MAGNETIC EFFECT OF CURRENT

KEY CONCEPT

The branch of physics which deals with the magnetism due to electric current or moving charge (i.e. electric current is equivalent to the charges or electrons in motion) is called electromagnetism.

Biot-Savart Law

Currents which arise due to the motion of charges are the source of magnetic fields. When charges move in a conducting wire and produce a current *I*, the magnetic field at any point *P* due to the current can be calculated by adding up the magnetic field contributions, $d\vec{B}$, from small segments of the wire $d\vec{s}$ (Figure).

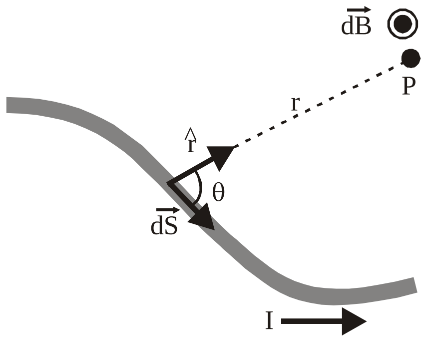


Figure : Magnetic field $d\vec{B}$ at point *P* due to a current-carrying element $Id\vec{s}$

These segments can be thought of as a vector quantity having a magnitude of the length of the segment and pointing in the direction of the current flow. The infinitesimal current source can then be written as $Id\vec{s}$.

Let *r* denote as the distance form the current source to the field point *P* and $\hat{r}$ the corresponding unit vector. The Biot-Savart law gives an expression for the magnetic field contribution, $d\vec{B}$, from the current source, $Id\vec{s}$,

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{s}\times\hat{r}}{r^2}$$

where μ_0 is a constant called the permeability of free space:

$\mu_0 = 4\pi \times 10^{-7}$ T.m/A here Tesla (T) is SI unit of $\vec{B}$

Adding up these contributions to find the magnetic field at the point *P* requires integrating over the current source,

$$\vec{B} = \int d\vec{B} = \frac{\mu_0 I}{4\pi}\int\frac{d\vec{s}\times\hat{r}}{r^2}$$

- According to $d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{\ell}\times\vec{r}}{r^3}$, direction of magnetic field vector $d\vec{B}$ is always perpendicular to the plane of vectors $(Id\vec{\ell})$ and ($\vec{r}$), where plane of $(Id\vec{\ell})$ and ($\vec{r}$) is the plane of wire.
- Magnetic field on the axis of current carrying conductor is always zero (θ = 0° or θ = 180°)

RIGHT HAND THUMB RULE

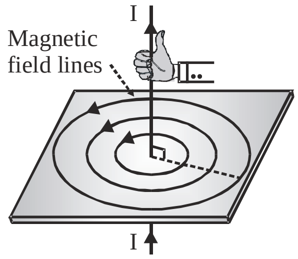
This rule gives the pattern of magnetic field lines due to current carrying wire.

(i) Straight current

Thumb $\rightarrow$ In the direction of current

Curling fingers $\rightarrow$ Gives field line pattern

Case I : wire in the plane of the paper

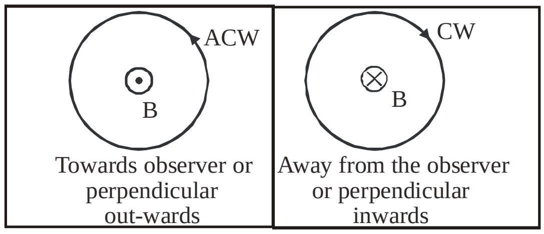


(ii) Circular current

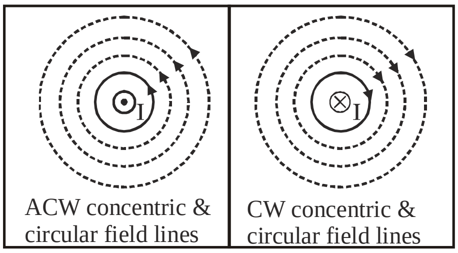
Curling fingers $\rightarrow$ In the direction of current,

Thumb $\rightarrow$ Gives field line pattern

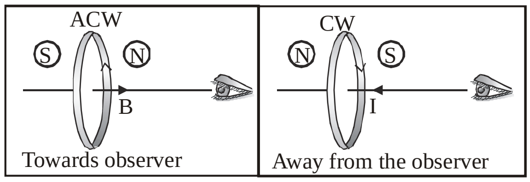
Case I : wire in the plane of the paper



Case II : Wire is $\perp$ to the plane of the paper.



Case II : Wire is $\perp$ to the plane of the paper



APPLICATION OF BIOT-SAVART LAW :

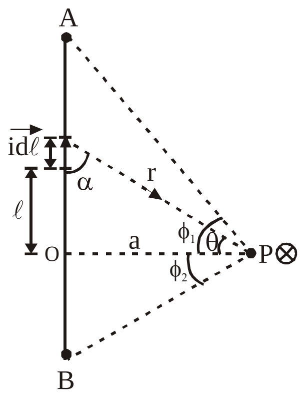
- **Magnetic field surrounding a thin straight current carrying conductor**

AB is a straight conductor carrying current i from B to A.

At a point P, whose perpendicular distance from AB is OP = a, the direction of field is perpendicular to the plane of paper, inwards (represented by a cross)

$\ell = a\tan\theta \Rightarrow dl = a\sec^2\theta d\theta$...(i)

$\alpha = 90° - \theta$ & $r = a\sec\theta$



- **By Biot-Savart's law**

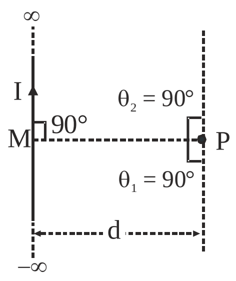
$$\overrightarrow{dB} = \frac{\mu_0}{4\pi}\frac{i d\ell \sin\alpha}{r^2} \otimes \text{ (due to a current element } i d\ell \text{ at point P)}$$

$$\Rightarrow B = \int dB = \int \frac{\mu_0}{4\pi}\frac{i d\ell \sin\alpha}{r^2} \text{ (due to wire AB) } \therefore B = \frac{\mu_0 i}{4\pi}\int \cos\theta d\theta$$

Taking limits of integration as $-\phi_2$ to ϕ_1

$$B = \frac{\mu_0 i}{4\pi a}\int_{-\phi_2}^{\phi_1}\cos\theta d\theta = \frac{\mu_0 i}{4\pi a}\left[\sin\theta\right]_{-\phi_2}^{\phi_1} = \frac{\mu_0 i}{4\pi a}\left[\sin\phi_1 + \sin\phi_2\right] \text{ (inwards)}$$

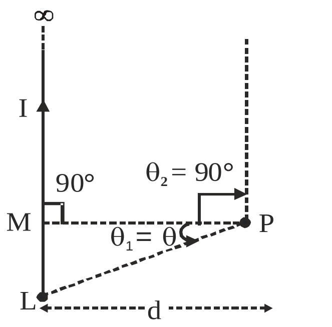
Ex. Magnetic field due to infinite length wire at point 'P'



