r = mv/qB$

Period of revolution, $T = \frac{2\pi r}{v} = \frac{2\pi}{v}.\frac{mv}{qB} = \frac{2\pi m}{qB}$

Frequency of revolution, $f = \frac{1}{T} = \frac{qB}{2\pi m}$

16. (a) A point charge q moving with speed v enters a uniform magnetic field B that is acting into the plane of paper as shown. What is the path followed by the Charge q and in which plane does it moves?



(b) How does the path followed by the charge get affected if its velocity has a component parallel?

(c) if an electric field E is also applied such that the particle continuous moving along the original straight line path, what should be the magnitude and direction of the electric field E.

Sol. (a) When a charged particle having charge q moves inside a magnetic field $\vec{B}$ with velocity $\vec{v}$, it experiences a force.

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

When $\vec{v}$ is perpendicular to $\vec{B}$, the force $\vec{F}$ on the charged particle provides the centripetal force and makes it move along a circular path.

The point charge travels in the plane perpendicular to both $\vec{v}$ and $\vec{B}$.

(b) If a component of velocity of the charge particle is parallel to the direction of the magnetic field, then the force experienced due to that component will be zero, because $F = qvB \sin 0° = 0$ and particle will move in straight line. Also, the force experienced by the component perpendicular to $\vec{B}$ moves the particle in a circular path. The combined effect of both the components will move the particle in a helical path.

(c) The direction of the magnetic force is along negative y axis, so the direction of the electric force should be along the positive Y axis to counter balance the magnetic force and then the charge particle will move in the straight line path.

Therefore, the direction of electric field is along the positive Y axis and its magnitude is given by $E = vB$.

17. In a chamber a uniform magnetic field of 6.5G ($1G = 10^{-4}T$) is maintained. An electron is shot into the field with a speed of 4.8×10^6 ms^{-1} normal to the field. Explain why the path

of the electron is a circle. Determine the radius of the circular orbit. Given that e = 1.6 × 10^{-19} C, m_e = 9.1 × 10^{-31}kg.

Sol. The perpendicular magnetic field exerts a force on the electron perpendicular to its path. This force continuously deflects the electron from its path and makes it moves along a circular path.

∴ Magnetic force on the electron = Centripetal force

$evB \sin 90° = \frac{m_e v^2}{r}$ or $r = \frac{m_e v}{eB}$

Now B = 6.5G = 6.5 × 10^{-4} T, v = 4.8 × 10^6 ms^{-1}

$\therefore r = \frac{9.1\times10^{-31}\times4.8\times10^6}{1.6\times10^{-19}\times6.5\times10^{-4}} = 4.2\times10^{-2}m = 4.2cm$

18. In previous question, obtain the frequency of revolution of the electron in its circular orbit. Does the answer depend on the speed of the electron? Explain.

Sol. Frequency of revolution of the electron in its circular orbit, $f = \frac{eB}{2\pi m} = \frac{1.6\times10^{-19}\times6.5\times10^{-4}}{2\times3.14\times9.1\times10^{-31}}$

= 18.18 × 10^6HZ = 18 MHz.

19. An electron emitted by a heated cathode and accelerated through a potential difference of 2.0 kV, enters a region with uniform magnetic field of 0.15T. Determine the trajectory of the electron if the field (i) is transverse to its initial velocity, (ii) makes and angle of 30° with the initial velocity.

Sol. V = 2.0kV, = 2 × 10^3V, B = 0.15T, e = 1.6 × 10^{-19}C., m = 9.1 × 10^{-31}kg

Potential difference V imparts kinetic energy to the electron given by ½ mv^2 = eV

Or Velocity gained by electron, $v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2\times1.6\times10^{-19}\times2\times10^3}{9.1\times10^{-31}}ms^{-1}} = 2.65\times10^7\ ms^{-1}$.

(i) When field $\vec{B}$ is transverse to the initial velocity $\vec{v}$, $evB \sin 90° = \frac{mv^2}{r}$

$\therefore r = \frac{mv}{eB} = \frac{9.1\times10^{-31}\times2.65\times10^7}{1.6\times10^{-19}\times0.15}m = 10^{-3}m = 1mm$

Thus the electron follows a circular trajectory of radius 1mm around o the field B.

(ii) When field $\vec{B}$ makes an angle 30° to the initial velocity $\vec{v}$,

$v_1 = v\sin30° = 2.65 \times 10^7 \times ½ = 1.33 \times 10^7\ ms^{-1}$.

$v_2 = v \cos 30° = 2.65 \times 10^7 \times 0.866 = 2.3 \times 10^7\ ms^{-1}$

The radius of the helical path is given by $r = \frac{mv_1}{eB} = \frac{mv\sin30°}{eB} = \frac{9.1\times10^{-31}\times1.33\times10^7}{1.6\times10^{-19}\times0.15}$

= 50.4×10^{-5}m = 0.50 mm

20. A magnetic field set up using Helmholtz coils is uniform in a small region and has a magnitude of 075 T. In the same region, a uniform electrostatic field is maintained in a direction normal to the common axis of the coils. A narrow beam of (single species) charged particles all accelerated through 15kV enters this region in a direction perpendicular to both the axis of the coils and the electrostatic field. If the beam remains undeflected when the electrostatic field is 9.0 × 10^5 Vm^{-1}, make a simple guess as to what the beam contains. Why is the answer not unique?

Sol. $B = 0.75T$, $E = 9.0 \times 10^5\ Vm^{-1}$, $V = 15kV = 15 \times 10^3 V$

For undeflected beam, velocity of charged particles must be, $e = \frac{E}{B} = \frac{9.0\times10^5}{0.75} ms^{-1} = 12\times10^5 ms^{-1}$.

But the kinetic energy of the charged particle is given by $\frac{1}{2} mv^2 = qV$

$\therefore \frac{q}{m} = \frac{1}{2} . \frac{v^2}{V^2} = \frac{1}{2} \times \frac{(12\times10^5)^2}{15\times10^3} Ckg^{-1} = 4.8 \times 10^7\ Ckg^{-1}$

Now for electrons, $\frac{q}{m} = \frac{1.6\times10^{-19}}{2\times1.67\times10^{-27}} = 4.8 \times 10^7\ Ckg^{-1}$.

Which means that the particle may be deuterons each of which contain one proton and one neutron. The answer is not unique because we have determined only the ratio of charge to mass. Other possible answer are He^{2+} and Li^{3+} etc.

(5 Marks Questions)

21. Particles of mass 1.6×10^{-27} kg and charge 1.6×10^{-19}C are accelerated in a cyclotron of dee radius 40cm. it employs a magnetic field 0.4 t. find the kinetic energy (in me v) of the particle beam imparted by the accelerator.

Sol. The kinetic energy imparted by accelerator, $KE = \frac{q^2B^2R^2}{2m} = \frac{(1.6\times10^{-19})(0.4)^2(40\times10^{-2})^2}{2\times(1.6\times10^{-27})}$

$= 204.8 \times 10^{-15} J = 1.28\ MeV$.

22. An α-particle is accelerated through a potential difference of 10 kV and moves along x-axis. It enters in a region of uniform magnetic field $B=2\times10^{-3}T$ acting along y-axis. Find the radius of its path.

Sol. Given $\Delta V = 10 \times 10^3 V$, $B = 2 \times 10^{-3} T$

Since charge is accelerated through ΔV, Velocity = $\sqrt{\frac{2q\Delta V}{m}}$ …(i)

Now when R enters a magnetic field, $qvB = \frac{mv^2}{r}$; $r = \frac{mv}{qB} = \frac{m}{qB}\sqrt{\frac{2q\Delta V}{m}} = \sqrt{\frac{2m\Delta V}{B^2 q}}$

For α particle, $q = 2e$, $m = 6.4 \times 10^{-27}$kg

$\therefore r = \sqrt{\frac{2\times6.4\times10^{-27}\times10^4}{(2\times10^{-3})^2\times2\times1.6\times10^{-19}}} = 10m$

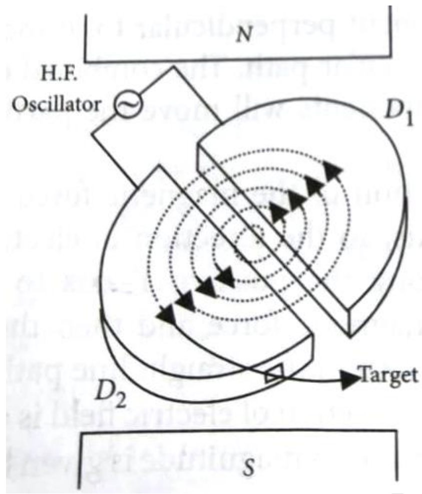
23. (a) Draw a schematic sketch of a cyclotron. Explain clearly the role of closed electric and magnetic field in accelerating the charge. Hence derive the expression for the kinetic energy acquired by the particles.

(b) An α-particles and a proton are released from the center of the cyclotron and made to accelerate.

(i) Can both be accelerate at the same cyclotron frequency? Give reason to justify your answer?

(ii) When they are accelerate in turn, which of the two will have higher velocity at the exit slit of the dees?

Sol. (a)



Electric field accelerates the particle when it passes through the gap and imparts energy to charged particles. Magnetic field makes the charged particles to move in semicircular paths.

Velocity of particle, $v = \frac{Bqr}{m}$

$\therefore K = \frac{1}{2}mv^2 = \frac{B^2q^2r^2}{2m}$

(b) (i) No. The cyclotron frequency depends on the mass of the particle.

(ii) Proton.

D. FORCE ON CURRENT CARRYING CURRENT CONDUCTOR

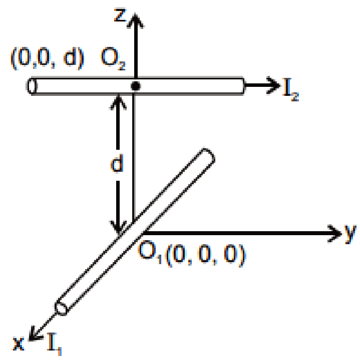
(1 Mark Questions)

1. What is the magnitude of magnetic force per unit length on a wire carrying a current of 8A and making an angle of 30° with the direction of a uniform magnetic field of 0.15T?

Sol. Given I = 8A, θ = 30°, B = 0.15T

As F = IlB sin θ, force per unit length, $f = \frac{F}{l} = lB\sin\theta = 8 \times 0.15 \times \sin 30° = 0.6\ Nm^{-1}$.

2. Two long wires carrying current I_1 and I_2 are arranged as shown in Fig. The one carrying current I_1 is along is the x-axis. The other carrying current I_2 is along a line parallel to the y-axis given by x = 0 and z = d. Find the force exerted at O_2 because of the wire along the x-axis.



Sol. At O_2 the magnetic field due to I_1 is along the y axis. So the radius of path to the Dees's will remain unchanged.

(2 Marks Questions)

3. A 3.0 cm wire carrying a current of 10A is placed inside a solenoid perpendicular to its axis. The magnetic field inside the solenoid is given to be 0.27T. What is the magnetic force on the wire?

Sol. Given l = 3.0cm = 0.03m, I = 10A, θ = 90°, B = 0.27T

$F = IlB \sin\theta = 10 \times 0.03 = 0.27 \times \sin 90° = 8.1 \times 10^{-2}$N

The direction of the force is given by Fleming's left hand rule.

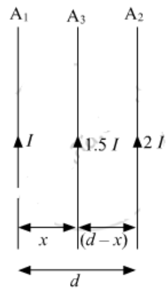
4. Two long and parallel straight wires A and B carrying currents 8.0A and 5.0A in the same direction are separated by a distance of 4.0cm. Estimate the force on a 10cm section of wire A.

Sol. Force per unit length of each wire is $f = \frac{\mu_0 I_1 I_2}{2\pi r} = \frac{4\pi\times10^{-7}\times8\times5}{2\pi\times4\times10^{-2}} = 2 \times 10^{-5}$N.

(3 Marks Questions)

5. Two infinitely long straight wires A_1 and A_2 carrying currents I and 2I following in the same direction are kept 'd' distance apart. Where should a third straight wire A_3 carrying current 1.5 I be placed between A_1 and A_2 so that is experience no net force due to A_1 and A_2? Does the net force acting on A_3 depend on the current flowing through it?

Sol.



Force on A_3 due to A_1, $f_1 = \frac{4\pi\times10^{-7}\times I\times1.5I}{2\pi x}$

Force on A_3 due to A_2, $f_2 = \frac{4\pi\times10^{-7}\times2I\times1.5I}{2\pi(d-x)}$

When there is no net force on A_3, $f_1 = f_2$

$= \frac{4\pi\times10^{-7}\times I\times1.5I}{2\pi x} = \frac{4\pi\times10^{-7}\times2I\times1.5I}{2\pi(d-x)}$

$d - x = 2x \Rightarrow x = d/3$

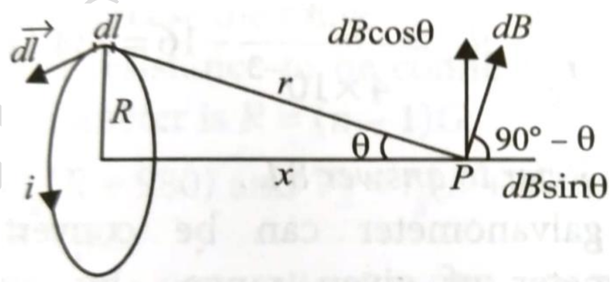
Hence from A_1 at d/3 there is no net force on A_3.

6. (a) Write an expression of magnetic moments associated with a current (I) carrying circular coil of radius r having N turns.

(b)Concede the above mentioned coil placed in YZ plane with its center at the origin. Derive expression for the value of fields due to it at point.

Sol. (a) The magnetic moment associated with a current (I) carrying a radius r having N turns, is given by $M = NIA = NI\pi r^2$.