Sol. $B_P = \dfrac{\mu_0 I}{4\pi d}[\sin 90° + \sin 90°]$

$$B_P = \frac{\mu_0 I}{2\pi d}$$

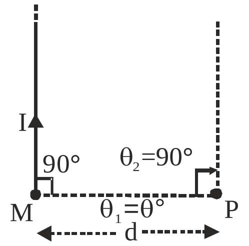
Ex. Magnetic field due to semi infinite length wire at point 'P'



Sol. $B_P = \dfrac{\mu_0 I}{4\pi d}[\sin\theta + \sin 90°]$

$B_P = \dfrac{\mu_0 I}{4\pi d}[\sin\theta + 1]$

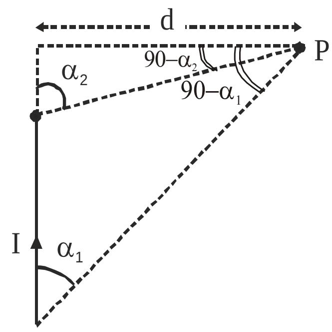
Ex. Magnetic field due to special semi infinite length wire at point 'P'



Sol. $B_P = \dfrac{\mu_0 I}{4\pi d}[\sin 0° + \sin 90°]$

$B_P = \dfrac{\mu_0 I}{4\pi d}$

Ex. If point 'P' lies out side the line of wire then magnetic field at point 'P' :

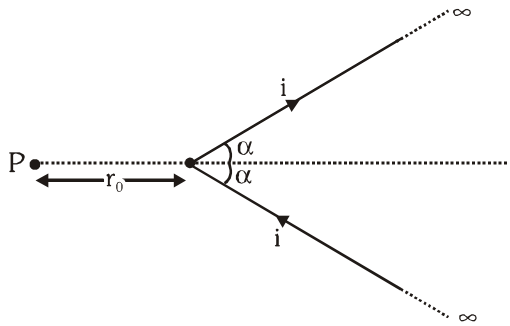


Sol. $B_P = \dfrac{\mu_0 I}{4\pi d}$

$\left[\sin(90-\alpha_1) - \sin(90-\alpha_2)\right]$

$= \dfrac{\mu_0 I}{4\pi d}(\cos\alpha_1 - \cos\alpha_2)$

Ex. A current carrying wire in the form of 'V' alphabet is kept as shown in the figure. Magnetic field intensity at point P which lies on the angular bisector of V is

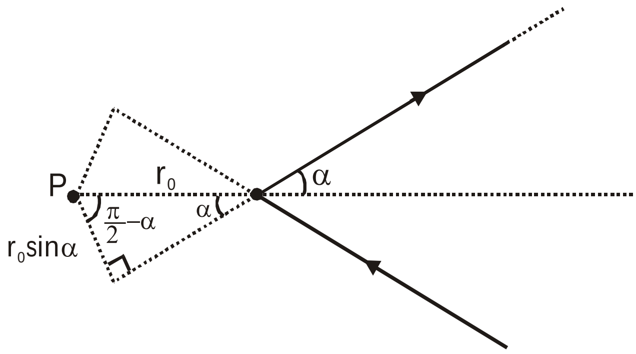


(A) $\dfrac{\mu_0 i}{4\pi r_0}[1-\cos\alpha]$ (B) $\dfrac{\mu_0 i}{2\pi r_0}[1-\cos\alpha]$

(C) $\dfrac{\mu_0 i}{4\pi r_0}\dfrac{[1-\cos\alpha]}{\sin\alpha}$ (D) $\dfrac{\mu_0 i}{2\pi r_0}\dfrac{[1-\cos\alpha]}{\sin\alpha}$

Ans. (D)

Sol. By using formula for stragith wire i.e.



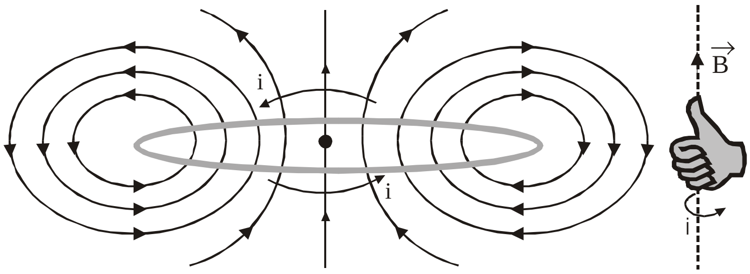
$B = \dfrac{\mu_0 I}{4\pi d}(\sin\theta_1 + \sin\theta_2)$

$B = 2\left[\dfrac{\mu_0 i}{4\pi r_0 \sin\alpha}(\sin 90° - \sin(90° - \alpha))\right]$

$= \dfrac{\mu_0 i}{2\pi r_0 \sin\alpha}[1-\cos\alpha]$

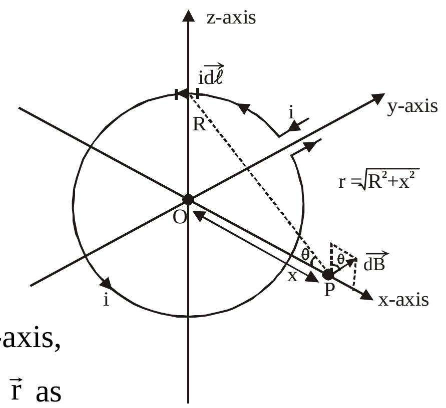
- **Magnetic field due to a loop of current**

Magnetic field lines due to a loop of wire are shown in the figure



The direction of magnetic field on the axis of current loop can be determined by right hand thumb rule. If fingers of right hand are curled in the direction of current, the stretched thumb is in the direction of magnetic field.

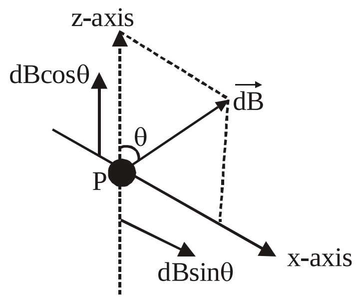
- **Calculation of magnetic field**



Consider a current loop placed in y-z plane carrying current i in anticlockwise sense as seen from positive x-axis. Due to a small current element $i d\vec{\ell}$ shown in the figure, the magnetic field at P is given by $dB = \frac{\mu_0}{4\pi}\frac{i d\ell \sin 90^0}{r^2}$.

The angle between $i d\vec{\ell}$ and $\vec{r}$ is 90^0 because $i d\vec{\ell}$ is along y-axis, while $\vec{r}$ lies in x-z plane. The direction of $\vec{dB}$ is perpendicular to $\vec{r}$ as shown. The vector $\vec{dB}$ can be resolved into two components, $dB\cos\theta$ along z-axis and $dB \sin\theta$ along x-axis.