(b) Magnetic field at a distance x from the centre of the ring due to element dl, dB $= \frac{\mu_0}{4\pi}\frac{idl\sin90°}{r^2}$



Since angle between $\vec{dl}$ and $\vec{r}$ is 90°. The component dBcosθ will get cancelled due to symmetry, $B = \int dB\sin\theta = \int\left(\frac{\mu_0}{4\pi}\frac{idl}{r^2}\right)(\sin\theta)$

Here r and θ are constants and $\sin\theta = R/r$

$B = \int\frac{\mu_0}{4\pi}\frac{idl}{r^2}\left(\frac{R}{r}\right) = \int\frac{\mu_0}{4\pi}\frac{idl}{r^3}$

$= \frac{\mu_0}{4\pi}\frac{idl}{r^3}\int dl = \frac{\mu_0}{4\pi}\frac{idl}{r^3}(2\pi R) = \frac{\mu_0 iR^2}{2r^2}$

Putting $r = (R^2 + x^2)^{1/2}$, we get $B = \frac{\mu_0 iR^2}{2(R^2+x^2)^{3/2}}$

For N turns, B = $\frac{\mu_0 NiR^2}{2(R^2+x^2)^{3/2}}$

7. A straight horizontal conducting rod of length 0.45 m and mass 60g is suspended by two vertical wires at its ends. A current of 5.0A is set up in the rod through the wires.
(a) What magnetic field should be set up normal to the conductor in order that the tension in the wires is zero?
(b) What will be the total tension in the wires if the direction of current is reversed, keeping the magnetic field same as before? (Ignore the mass of the wires) g = 9.8 ms^{-2}.

Sol. Here l = 0.45m, m = 60g = 0.06kg, I = 5.0A, g = 9.8 ms^{-2}
(a) Tension in the supporting wires wil be zero when the weight of the rod is balanced by the upward force IlB of the magnetic field, i.e. IlB = mg
∴ B = $\frac{mg}{Il} = \frac{0.06\times9.8}{5\times0.45}$ T = 0.26T
So the horizontal magnetic field of 0.26T normal to the conductor must be applied in such a direction that the Fleming's left hand rule give s a magnetic force in the upward direction.
(b) If the direction of current is reversed, the magnetic force will act in the downward direction. Hence the total tension in the wires will be
T = 2 × the weight of the rod
= 2 × 0.06 × 9.8N = 1.176N

8. The wires which connect the battery of an automobile to its starting motor carry a current of 300A (for a short time). What is the force per unit length between the wires if they are 70cm long and 1.5cm apart? Is the force attractive or repulsive?

Sol. $I_1 = I_2$ = 300A, r = 1.5cm = 1.5×10^{-2}m. l = 70cm = 0.70m.
The force per unit length between the wires is f = $\frac{\mu_0 I_1 I_2}{2\pi r} = \frac{4\pi\times10^{-7}\times300\times300}{2\pi\times1.5\times10^{-2}}$ Nm^{-1}
= 1.2 Nm^{-1}.
Total force between the wires, F = f × l = 1.2 × 0.70 = 0.84N
As the current in the two wires are in opposite directions, the force is repulsive.

9. A circular coil of 20 turns and radius 10cm is placed in a uniform magnetic field of 0.10T normal to the plane of the coil. If the current in the coil is 5.0A, what is the
(a) total torque on the coil.
(b) total force on the coil
(c) average force on each electron in the coil due to the magnetic field?
(The coil is made of copper wire of cross-sectional area 10^{-5} m^2 and the free electron density in copper is given to be about (10^{29} m^{-3})).

Sol. N = 20, r = 10cm = 0.10m, B -= 0.10T, l = 50A, θ = 0°
(a) Torque on the coil, τ = NlBA sin θ = 0 [since θ = 0°]
(b) Magnetic forces on the opposite arms of coil are equal and opposite and at in the same plane; hence the total force on the coil is zero.
(c) Force on each electron is F = evB = $\frac{BI}{nA}$ [since I =enAv]
For given wire, n = $10^{29}m^{-3}$, A = $10^{-5}m^2$
∴ F = $\frac{0.1\times5}{10^{29}\times10^{-5}}$ N = 5×10^{-25}N

10. A solenoid 60cm long and of radius 4.0cm has 3 layers of windings of 300 turns each. A 2.0 cm long wire of mass 2.5g lies inside the solenoid near its centre normal to its axis; both the wire and the axis of the solenoid are in the horizontal plane. The wire is connected through two leads parallel to the axis of the solenoid to an external battery which supplies a current of 6.0A in the wire. What value of current (with appropriate sense of circulation) in the windings of the solenoid can support the weight of the wire? G = 9.8 ms^{-2}

Sol. Let I be the current in the windings of the solenoid which can support the weight of the wire. The magnetic field inside the solenoid along its axis will be B = $\mu_0 nl$

Here n = $\frac{\text{Total number of turms}}{\text{Length of the solenoid}} = \frac{300\times3}{60\times10^{-2}}$ = 1500 turns m^{-1}

∴ B = 4π ×10^{-7} × 1500 × I = 6π × 10^{-4} I tesla

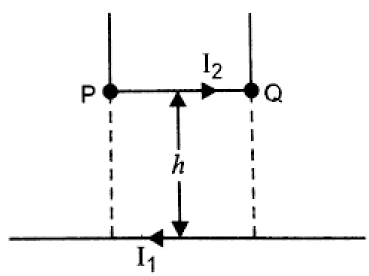
This field acts as perpendicular to the current carrying wire. Therefore the magnetic force on the wire will be F = l'lB = 6×(2×10^{-2})×6π × 10^{-4} I Newton.

The current I would support the wire if the above force equals the weight of the wire,

i.e. 6 × 2 × 10^{-2} × 6π ×10^{-4}l = 2.5 × 10^{-3} × 9.8

or I = $\frac{2.5\times10^{-3}\times9.8}{72\times3.14\times10^{-6}}$A = 108.3A

11. A long straight wire carrying current of 25A rests on a table as shown in Fig. Another wire PQ of length 1m, mass 2.5 g carries the same current but in the opposite direction. The wire PQ is free to slide up and down. To what height will PQ rise?



Sol. F = Bll sin θ = Bll

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

F = mg = $\frac{\mu_0 I^2 l}{2\pi h}$

h = $\frac{\mu_0 I^2 l}{2\pi mg} = \frac{4\pi\times10^{-7}\times250\times25\times1}{2\pi\times2.5\times10^{-3}\times9.8}$

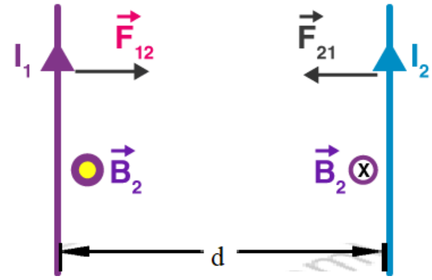
= 51 × 10^{-4}

h = 0.51 cm

(5 Marks Questions)

12. Two long straight parallel conductor carrying steady current I_1 and I_2 are secreted by a distance 'd'. Explain briefly with the help of suitable diagram. How the magnetic field due to one conductor acts on the other. Hence deduce the expression for the forcing acting between the two conductors. Mention the nature of this force.

Sol.



When two parallel infinite straight wires carrying currents I_1 and I_2 are placed at a distance d from each other, then current I_1 produces magnetic field, which at any point on the second current carrying wire is $B_1 = \frac{\mu_0 I_1}{2\pi d}$ directed inwards perpendicular to plane of wires.

So, the current (I_2) carrying wire then experiences a force due to this magnetic field which on its length l is given by

$\vec{F}_{21} = I_2(\vec{l} \times \vec{B}_1)$

$F_{21} = F_{12} = I_2 l B_1 \sin 90° = I_2 l \times \frac{\mu_0 I_1}{2\pi d}$ or $F_{21} = F_{123} = \frac{\mu_0 I_1 I_2}{2\pi d} l$

The vector product $(\vec{l} \times \vec{B}_1)$ has a direction towards the wire carrying current I_1. Hence both the wires attract each other.

So, force per unit length that each wire exerts on the other is, $f = \frac{\mu_0 I_1 I_2}{2\pi d}$.

If $I_1 = I_2 = 1A$ and $d = 1m$ and $l = 1m$, then $f = \frac{\mu_0}{2\pi} = 2 \times 10^{-7} m^{-1}$

Thus electric current through each of two parallel long wires placed at distance of 1m from each other is said to be 1 ampere. If they exert a force of 2×10^{-7} Nm^{-1} on each other.

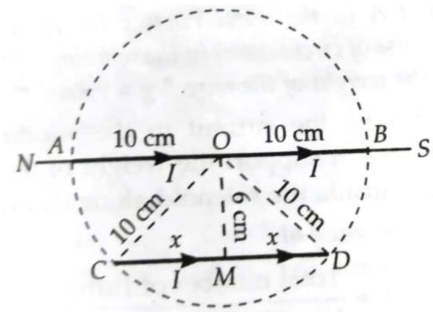
13. A uniform magnetic field of 1.5T exists in a cylindrical region of radius 10.0 cm, its direction being parallel to the axis along east to west. A wire carrying current of 7.0A in the north to south direction passes through this region. What is the magnitude and direction of the force on the wire if

(i) the wire intersects the axis

(ii) the wire is turned from N-S to north east or north west direction

(iii) the wire in the N-S direction is lowered from the axis by a distance of 6.0 cm?

Sol. Here B = 1.5T, I = 7.0A.



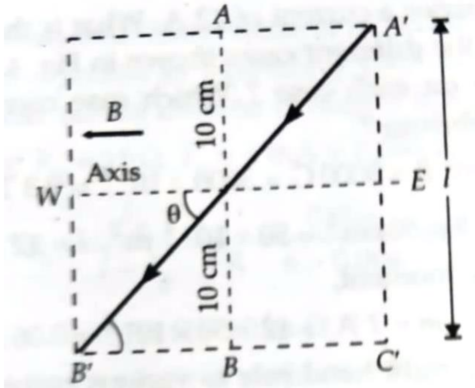
(i) As shown in figure, length of the wire in cylindrical region = diameter AB of cylindrical region = 20cm = 0.20m

As the wires lies in NS direction and field acts along EW direction, so θ = 90°

∴ Force on wire, F = IBl sin θ = 7 × 1.5 × 0.20 × 1 = 2.1N

By Fleming's left hand rule, this force acts in the vertically downwards direction.

(ii) When the wire turns from NS to NE or NW direction, suppose it makes angle q with field B as shown in figure below. The length of wire in magnetic field, A'B' = l' say



Clearly $\frac{l}{l'} = \sin\theta$ or l' = $\frac{l}{\sin\theta}$

Force on wire, F = Il'sinθ = I.$\frac{l}{\sin\theta}$. Bsinθ = IlB = 2.1N

This force acts in the vertically downward direction.

(iii) As shown in figure (i) when the wire is lowered by 6.0cm, length of the wire in the magnetic field = 2x

But x = $\sqrt{10^2 - 6^2}$ = 8cm = 0.08m

∴ 2x = 0.16, θ = 90°

Force on wire, F = IlB = 7 × 0.16 × 0.15 = 1.68N

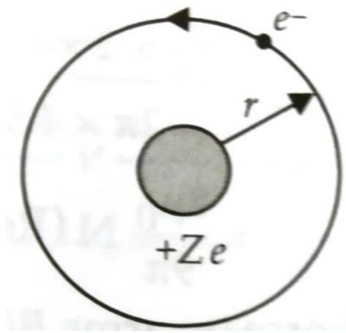
This force also acts in the vertically downward direction.

E. MAGNEITC DIPOLE MOMENT

(3 Marks Questions)

1. An electron of mass m_e revolves around a nucleus of charge +Ze . show that it behaves like a tiny magnetic moments associated with it is expressed as $\vec{\mu} = -\frac{e}{2m_e}\vec{L}$ where l is the orbital angular momentum of the electron. Give the signification of negative sign.

Sol.



The electron of charge (- e) performs uniform circular motion around a stationary heavy nucleus of charge +Ze. This constitutes a current I and forms a loop which behaves like a tiny magnetic dipole.

I = e/T T = time period) …(i)

Let r be the orbital radius of the electron and v the orbital speed. Then,

T = 2πr/v …(ii)

From (i) and (ii), I = ev/2πr

Magnetic moment $\mu = I\,\pi r^2 = evr/2$

The direction of magnetic moment is into the plane of paper.

Now, $\mu = \frac{e}{2m_e}(m_e vr) = \frac{e}{2m_e}L$ where L is the magnitude of angular momentum of the electron.

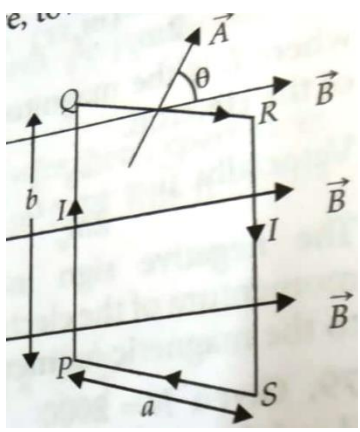
Vectorially, $\vec{\mu} = \frac{-e}{2m_e}\vec{L}$

The negative sign indicates the angular momentum of the electron is opposite in direction to the magnetic moment.

2. (a) Show that the planner loop carrying a current I, having N closely wound turns and area of cross-sectional A, possesses a magnetic moment $\vec{m} = NI\,\vec{A}$.

(b) When this loop is placed in a magnetic field $\vec{B}$, find out the expression for the torque acting on it.

Sol.

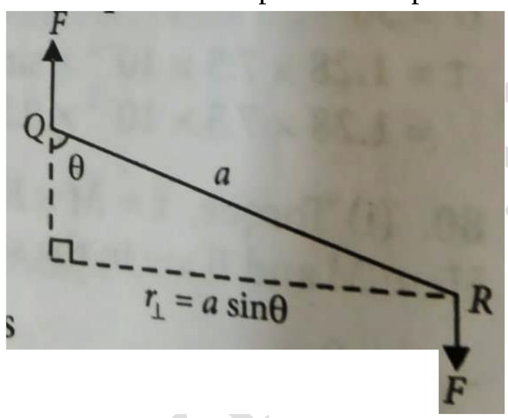


Sol. When a rectangular loop PQRS if sides 'a' and 'b' carrying a current I is placed in uniform magnetic field $\vec{B}$, such that area vector $\vec{A}$ makes an angle θ with direction of magnetic field, then forces on the arms QR and Sp of loop are equal, opposite and collinear, thereby perfectly cancel each other, whereas forces on the arm sPQ and RS of loop are equal and opposite but not collinear, so they give rise to torque on the loop. Force on side PQ or RS of loop is F = ibB sin 90° = lb B and perpendicular distance between two non collinear forces is r_1 = sinθ

So, torque $\tau = Fr_1$ -= ibB a sin θ – I ba B sinθ

Or τ = IAB sin θ and if loop has N turns, then τ = NIAB sinθ. In vector form, $\vec{\tau} = \vec{M} \times \vec{B}$

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



(a) If the plane of loop is normal to the direction of the magnetic field i.e. θ = 0° between $\vec{B}$ and $\vec{A}$ then the loop does not experience any torque i.e., $\tau_{min} = 0$.