For any two diametrically opposite current elements, the components along x-axis add up, while the other two components cancel out. Therefore, the field at P is due to x-component of field only. Hence, we have



$$\therefore\ B = \frac{\mu_0}{4\pi}\frac{i\times 2\pi R^2}{\left(R^2+x^2\right)^{3/2}} \quad \left(\because r = \sqrt{R^2+x^2}\right)$$

(a) At the centre, x = 0, $B_{centre} = \frac{\mu_0 i}{2R}$

(b) At points very close to centre, x << R $\Rightarrow B = \frac{\mu_0 i}{2}\left(1+\frac{x^2}{R^2}\right)^{-3/2} = \frac{\mu_0 i}{2}\left(1-\frac{3x^2}{2R^2}\right)$

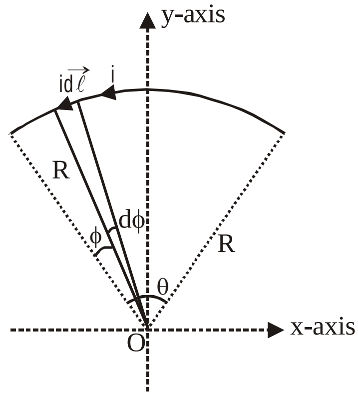
(c) At points far off from the centre, x >> R $\Rightarrow B = \frac{\mu_0 \ell}{4\pi}\frac{2\pi R^2}{x^3}$

(d) The result in point (c) is also expressed as $B = \frac{\mu_0}{4\pi}\frac{2M}{x^3}$

where $M = \ell \times \pi R^2$, is called magnetic dipole moment.

Ex. Find the magnetic field at the centre of a current carrying conductor bent in the form of an arc subtending angle θ at its centre. Radius of the arc is R.

Sol. Let the arc lie in x-y plane with its centre at the origin.



Consider a small current element $id\vec{\ell}$ as shown.

The field due to this element at the centre is

$$dB = \frac{\mu_0}{4\pi}\frac{id\ell\sin 90^0}{R^2} \quad \left(\because id\vec{\ell} \text{ and R are perpendicular}\right)$$

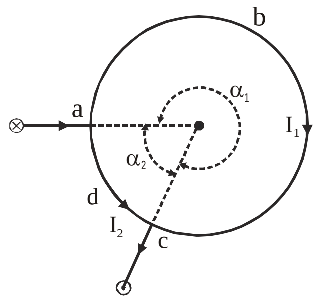
Now $d\ell = Rd\phi \;\therefore dB = \dfrac{\mu_0}{4\pi}\dfrac{iRd\phi}{R^2} \Rightarrow dB = \dfrac{\mu_0}{4\pi}\dfrac{i}{R}d\phi$

The direction of field is outward perpendicular to plane of paper

$$\text{Total magnetic field } B = \int dB \therefore B = \frac{\mu_0 i}{4\pi R}\int_0^\theta d\phi = \frac{\mu_0 i}{4\pi R}[\phi]_0^\theta \;\therefore\; B = \frac{\mu_0 i}{4\pi R}\theta$$

Ex. Find the magnetic field at the centre of a current carrying conductor bent in the form of an arc subtending angle α_1 and α_2 at the centre.

Sol. Magnetic field at the centre of arc abc and adc wire of circuit loop



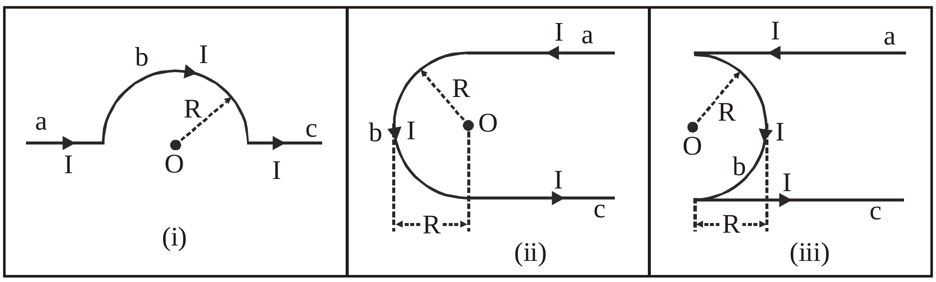
$$B_{abc} = \frac{\mu_0 I_1\alpha_1}{4\pi r} \text{ and } B_{adc} = \frac{\mu_0 I_2\alpha_2}{4\pi r} \Rightarrow \frac{B_{abc}}{B_{adc}} = \frac{I_1\alpha_1}{I_2\alpha_2}$$

$$\because \quad \text{angle} = \frac{\text{arc length}}{\text{radius}} \Rightarrow \frac{\alpha_1}{\alpha_2} = \frac{\ell_1}{\ell_2}$$

$$\therefore V = I_1R_1 = I_2R_2 \Rightarrow \frac{I_1}{I_2} = \frac{R_2}{R_1} \Rightarrow \frac{I_1}{I_2} = \frac{\ell_2}{\ell_1} \left(\because R = \frac{\rho\ell}{A} \Rightarrow R \propto \ell\right)$$

$$\therefore \frac{B_{abc}}{B_{adc}} = \left(\frac{\ell_2}{\ell_1}\right)\left(\frac{\ell_1}{\ell_2}\right) \Rightarrow \frac{B_{\alpha_1}}{B_{\alpha_2}} = \frac{1}{1}$$

Ex. Calculate the field at the centre of a semi-circular wire of radius R in situations depicted in figure (i), (ii) and (iii) if the straight wire is of infinite length.



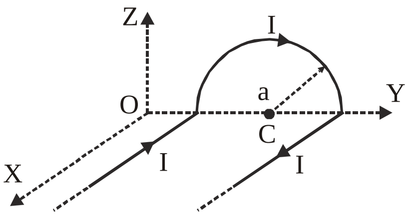
Sol. The magnetic field due to a straight current carring wire of infinite length, for a point at a distance R from one of its ends is zero if the point is along its length and $\dfrac{\mu_0 I}{4\pi R}$ if the point is on a line perpendicular to its length while at the centre of a semicircular coil is $\dfrac{\mu_0 I}{4R}$ so net magnetic field at the centre of semicircular wire is $\vec{B}_R = \vec{B}_a + \vec{B}_b + \vec{B}_c$

(i) $\vec{B}_R = 0 + \frac{\mu_0}{4}\frac{I}{R} \otimes + 0 = \frac{\mu_0 I}{4R} \otimes$(into the page)

(ii) $\vec{B}_R = \frac{\mu_0}{4\pi}\frac{I}{R}\odot + \frac{\mu_0}{4}\frac{I}{R}\odot + \frac{\mu_0}{4\pi}\frac{I}{R}\odot = \frac{\mu_0}{4\pi}\frac{I}{R}[\pi + 2] \odot$ (out of the page)

(iii) $\vec{B}_R = \frac{\mu_0}{4\pi}\frac{I}{R}\odot + \frac{\mu_0}{4}\frac{I}{R}\otimes + \frac{\mu_0}{4\pi}\frac{I}{R}\odot = \frac{\mu_0}{4\pi}\frac{I}{R}[\pi - 2]\otimes$ (into the page)

Ex. A long wire bent as shown in the figure carries current I. If the radius of the semi-circular portion is "a" then find the magnetic induction at the centre C.