(b) If the plane of loop is parallel to the direction of magnetic field i.e. θ = 90° between $\vec{B}$ and $\vec{A}$ then the loop experiences maximum torque, i.e., τ_{max} = NIAB.

3. A current carrying circular loop of radius R is placed in the x-y plane with centre at the origin. Half of the loop with x>0 is now bent so that it now lies in the y-z plane.

(a) The magnitude of the magnetic moment now diminishes

(b) The magnetic moment does not change.

(c) The magnitude of B at (0, 0, z), z>>R increases

(d) The magnitude of B at (0, 0, z), z>>R is unchanged.

Ans. (a)

F. TORQUE ON COIL AND GALVANOMETER

(1 Mark Questions)

1. A circular current loop of magnetic moment M is in an arbitrary orientation in an external magnetic field B. The work done to rotate the loop by 30° about an axis perpendicular to its plane is

(a) MB (b) √3 MB/2 (c) Mb/2 (d) zero

Ans. (d)

2. How are figure of merit and current sensitivity of galvanometer related to each other?

____
____

3. If the current is increased by 1% in a moving coil galvanometer, what will be the percentage increase in deflection?

____
____

(2 Marks Questions)

4. A square coil of the side 10cm consists of 20 turns and carries a current of 12A. The coil is suspended vertically and normal to the plane of the coil and makes an angle of 30° with the direction of a uniform horizontal magnetic field of magnitude 0.80T. What is the magnitude of torque experienced by the coil?

Sol. Given A = 0.10m × 0.10m = $0.01m^2$, N = 20, I = 12A, θ = 30°, B = 0.80T

Magnitude of torque is, τ = NIBA sin θ = 20 × 12 × 0.80 × 0.01 × sin 30° = 0.96Nm.

(3 Marks Questions)

5. (a) Define current sensitivity of a galvanometer. Write its expression.

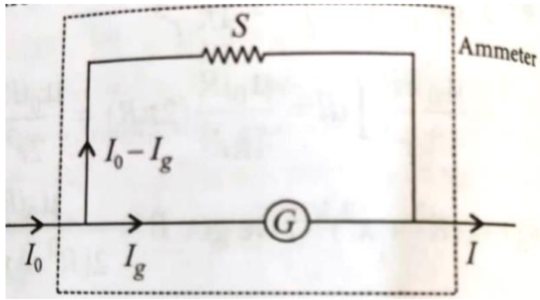
(b) A galvanometer has resistance G and shows full scale deflection for current I_g

(i)How can it be converted into an ammeter to measure current up to I_0

(ii) What is the effective resistance of this ammeter?

Sol. (a) Current sensitivity: It is defined as the deflection of coil per unit current flowing in it, i.e., $I_S = \frac{\theta}{I} = \frac{NAB}{k}$

(b) A galvanometer can be converted into an ammeter of given range by connecting a suitable low resistance S called shunt in parallel to the given galvanometer, whose value is given by $S = \left(\frac{I_g}{I_0 - I_g}\right)G$ where I_g is the current for fill scale deflection of galvanometer, I_0 is the current to be measured by the galvanometer and G is the resistance of galvanometer.



In order to increase the rang of an ammeter n times, the value of shunt resistance to be connected in parallel is S = G/(n – 1).

6. Two moving coils galvanometers M_1 and M_2 have the following particulars:

$R_1 = 10\Omega, N_1 = 30, A_1 = 3.6\times10^{-3}m^2, B_1 = 0.25T$

$R_2 = 14\Omega, N_2 = 42, A_2 = 1.8\times10^{-3}m^2, B_2 = 0.25T$

The spring constants are identical for the two springs. Determine the ratio of (i) current sensitivity and (ii) voltage sensitivity of M_2 and M_1.

Sol. Let torsion foe each meter= k

For a galvanometer, we have NIBA = kα

Its current sensitivity is defined as the deflection produced per unit current, i.e., $\frac{\alpha}{I} = \frac{NBA}{k}$

$\therefore \frac{\text{Current sensitivity of } M_2}{\text{Current sensitivity of } M_1} = \frac{N_2B_2A_2/k}{N_1B_1A_1/k} = \frac{N_2B_2A_2}{N_1B_1A_1} = \frac{42\times0.50\times1.8\times10^{-3}}{30\times0.25\times3.6\times10^{-3}} = \frac{7}{5} = 1.4$

Voltage sensitivity of a galvanometer is define as the defelction produced per unit voltage, i.e. $\frac{\alpha}{V} = \frac{\alpha}{IR} = \frac{NBA}{kR}$

$\frac{\text{Voltage sensitivity of } M_2}{\text{Voltage sensitivity of } M_1} = \frac{N_2B_2A_2/kR_2}{N_1B_1A_1/kR_1} = \frac{N_2B_2A_2}{N_1B_1A_1} \times \frac{R_1}{R_2} = \frac{7}{5} \times \frac{10}{14} = 1$

7. (a) A circular coil of 30 turns and radius 8.0 cm carrying a current of 6.0A is suspended vertically in a uniform horizontal magnetic field of magnitude 1.0T. The field lines make an angle 60° with the normal to the coil. Calculate the magnitude of the counter torque that must be applied to prevent the coil from turning.

(b) Would your answer change if the circular coil in (a) were replaced by a planar coil of some irregular shape that encloses the same area?

Sol. (a) N = 20, r = 8.0cm = 0.08m, l = 6.0A, B = 1T, θ = 60°

Magnitude fo counter torque = magnitude of defelcting torque

= NIBA sinθ = 30 × 6 × 1 × (3.14 × 0.08 × 0.08)sin 60°

= 30 × 6 × 3.14 × 64 × 10^{-4} × 0.866 = 3.1 Nm

(b) No, the answer would not change because the above formula fro the torque is true for a planar loop of any slope.

8. A galvanometer coil has resistance of 12Ω and meter shows full scale deflection for a current of 3 mA. How will you convert the meter into a voltmeter of range 0 to 18V?

Sol. Here $R_g = 12\Omega$, $I_g = 3mA = 3 \times 10^{-3}A$, $V = 18V$

$R = \frac{V}{I_g} - R_g = \frac{18}{3\times10^{-3}} - 12 = 6000 - 12 = 5988\ \Omega.$

By connecting a resistance of 5988 in series with the given galvanometer we get a voltmeter of range 0 to 18 V.