Sol. Due to semi circular part

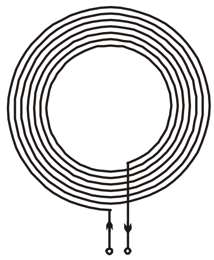
$$\vec{B}_1 = \frac{\mu_0 I}{4a}\left(-\hat{i}\right)$$

due to parallel parts of currents

$$\vec{B}_2 = 2 \times \frac{\mu_0 I}{4\pi a}(-\hat{k}),\ B_{net} = B_C = \vec{B}_1 + \vec{B}_2 = \frac{\mu_0 I}{4a}(-\hat{i}) + \frac{\mu_0 I}{2\pi a}(-\hat{k})$$

magnitude of resultant field $B = \sqrt{B_1^2 + B_2^2} = \frac{\mu_0 I}{4\pi a}\sqrt{\pi^2 + 4}$

Ex. A thin insulated wire forms a plane spiral of N = 100 tight turns carrying a current I = 8 mA. The radii of inside and outside turns (Fig.) are equal to a = 50 mm and b = 100 mm.
Find the magnetic induction at the centre of the spiral;



Ans. $B = \frac{\mu_0 IN\, ln\ (b/a)}{2(b-a)} = 7\ \mu T$;

Sol. From Biot-Savart's law, the magnetic induction due to a circular current carrying wire loop at its centre is given by,

$$B_r = \frac{\mu_0}{2r} i$$

The plane spiral is made up of concentric circular loops, having different radii, varying from a to b. Therefore, the total magnetic induction at the centre,

$$B_0 = \int \frac{\mu_0}{2r} dN$$

where $\frac{\mu_0}{2r}$ i is the contribution of one turn of radius r and dN is the number of turns in the interval (r, r + dr).

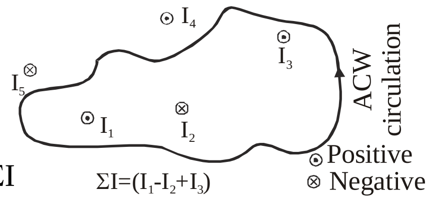
i.e. $dN = \frac{N}{b-a} dr$

Substituting in equation (1) and integrating the result over r between a and b, we obtain,

$$B_0 = \int_a^b \frac{\mu_0 i}{2r}\frac{N}{(b-a)} dr = \frac{\mu_0 iN}{2(b-a)} \ln \frac{b}{a}$$

AMPERE'S CIRCUITAL LAW

Ampere's circuital law state that line integral of the magnetic field around any closed path in free space or vacuum is equal to μ_0 times of net current or total current which crossing through the area bounded by the closed path. Mathematically $\oint \vec{B} \cdot d\vec{\ell} = \mu_0 \Sigma I$



This law independent of size and shape of the closed path.

Any current outside the closed path is not included in writing the right hand side of law

Note :

- This law suitable for infinite long and symmetrical current distribution.
- Radius of cross section of thick cylinderical conductor and current density must be given to apply this law.

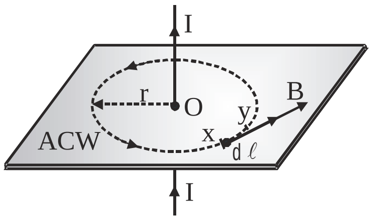
APPLICATION OF AMPERE'S CIRCUITAL LAW

- **Magnetic field due to infinite long thin current carrying straight conductor**

Consider a circle of radius 'r'. Let XY be the small element of length $d\ell$. $\vec{B}$ and $d\vec{\ell}$ are in the same direction because direction of along the tangent of the circle. By A.C.L.

$$\oint \vec{B} \cdot d\vec{\ell} = \mu_0 \Sigma I \,, \oint B\, d\ell \cos\theta = \mu_0 I \quad (\text{where } \theta = 0°)$$

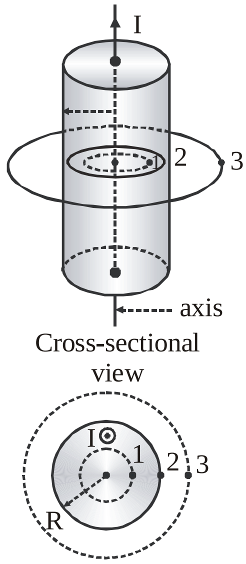
$$\oint B\, d\ell \cos 0° = \mu_0 I \Rightarrow B \oint d\ell = \mu_0 I \quad (\text{where } \oint d\ell = 2\pi r)$$



$$B(2\pi r) = \mu_0 I \Rightarrow B = \frac{\mu_0 I}{2\pi r}$$

- **Magnetic field due to infinite long solid cylinderical conductor**
- For a point inside the cylinder r < R, Current from area πR^2 is = I

so current from area πr^2 is = $\frac{I}{\pi R^2}(\pi r^2) = \frac{I r^2}{R^2}$



By Ampere circuital law for circular path 1 of radius r

$$B_{in}(2\pi r) = \mu_0 I' = \mu_0 \frac{I r^2}{R^2} \Rightarrow B_{in} = \frac{\mu_0 I r}{2\pi R^2} \Rightarrow B_{in} \propto r$$

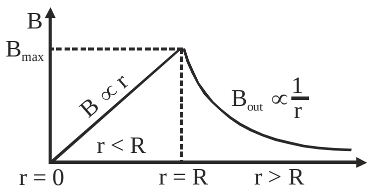
- For a point on the axis of the cylinder (r = 0); $B_{axis} = 0$
- For a point on the surface of cylinder (r = R)

By Ampere circuital law for circular path 2 of radius R

$$B_s(2\pi R) = \mu_0 I \Rightarrow B_s = \frac{\mu_0 I}{2\pi R} \quad (\text{it is maximum})$$

- For a point outside the cylinder (r > R) :-

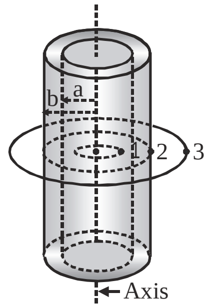
By Ampere circuital law for circular path 3 of radius r



$$B_{out}(2\pi r) = \mu_0 I \Rightarrow B_{out} = \frac{\mu_0 I}{2\pi r} \Rightarrow B_{out} \propto \frac{1}{r}$$

Magnetic field outside the cylinderical conductor does not depend upon nature (thick/thin or solid/hollow) of the conductor as well as its radius of cross section.

- **Magnetic field due to infinite long hollow cylinderical conductor**
- For a point at a distance r such that r < a < b $B_1 = 0$
- For a point at a distance r such that a < r < b



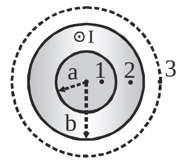
Side View

$$B_2(2\pi r) = \mu_0 I' \Rightarrow B_2(2\pi r) = \mu_0 I\left(\frac{r^2-a^2}{b^2-a^2}\right)$$

$$B_2 = \frac{\mu_0 I}{2\pi r}\left(\frac{r^2-a^2}{b^2-a^2}\right)$$

r = a (inner surface) $\Rightarrow B_{IS} = 0$

r = b (outer surface) $\Rightarrow B_{OS} = \frac{\mu_0 I}{2\pi b}$ (maximum)

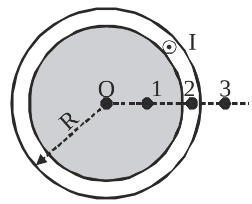


Cross sectional view

- For a point at a distance r such that r > b > a, $B_3(2\pi r) = \mu_0 I \Rightarrow B_3 = \frac{\mu_0 I}{2\pi r}$
- For a point at the axis of cylinder r = 0 $B_{axis} = 0$

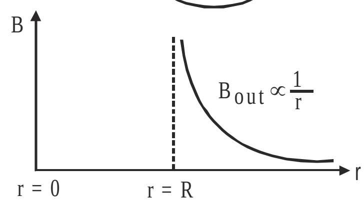
Magnetic field at specific positions for thin hollow cylinderical conductor

At point 1 $B_1 = 0$



At point 2 $B_2 = \frac{\mu_0 I}{2\pi R}$ (maximum) [outer surface] and

$B_2 = 0$ (minimum) [inner surface]



At point 3 $B_3 = \frac{\mu_0 I}{2\pi r}$ (for the point on axis $B_{axis} = 0$)

Ex. **Non-Uniform Current Density :** Consider an infinitely long, cylindrical conductor of radius *R* carrying a current *I* with a non-uniform current density $J = \alpha r$
where α is a constant. Find the magnetic field everywhere.

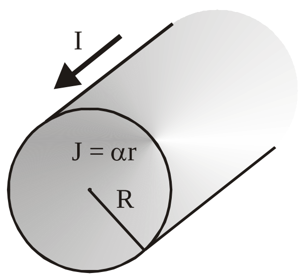


Figure : Non-uniform current density

Solution :

The problem can be solved by using the Ampere's law:

$$\oint \vec{B}.d\vec{s} = \mu_0 I_{enc}$$

Where the enclosed current I_{enc} is given by

$$I_{enc} = \int \vec{J}\,.\,d\vec{A} = \int(\alpha r')(2\pi r' dr')$$

(a) For r < R, the enclosed current is $I_{enc} = \int_0^r 2\pi\alpha r'^2\, dr' = \dfrac{2\pi\alpha r^3}{3}$

Applying Ampere's law, the magnetic field at P_1 is given by

$$B_1(2\pi r) = \frac{2\mu_0\pi\alpha r^3}{3} \quad \text{or } B_1 = \frac{\alpha\mu_0}{3} r^2$$

The direction of the magnetic field $\vec{B}_1$ is tangential to the Amperian loop which encloses the currect.

(b) For r > R, the enclosed current is : $I_{enc} = \int_0^R 2\pi\alpha r'^2 dr' = \dfrac{2\pi\alpha R^3}{3}$

which yields $B_2(2\pi r) = \dfrac{2\mu_0\pi\alpha R^3}{3}$

Thus, the magnetic field at a point P_2 outside the conductor is ;

$$B_2 = \frac{\alpha\mu_0 R^3}{3r}$$

A plot of B as a function of r is shown in figure.

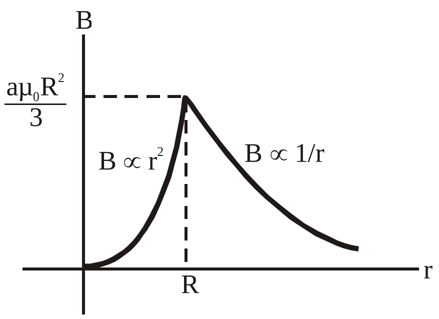
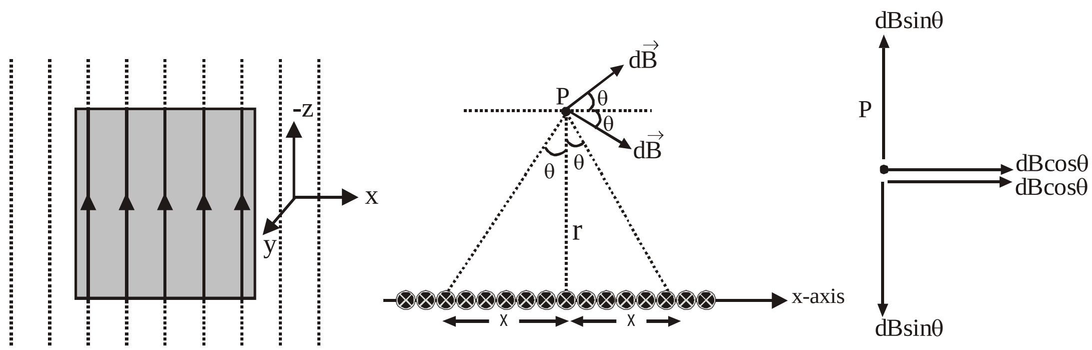


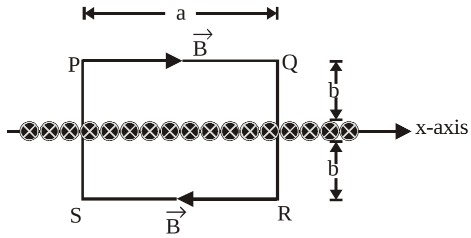
Figure : The magnetic field as a function of distance away from the conductor

Magnetic field due to an infinite plane sheet of current



An infinite sheet of current lies in x-z plane, carrying current along-z axis. The field at any point P on y is along a line parallel to x-z plane. We can take a rectangular amperian loop as shown. If you traverse the loop in clockwise direction, inward current will be positive.

By Ampere circuital law, $\oint_{PQRS} \vec{B}.d\vec{\ell} = \mu_0 \ell_{enclosed}$ ....(i)



Let λ represents current per unit length.

The current enclosed is given by $\ell_{enclosed} = \lambda a$

Now, $\oint_{PQRS} \vec{B}.d\vec{\ell} = \int_{PQ} \vec{B}.d\vec{\ell} + \int_{QR} \vec{B}.d\vec{\ell} + \int_{RS} \vec{B}.d\vec{\ell} + \int_{SR} \vec{B}.d\vec{\ell}$

Now, $\int_{QR} \vec{B}.d\vec{\ell} = \int_{SP} \vec{B}.d\vec{\ell} = 0$ as $\vec{B} \perp \overrightarrow{d\ell}$

Also, $\int_{PQ} \vec{B}.d\vec{\ell} + \int_{RS} \vec{B}.d\vec{\ell} = 2 \times B \times a \left(\text{as } \vec{B} \| d\vec{\ell}\right) \therefore 2B \times a = \mu_0 \lambda a \Rightarrow B = \frac{\mu_0 \lambda}{2}$

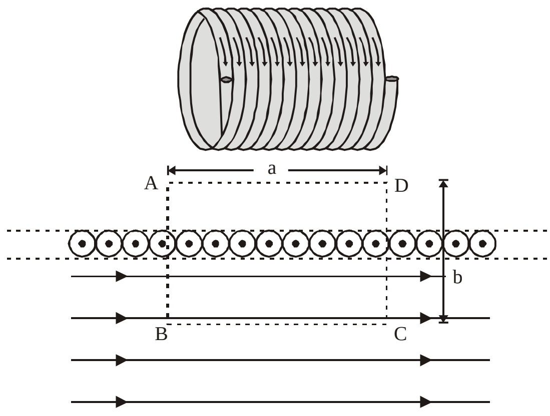
MAGNETIC FIELD DUE TO SOLENOID

It is a coil which has length and used to produce uniform magnetic field of long range. It consists a conducting wire which is tightly wound over a cylinderical frame in the form of helix. All the adjacent turns are electrically insulated to each other. The magnetic field at a point on the axis of a solenoid can be obtained by superposition of field due to large number of identical circular turns having their centres on the axis of solenoid.