9. A galvanometer of resistance of 15Ω and the meter shows full scale deflection for a current of 4mA. How will you convert the meter into an ammeter of range 0 to 6A?

Sol. Here $R_g = 15\Omega$, $I_g = 4mA = 0.004A$, $I = 6A$

$R_S = \frac{I_g}{I - I_g} \times R_g = \frac{0.004}{6 - 0.004} \times 15 = 0.1010\Omega = 10m\Omega.$

By connecting a shunt of resistance 10mΩ across the given galvanometer, we get an ammeter of range 0 to 6A.

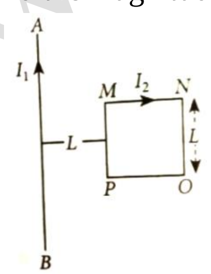
10. A galvanometer needs 50mV for a full scale deflection of 50 divisions. Find its voltage sensitivity. What must be its resistance if its current sensitivity is 1 division/ μA?

Sol. Voltage sensitivity, $V_S = \frac{\alpha}{V} = \frac{50\ \text{divisions}}{50\ \text{mV}} = \frac{50\ \text{divisions}}{50\times10^{-3}} = 10^3 \text{div V}^{-1}$

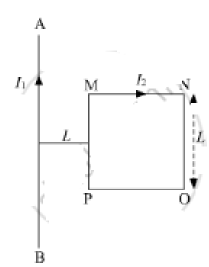
Resistance of galvanometer, $R_S = \frac{I_S}{V_S} = \frac{1\ \text{div}\ \mu A^{-1}}{10^3\ \text{div V}^{-1}} = \frac{10^6\ \text{div A}^{-1}}{10^3\ \text{div V}^{-1}} = 1000\Omega.$

(5 Marks Questions)

11. A square shaped current carrying loop MNOP is placed near a straight long current carrying wire AB as shown in the figure the wire and the loop lie in the loop experience a net force F toward the wire, find the magnitude of the force on the side NO of the loop.



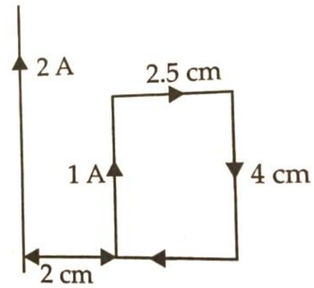
Sol. The net force acting on the loop



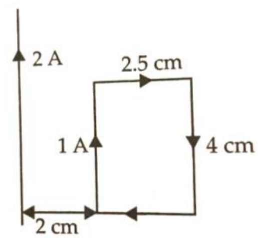
$\vec{F}_{Net} = \vec{F}_{PM} - \vec{F}_{NO} = \frac{\mu_0 I_1 I_2}{2\pi L} - \frac{\mu_0 I_1 I_2}{4\pi L}$

Now the force acting on the side NO, $\vec{F}_{NO} = \frac{\mu_0 I_1 I_2}{4\pi L} = \frac{\mu_0 I_1 I_2}{4\pi} = F_{Net}.$

12. A rectangular loop of wire of size 2.5 cm ×4cm carriers a steady current of 1 A. A straight wire carrying 2A currents is kept near the loop as shown. If the loop and wire are coplanar, find the (i) torque acting on the loop and (ii) the magnitude and direction of the force on the loop due to the current carrying wire.



Sol. (i) Torque, $\vec{\tau} = \vec{M} \times \vec{B}$ = MB sin θ. Here M and B are in the same direction, i.e., θ = 0°.
∴ $\vec{\tau} = 0$.
(ii)



Force between two currents carrying wires, $F = \frac{\mu_0 I_1 I_2 l}{2\pi r}$

Force on arm AB, $F_{AB} = \frac{\mu_0 \times 2 \times 1 \times 4 \times 10^{-2}}{2\pi \times 2 \times 10^{-2}} = \frac{2\mu_0}{\pi}$ N (Attractive towards the wire)

Force on arm CD, $F_{CD} = \frac{\mu_0 \times 2 \times 1 \times 4 \times 10^{-2}}{2\pi \times 4.5 \times 10^{-2}} = \frac{8\mu_0}{9\pi}$ N (Repulsive, away from the wire)

Forces on arms BC and DA are equal and opposite,. So, they cancel out each other.

Net force on the loop is $F = F_{AB} - F_{CD} = \frac{\mu_0}{\pi}\left[2 - \frac{8}{9}\right] = \frac{10\mu_0}{9\pi} = \frac{10 \times 4\pi \times 10^{-7}}{9\pi}$

$= 4.44 \times 10^{-7}$ N (Attractive towards the wire)

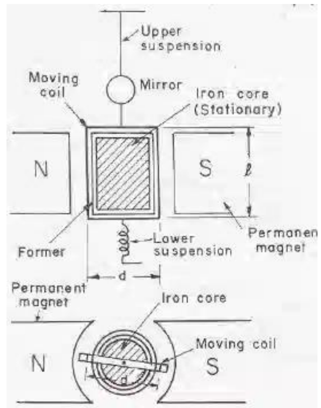
13. (a) Define the current sensitivity of a galvanometer.
(b) The coil area of a galvanometer is 16×10^{-4} m^2it consist of 200 turns of a wire and is in a magnetic field of 0.2T. the restoring torque constant of the suspension fiber is 10^{-6} N m per degree. Assuming the magnetic field to be radial, calculate the maximum current that can be measured by the galvanometer if the scale can accommodate 30 deflections.

Sol. (a) Same as 5(a)
(b) A = 16×10^{-4} m^2, N = 200, B = 0.2T, k = 10^{-6} Nm/degree, θ = 30°,

$I = \frac{k}{NBA}\theta = \frac{10^{-6} \times 30}{200 \times 0.2 \times 16 \times 10^{-4}} = 4.69 \times 10^{-4}$A.

14. (a) Explain using a labeled diagram, the principle and working of a moving coil galvanometer. What is the function of (i) soft iron core?
(b) Define the terms (i) current sensitivity and (ii)voltage sensitivity of a galvanometer why does increasing the current sensitivity not necessarily increase voltage sensitivity.

Sol. (a) A galvanometer is used to detect current in a circuit.



Principle and working: When current (I) is passed in the coil, torque τ acts on the coil, is given by τ = NIAB sin θ where θ is the angle between the normal to plane of coil and the magnetic field of strength B, N is the number of turns in a coil.
When the magnetic field is radial, as in case of cylindrical pole pieces and soft iron core, then in every position of coil, the plane of the coil, is parallel to the magnetic field lines, so that $\theta = 90°$ and $\sin 90° = 1$.
Deflecting torque, τ = NIAB.
If C is torsional rigidity of the wire and θ is the twist of suspension strip, then restoring torque = $C\theta$
Therefore $\theta = \frac{NAB}{C} I$ i.e. $\theta \propto I$. Deflection of coil is directly proportional to current flowing in the coil and hence we can construct a linear scale.
The uniform radial magnetic field keeps the plane of the coil always parallel to the direction of the magnetic field, i.e. the angel between the plane of the coil and the magnetic field is zero for all the orientations of the coil.
(b) (i) Same as 5 (a)
(ii) Voltage sensitivity: Current sensitivity/R. Thus on increasing the current sensitivity, voltage sensitivity may or may not increase because of similar changes in the resistance of the coil, which may also increase due to increase in temperature.