Magnetic field due to a long solenoid

A solenoid is a tightly wound helical coil of wire. If length of solenoid is large, as compared to its radius, then in the central region of the solenoid, a reasonably uniform magnetic field is present. Figure shows a part of long solenoid with number of turns/length n.We can find the field by using Ampere circuital law.

Consider a rectangular loop ABCD. For this loop $\oint_{ABCD} \vec{B}.\overrightarrow{d\ell} = \mu_0 i_{enc}$



(Magnetic field lines)

Now

$$\oint_{ABCD} \vec{B}.\overrightarrow{d\ell} = \oint_{AB} \vec{B}.\overrightarrow{d\ell} + \oint_{BC} \vec{B}.\overrightarrow{d\ell} + \oint_{CD} \vec{B}.\overrightarrow{d\ell} + \oint_{DA} \vec{B}.\overrightarrow{d\ell} = B \times a$$

This is because $\oint_{AB} \vec{B}.\overrightarrow{d\ell} = \oint_{CD} \vec{B}.\overrightarrow{d\ell} = 0,\ \vec{B} \perp \overrightarrow{d\ell}$.

And, $\oint_{DA} \vec{B}.\overrightarrow{d\ell} = 0$

($\because$ $\vec{B}$ outside the solenoid is negligible

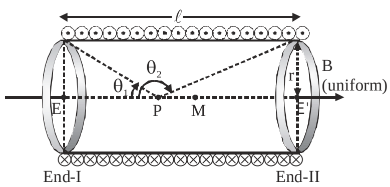
Now, $i_{enc} = (n \times a) \times i\ s \Rightarrow B \times a = \mu_0 (n \times a \times i)$

$\Rightarrow B = \mu_0 ni$

Finite length solenoid :

Its length and diameter are comparable. By the concept of BSL magnetic field at the axial point 'P' obtained as :

$$B_P = \frac{\mu_0 nI}{2}(\cos\theta_1 - \cos\theta_2)$$



Angle θ_1 and θ_2 both measured in same sense from the axis of the solenoid to end vectors.

Infinite length solenoid :

Its length very large as compared to its diameter i.e. ends of solenoid tends to infinity.

(a) Magnetic field at axial point which is well inside the solenoid

$$\theta_1 \simeq 0° \text{ and } \theta_2 \simeq 180° \Rightarrow B \simeq \frac{\mu_0 nI}{2}[\cos 0° - \cos 180°] \simeq \frac{\mu_0 nI}{2}[(1)-(-1)] \simeq \mu_0 nI$$

(b) Magnetic field at both axial end points of solenoid

$$\theta_1 = 90° \text{ and } \theta_2 \simeq 180° \Rightarrow B \simeq \frac{\mu_0 nI}{2}[\cos 90° - \cos 180°] \simeq \frac{\mu_0 nI}{2}[(0)-(-1)] \simeq \frac{\mu_0 nI}{2}$$

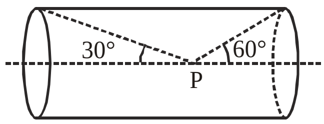
Ex. The length of solenoid is 0.1m. and its diameter is very small. A wire is wound over it in two layers. The number of turns in inner layer is 50 and that of outer layer is 40. The strength of current flowing in two layers in opposite direction is 3A. Then find magnetic induction at the middle of the solenoid.

Sol. Direction of magnetic field due to both layers is opposite, as direction of current is opposite so

$$B_{net} = B_1 - B_2 = \mu_0 n_1 I_1 - \mu_0 n_2 I_2 = \mu_0 \frac{N_1}{\ell} I - \mu_0 \frac{N_2}{\ell} I \quad (\because I_1 = I_2 = I)$$

$$= \frac{\mu_0 I}{\ell}(N_1 - N_2) = \frac{4\pi \times 10^{-7} \times 3}{0\cdot 1}(50-40) = 12\pi \times 10^{-5}\text{ T}$$

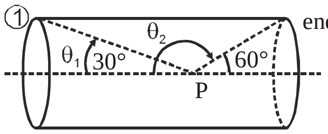
Ex. Find out magnetic field at axial point 'P' of solenoid shown in figure (where turn density 'n' and current through it is I)



Sol. Magnetic field at point 'P' due to finite length solenoid

$$B_P = \frac{\mu_0 nI}{2}[\cos\theta_1 - \cos\theta_2],$$

where $\theta_1 = 30°$ (CW),

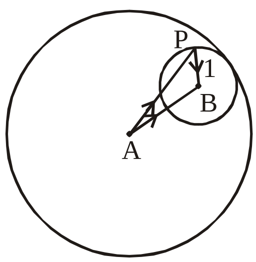


$$\theta_2 = (180°-60°) = 120° \text{ (CW)} = \frac{\mu_0 nI}{2}[\cos 30° - \cos 120°]$$

$$= \frac{\mu_0 nI}{2}\left[\frac{\sqrt{3}}{2} - \left(-\frac{1}{2}\right)\right] = \frac{\mu_0 nI}{4}(\sqrt{3}+1)$$

Ex. Inside a long straight uniform wire of round cross-section there is a long round cylindrical cavity whose axis is parallel to the axis of the wire and displaced from the latter by a distance I. A direct current of density j flows along the wire. Find the magnetic induction inside the cavity. Consider, in particular, the case I = 0.

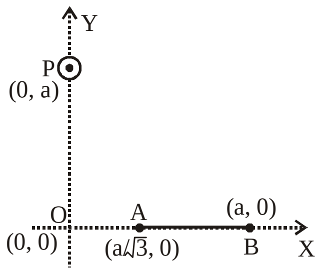
Sol. We can think of the given current which will be assumed uniform, as arising due to a negative current, flowing in the cavity, superimposed on the true current, everywhere including the cavity. Then from the previous problem, by superposition



$$\vec{B} = \frac{1}{2}\mu_0 \vec{j} \times (\vec{AP} - \vec{BP}) = \frac{1}{2}\mu_0 \vec{j} \times \vec{\ell}$$

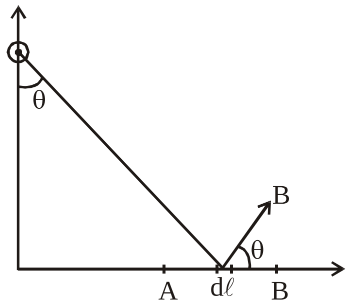
If $\vec{\ell}$ vanishes so that the cavity is concentric with the conductor, there is no magnetic field in the cavity.

Ex. An infinite current carrying conductor, parallel to z-axis is situated at point P as shown in the figure. Value of $\int_A^B \vec{B}\cdot d\vec{\ell}$ is given by $\alpha \dfrac{\mu_0 i}{96}$, then fill the value of α in OMR sheet ?



Ans. 4

Sol. $d\ell = d(a\tan\theta) = a\sec^2\theta d\theta.$



$$B = \frac{\mu_0 i}{2\pi a}\cos\theta$$

$$\therefore \int B.d\ell = \int_{\frac{\pi}{6}}^{\frac{\pi}{4}} \frac{\mu_0 i}{2\pi a}\cos\theta\ a\sec^2\theta d\theta.\cos\theta = \frac{\mu_0 i}{2\pi}\int_{\pi/6}^{\pi/4} d\theta = \frac{\mu_0 i}{2\pi}\cdot\frac{\pi}{12} = \frac{\mu_0 i}{24}.$$

MOTION OF A CHARGED PARTICLE IN A MAGNETIC FIELD

Motion of a charged particle when it is moving collinear with the field magnetic field is not affected by the field (i.e. if motion is just along or opposite to magnetic field) ($\because$ F = 0). The following two cases are possible :

- **Case I :**

When the charged particle is moving perpendicular to the field.

The angle between $\vec{B}$ and $\vec{v}$ is $\theta=90°$. So the force will be maximum (= qvB) and always perpendicular to motion (and also field); Hence the charged particle will move along a circular path (with its plane perpendicular to the field). Centripetal force is provided by the force qvB, So $\dfrac{mv^2}{r} = qvB \Rightarrow r = \dfrac{mv}{qB}$

Angular frequency of circular motion, called cyclotron or gyro-frequency. $\omega = \dfrac{v}{r} = \dfrac{qB}{m}$

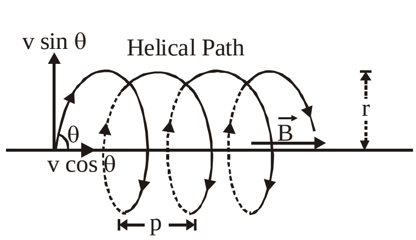
and the time period, $T = \dfrac{2\pi}{\omega} = 2\pi\dfrac{m}{qB}$ i.e., time period (or frequency) is independent of speed of particle and radius of the orbit. Time period depends only on the field B and the nature of the particle, i.e., specific charge (q/m) of the particle.

This principle has been used in a large number of devices such as cyclotron (a particle accelerator), bubble-chamber (a particle detector) or mass-spectrometer etc.

Note that $\vec{F}_B$ is always perpendicular to $\vec{v}$ and $\vec{B}$, and cannot change the particle's speed *v* (and thus the kinetic energy). In other words, magnetic force cannot speed up or slow down a charged particle. Consequently, $\vec{F}_B$ can do no work on the particle :

$$dW = \vec{F}_B \bullet d\vec{s} = q(\vec{v}\times\vec{B})\bullet\vec{v}dt = q(\vec{v}\times\vec{v})\bullet\vec{B}dt = 0$$

- **Case II :**



The charged particle is moving at an angle θ to the field :
($\theta \neq 0°, 90°$ or $180°$)
Resolving the velocity of the particle along and perpendicular to the field.The particle moves with constant velocity $v\cos\theta$ along the field
($\because$ no force acts on a charged particle when it moves parallel to the field).
And at the same time it is also moving with velocity $v\sin\theta$ perpendicular to the field due to which it will describe a circle (in a plane perpendicular to the field)

Radius of the circular path $r = \dfrac{m(v\sin\theta)}{qB}$ and Time period $T = \dfrac{2\pi r}{v\sin\theta} = \dfrac{2\pi m}{qB}$

So the resultant path will be a helix with its axis parallel to the field $\vec{B}$ as shown in fig.

The pitch p of the helix = linear distance travelled in one rotation $p = T(v\cos\theta) = \dfrac{2\pi m}{qB}(v\cos\theta)$

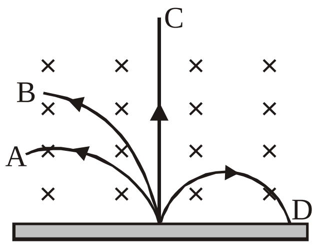
Ex. An electron emitted by a heated cathode and accelerated through a potential difference of 2.0 kV enters a region with uniform magnetic field of 0.15 T. Determine the radius of the trajectory of the electron if the field is –
(a) Transverse to its initial velocity (b) Makes an angle of 30° with the initial velocity
[Given : $m_e = 9 \times 10^{-31}$ kg]

Sol. $\dfrac{1}{2}mv^2 = eV \Rightarrow v = \sqrt{\dfrac{2eV}{m}} = \sqrt{\dfrac{2\times1.6\times10^{-19}\times2\times10^{3}}{9\times10^{-31}}} = \dfrac{8}{3}\times 10^7$ m/s

(a) Radius $r_1 = \dfrac{mv}{qB} = \dfrac{9\times10^{-31}\times(8/3)\times10^{7}}{1.6\times10^{-19}\times0.15} = 10^{-3}$ m = 1mm

(b) Radius $r_2 = \dfrac{mv\sin\theta}{qB} = r_1\sin\theta = 1\times\sin30° = 1\times\dfrac{1}{2} = 0.5$ mm

Ex. A neutron, a proton, an electron an α-particle enter a region of constant magnetic field with equal velocities. The magnetic field is along the inwards normal to the plane of the paper. The tracks of the particles are shown in fig. Relate the tracks to the particles.



Sol. Force on a charged particle in magnetic field $\vec{F} = q(\vec{v}\times\vec{B})$
For neutron q = 0, F = 0 hence it will pass undeflected.
i.e., tracks C corresponds to neutron.
If the particle is negatively charged, i.e. electron. $\vec{F} = -e(\vec{v}\times\vec{B})$
It will experience a force to the right; so track D corresponds to electron.
If the charge on particle is positive. It will experience a force to the left; so both tracks A and B corresponds to positively charged particles (i.e., protons and α-particles). When motion of charged particle perpendicular to the magnetic field the path is a circle with radius

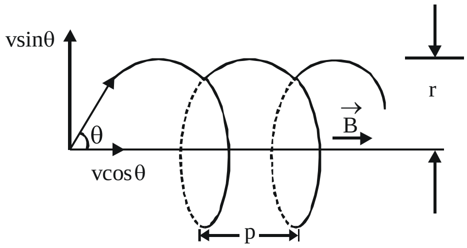
$r = \dfrac{mv}{qB}$ i.e. $r \propto \dfrac{m}{q}$ and as $\left(\dfrac{m}{q}\right)_\alpha = \left(\dfrac{4m}{2e}\right)$ while $\left(\dfrac{m}{q}\right)_p = \dfrac{m}{e} \Rightarrow \left(\dfrac{m}{q}\right)_\alpha > \left(\dfrac{m}{q}\right)_p$

So $r_\alpha > r_p \Rightarrow$ track B to α-particle and A corresponds to proton.

Ex. A beam of protons with velocity 4×10^5 m/s 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 helix. Mass of proton=1.67×10^{-27}kg.