15. The scale of a galvanometer is divided into 150 equal divisions. The galvanometer has the current sensitivity of 10 divisions per mA and the voltage sensitivity of 2 divisions per mV. How the galvanometer can be designed to read (i) 6A division^{-1} and (ii) 1V per division^{-1}? [Ans. (i) $8.33\times10^{-5}\ \Omega$ in parallel (ii) 9995 Ω in series]

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G. CASE STUDY

1. **Motion of a Charged particle in a Uniform magnetic Field:** The force experienced by a particle on charge q moving with a velocity **v** in a uniform magnetic field **B** is given by: $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$
which is perpendicular to both **v** and **B**. Since **F** is perpendicular to v, no work is done on the charged particle moving in a uniform magnetic field. If **v** is perpendicular to **B**, the force cannot change the kinetic energy of the particle. Hence the magnitude of **v** cannot change, only the direction of motion changes continuously. These are exactly the conditions for uniform circular motion. Thus, if **v** is perpendicular to **B**, the charged particle follows a circular path whose radius is given by $r = \frac{mv}{qB}$
The frequency of revolution of the particle along the circular path is given by, $\nu = \frac{qB}{2\pi m}$

(i) A proton and an alpha particles are projected perpendicular to a uniform magnetic field with equal velocities. The mass of an alpha particle is 4 times that of a proton and its charge is twice that of a proton. If r_p and r_α are radii of their circular path, then the ratio r_p/r_α is

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

Ans. (b) Use $r = \frac{mv}{qB}$. The correct answer is (b).

(ii) In Qs (i) what is the ratio r_p/r_α if the two particles have equal kinetic energies before entering the region of the magnetic field.

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

Ans. (b)b Kinetic energy $K = ½ mv^2$ which gives $v = \sqrt{\frac{2K}{m}}$. Hence $r = r = \frac{mv}{qB} = \frac{1}{qB}\sqrt{2mK}$
Using this relation we find the t the correct choice is (b).

(iii) In Qs (i) what is the ratio r_p/r_α if the two particles have equal linear momenta before entering the region of the magnetic field.

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

Ans. (c) Linear momentum, p = mv. Hence $r = r = \frac{mv}{qB} = \frac{p}{qB}$. Using this relation we find that the correct choice is (c).

(iv) In Qs (i) what is the ratio r_p/r_α if the two particles are accelerated through the same potential difference before entering the region of the magnetic field

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

Ans. (a) Kinetic energy gained by a particle of charge q when it is accelerated through a potential difference V is K = qV

Hence $\frac{1}{qB}\sqrt{2mK} = \frac{1}{B}\sqrt{\frac{2mV}{1}}$. Using this relation we find that the correct choice is (a).

(v) Which of the following particles in motion cannot be deflected by magnetic fields?

(a) Protons (b) Beta particles (c) Alpha particles (d) Neutrons

Ans. (d). The correct choice is (d) because neutrons have no charge.

2. **The cyclotron:** The cyclotron which is used to accelerate charged particles such as protons, deuterons, alpha particles, etc, to a very high energies. The principle on which a cyclotron works is based on the fat that an electric field can accelerate a charged particle and a magnetic field can throw it into a circular orbit. A particle of charge +q experiences a force qE in an electric field E and this force is independent of the velocity of the particle. The particle is accelerated in the direction of the field. On the other hand, a magnetic field at right angles to the direction of motion of the particle throws the particle in a circular orbit in which the particle revolves with a frequency that doe no depend on its speed. A modest potential difference is used as a source of electric field. If a charged particle is made to pass through this potential difference a number of times, it will acquire an enormously large velocity and hence kinetic energy.

(i) Which of the following cannot be accelerated in a cyclotron?

(a) Protons (b) Deuterons (c) Alpha particles (d) Neutrons

Ans. (d) The correct choice is (d) because neutrons have no charge.

(ii) The working of cyclotron is based on the fact that

(a) the force experienced by a charged particle in an electric field is independent of its velocity.

(b) the radius of the circular orbit of a charged particle in a magnetic field increases with increase in its speed.

(c) at a given speed, the radius of the circular orbit is the same for particles having the same charge to mass ratio.

(d) the frequency of revolution of the particle along the circular path does not depend on its speed

Ans. (d)

(iii) Cyclotron is not suitable for accelerating

(a) electrons (b) protons (c) deuterons (d)alpha paritcles

Ans. (a). The correct choice is (a). Because of extremely small mass, the frequency of circulation of electrons is very high. Oscillators of such high frequencies are not easily obtainable.

H. ASSERTION REASON TYPE QUESTIONS

(a) If both assertion and reason are true and reason is the correct explanation of assertion.
(b) If both assertion and reason are true but reason is not the correct explanation of assertion.
(c) If assertion is true but reason is false **(d) If both assertion and reason are false**
(e) If assertion is false but reason is true.

1. Assertion: If an electron is not deflected while passing through a certain region of space, then only possibility is that there is no magnetic field in this region.
Reason: Force is directly proportional to magnetic field applied.

Ans. (e) Assertion is false but reason is true
In this case we cannot be sure about the absence of the magnetic field because if the electron moving parallel to the direction of magnetic field, the angle between velocity and applied magnetic field is zero and the force experienced by the electron is zero (F = 0). Then also electron passes without deflection.

2. Assertion: Free electrons always keep on moving in a conductor even then no magnetic force act on them in magnetic field unless a current is passed through it.
Reason: The average velocity of free electron is zero.

Ans. (a) Both assertion and reason are true and reason is the correct explanation of assertion.
In the absence of the electric current, the free electrons in a conductor are in a state of random motion, like molecule in a gas. Their average velocity is zero i.e. they do not have any net velocity in a direction. As a result, there is no net magnetic force on the free electrons in the magnetic field. On passing the current, the free electrons acquire drift velocity in a definite direction, hence magnetic force acts on them, unless the field has no perpendicular component.

3. Assertion: Out of galvanometer, ammeter and voltmeter, resistance of ammeter is lowest and resistance of voltmeter is highest.
Reason: An ammeter is connected in series and a voltmeter is connected in parallel in a circuit.

Ans. (b) Both assertion and reason are true but reason is not the correct explanation of assertion.
In a voltmeter, a high resistance is connected in series with a galvanometer. That is why resistance of voltmeter is highest. In an ammeter, a low resistance in parallel with a galvanometer. That is why resistance of ammeter is lowest.

4. Assertion: For a point on the axis if a circular coil carrying current, magnetic field is maximum at the centre of the coil.
Reason: magnetic field is inversely proportional to the distance of point from the circular coil.

Ans. (a) Both assertion and reason are true and reason is the correct explanation of assertion.
The magnitude of the magnetic field produced due to flow of current through a circular loop at a point on its axis is given by $B = \frac{\mu_0}{4\pi}\frac{2\pi I a^2}{(a^2+x^2)^{3/2}}$

This is maximum at centre of loop, where x = 0

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

5. Assertion: A solenoid tends to expand, when a current passes through it.
Reason: Two straight parallel metallic wires carrying current in same direction repel each other.

Ans. (d) Both assertion and reason are false.
When current flows through a solenoid, the currents in the various turns of the solenoid are parallel and in the same direction,. Since the currents flowing through parallel wires in the same direction lead to force of attraction between them, the turns of the solenoid will also attract each other and as a result, the solenoid tends to contract.

I. CHALLENGING PROBLEMS

1. A magnetic field of 100 G (1G = 10^{-4} T) is required which is uniform in a region of linear dimension about 10cm and area of cross-section about 10^{-3} m^2. The maximum current carrying capacity of a given coil of wire is 15A and the number of turns per unit length that can be wound round a core is at most 1000 turns m^{-1}, Suggest some appropriate design particulars of a solenoid for the required purpose. Assume the core is not ferromagnetic.

Sol. Here B = 100G = 10^{-2}T, l = 15A, n = 1000 turns m^{-1}
Magnetic field inside a solenoid, $B = \mu_0 nI$

$\therefore nI = \frac{B}{\mu_0} = \frac{10^{-2}}{4\pi\times10^{-7}} = 7955 \approx 8000$

We may take l = 10A, then n – 800
The solenoid may have length 50cm and area of square section 5 × $10^{-2}m^2$ (five times the given value) so as to avoid edge effects, etc.

2. For a circular coil of radius R and N turns carrying current I, the magnitude of the magnetic field at a point on its axis at a distance x from its centre is given by

$$B = \frac{\mu_0 IR^2 N}{2(x^2 + R^2)^{3/2}}$$

(a) Show that this reduces to the familiar result for field at the centre of the coil.
(b) Consider two parallel co-axial circular coils of equal radius R, and number of turns N, carrying equal currents in the same direction, and separated by a distance R. Show that the field on the axis around the mid-point between the coils is uniform over a distance that is small as compared to R and is given by

$$B = 0.72\frac{\mu_0 NI}{R}$$

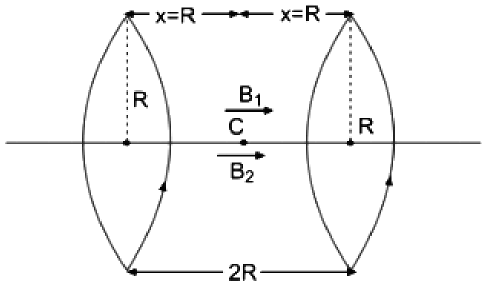
Such an arrangement used to produce a nearly uniform magnetic field over a small region is known as Helmholtz coils.

Sol. (a) Given $B = \frac{\mu_0 I R^2 N}{2(x^2+R^2)^{3/2}}$

At the centre of the coil, x = 0, so $B = \frac{\mu_0 I R^2 N}{2R^3} = \frac{\mu_0 I N}{2R}$

This is the standard result for the field at the centre of the coil.

(b) As shown in figure, consider a small region of length 2d about the midpoint O between the two coils.



Given $B = \frac{\mu_0 I R^2 N}{2(x^2+R^2)^{3/2}}$

Therefore, the magnetic field at the point P due to coil 1, $B_1 = \frac{\mu_0 I R^2 N}{2\left[R^2+\left(\frac{R}{2}+d\right)^2\right]^{3/2}}$, acting along PO_2.

Magnetic field at point P due to coil 2, $B_2 = \frac{\mu_0 I R^2 N}{2\left[R^2+\left(\frac{R}{2}-d\right)^2\right]^{3/2}}$ acting along PO_2

Total magnetic field at the point P will be $B = B_1 + B_2$

$$= \frac{\mu_0 I R^2 N}{2}\left[\frac{1}{\left(R^2+\frac{R^2}{4}+d^2+Rd\right)^{3/2}} + \frac{1}{\left(R^2+\frac{R^2}{4}+d^2-Rd\right)^{3/2}}\right]$$

$$= \frac{\mu_0 I R^2 N}{2}\left[\frac{1}{\left(\frac{5R^2}{4}+Rd\right)^{3/2}} + \frac{1}{\left(\frac{5R^2}{4}-Rd\right)^{3/2}}\right]$$ [Neglecting d^2, as d <<R]

$$= \frac{\mu_0 I R^2 N}{2\left(\frac{5R^2}{4}\right)^{3/2}}\left[\frac{1}{\left(1+\frac{4d}{5R}\right)^{3/2}} + \frac{1}{\left(1-\frac{4d}{5R}\right)^{3/2}}\right]$$

$$= \frac{\mu_0 I N}{2R}\left(\frac{4}{5}\right)^{3/2}\left[\left(1+\frac{4d}{5R}\right)^{-3/2} + \left(1-\frac{4d}{5R}\right)^{-3/2}\right]$$

$$= \frac{\mu_0 I N}{2R}\left(\frac{4}{5}\right)^{3/2}\left[\left(1-\frac{6d}{5R}\right) + \left(1+\frac{6d}{5R}\right)\right]$$ [Expanding by binomial theorem and neglecting higher powers of d/R]

Or $B = 0.72\,\frac{\mu_0 I N}{2R}$

Magnetic field will also be same at the point Q. In fact, it wil be uniform over the small region of length 2d around the midpoint O.

3. A galvanometer with a coil of resistance 12.0 Ω shows full scale deflection for a current of 25 mA. How will you convert the meter into: (i) an ammeter of range 0 to 7.5A (ii) a voltmeter of range 0 to 10.0V.

Determine the net resistance of the meter in each case. When an ammeter is put in a circuit, does it read (slightly) less or more than the actual current in the original circuit?

When a voltmeter is put across a part of the circuit, does it read (slightly) less than or more than the original voltage drop? Explain.

Sol. (i) For conversion into ammeter: $R_g = 12\Omega$, $I_g = 2.5mA = 0.0025A$, $I = 7.5A$

$R_S = \frac{I_g}{I - I_g} \times R_g = \frac{0.0025}{7.5 - 0.0025} \times 12 = \frac{2.5 \times 12 \times 10^{-3}}{7.4975} = 4.0 \times 10^{-3}\Omega$

So by connecting a shunt resistance of $4.0 \times 10^{-3}\Omega$ in parallel with the galvanometer, we get an ammeter of range 0 to 7.5A.

Net resistance R_A is given by: $\frac{1}{R_A} = \frac{1}{12} + \frac{1}{4 \times 10^{-3}} = \frac{3001}{12}$

Or $R_A = \frac{12}{3001}\Omega = 4 \times 10^{-3}\Omega$.

When an ammeter is put in a circuit, it reads slightly less than the actual current in the original circuit because a very small resistance is introduced in the circuit.

(ii) For conversion into voltmeter: $R_g = 12\Omega$, $I_g = 2.5 \times 10^{-3}A$. $V = 10V$

$\therefore R = \frac{V}{I_g} - R_g = \frac{10}{2.5 \times 10^{-3}} - 12$

$= 4000 - 12 = 3988\Omega$.

So, by connecting a resistance of 3988Ω in series with the galvanometer, we get a voltmeter of range 0 to 10V.

Now resistance, $R_V = (3988 + 12)\Omega = 4000\Omega$.

Because voltmeter draws small current for its deflection, so it reads slightly less the original voltage drop.

SPACE FOR ROUGH WORK

SPACE FOR NOTES