Sol. Radius of helix $r = \dfrac{mv\sin\theta}{qB}$ ($\therefore$ component of velocity $\perp$ to field is vsinθ)

$$= \frac{(1.67\times10^{-27})(4\times10^{5})\sqrt{\frac{3}{2}}}{(1.6\times10^{-19})0.3} = \frac{2}{\sqrt{3}} \times 10^{-2}\text{m} = 1.2\text{cm}$$



Again, pitch $p = v\cos\theta \times T$ (where $T = \dfrac{2\pi r}{v\sin\theta}$)

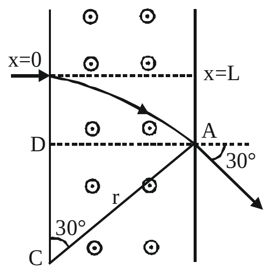
$$\therefore\ p = \frac{v\cos\theta\times 2\pi r}{v\sin\theta} = \frac{\cos 60°\times 2\pi\times(1.2\times10^{-2})}{\sin 60°} = 4.35\times 10^{-2}\text{m} = 4.35\text{cm}$$

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

(a) Find the value of L if the particle emerges from the region of magnetic field with its final velocity at an angle 30° to 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 upto 2.1 L.

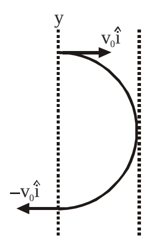
Sol. (a) The particle is moving with velocity $v_0\hat{i}$, perpendicular to magnetic field $B_0\hat{k}$. Hence the particle will move along a circular arc OA of radius $r = \dfrac{mv_0}{qB_0}$



Let the particle leave the magnetic field at A.

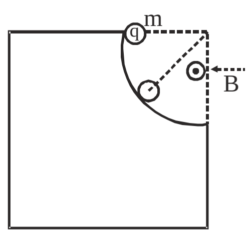
From ΔCDA, $\sin 60° = \dfrac{AD}{CA} = \dfrac{L}{r} \Rightarrow L = r\sin 30° = \dfrac{r}{2}\ \therefore L = \dfrac{mv_0}{2qB_0}$

(b) As the magnetic field extends upto 2.1 L i.e., L > 2r, so the particle completes half cycle before leaving the magnetic field, as shown in figure.
The magnetic field is always perpendicular to velocity vector, therefore the magnitude of velocity will remain the same.

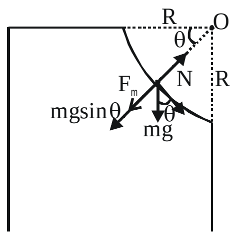


$\therefore$ Final velocity $= v_0(-\hat{i}) = -v_0\hat{i}$ Time spent in magnetic field $= \dfrac{\pi r}{v_0} = \dfrac{\pi m}{qB_0}$

Ex. A charged sphere of mass m and charge q starts sliding from rest on a vertical fixed circular track of radius R from the position as shown in figure. There exists a uniform and constant horizontal magnetic field of induction B. Find the maximum force exerted by the track on the sphere.



Sol. Magnetic force on sphere $F_m = qvB$ (directed radially outward)



$$\because \ N - mg\sin\theta - qvB = \frac{mv^2}{R}$$

$$\Rightarrow N = \frac{mv^2}{R} + mg\sin\theta + qvB$$

Hence, at $\theta = \pi/2$ we get $N_{max} = \dfrac{2mgR}{R} + mg + qB\sqrt{2gR} = 3mg + qB\sqrt{2gR}$

Ex. A particle of charge q and mass m starts moving from the origin under the action of an electric field $\vec{E} = E_0\hat{i}$ and magnetic field $\vec{B} = B_0\hat{i}$ with velocity $\vec{v} = v_0\hat{j}$. The speed of the particle will become $2v_0$ after a time :-

(A) $t = \dfrac{2mv_0}{qE}$ (B) $t = \dfrac{2Bq}{mv_0}$ (C) $t = \dfrac{\sqrt{3}\,Bq}{mv_0}$ (D) $t = \dfrac{\sqrt{3}\,mv_0}{qE}$

Ans. (D)

Sol. Charged particle will move in a Helical path.

$$\vec{F} = q\vec{E} + q\vec{v}\times\vec{B}$$

$\vec{a} = \dfrac{qE\hat{i}}{m}$ this part will increase x component of velocity

$+$

$\dfrac{qv_0 \times B}{m}$ (in y-z plane) this term will provide centripetal acceleration.

$$v_x = \frac{qE}{m}\cdot t$$

$$v = \sqrt{v_x^2 + v_0^2}$$

$$2v_0 = \sqrt{\left(\frac{qE}{m}t\right)^2 + v_0^2}$$

$$\sqrt{3}v_0 = \frac{qE}{m}t$$

$$t = \frac{\sqrt{3}mv_0}{qE}$$

(1) Velocity Selector :

In the presence of both electric field $\vec{E}$ and magnetic field $\vec{B}$, the total force on a charged particle is

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

This is known as the Lorentz force. By combining the two fields, particles which move with a certain velocity can be selected. This was the principle used by J. J. Thomson to measure the charge-to-mass ratio of the electrons. In Figure the schematic diagram of Thomson's apparatus is depicted.

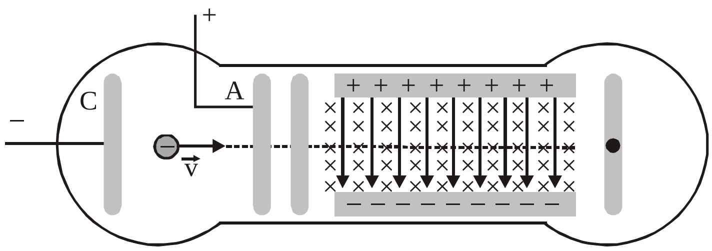


Figure : Thomson's apparatus

The electrons with charge $q = -e$ and mass m are emitted from the cathode C and then accelerated toward slit A. Let the potential difference between A and C be $V_A - V_C = \Delta V$. The change in potential energy is equal to the external work done in accelerating the electrons: $\Delta U = W_{ext} = q\Delta V = -e\Delta V$. By energy conservation, the kinetic energy gained is $\Delta K = -\Delta U = mv^2/2$. Thus, the speed of the electrons is given by

$$v = \sqrt{\frac{2e\Delta V}{m}}$$

If the electrons further pass through a region where there exists a downward uniform electric field, the electrons, being negatively charged, will be deflected upward. However, if in addition to the electric field, a magnetic field directed into the page is also applied, then the electrons will experience an additional downward magnetic force $-e\vec{v} \times \vec{B}$. When the two forces exactly cancel, the electrons will move in a straight path. From Eq., we see that when the condition for the cancellation of the two forces is given by $eE = evB$. which implies

$$v = \frac{E}{B}$$

In other words, only those particles with speed $v = E / B$ will be able to move in a straight line. Combining the two equations, we obtain

$$\frac{e}{m} = \frac{E^2}{2(\Delta V)B^2}$$

By measuring E, ΔV and B, the charge-to-mass ratio can be readily determined. The most precise measurement to date is $e/m = 1.758820174(71) \times 10^{11}$ C/kg.

(2) Mass Spectrometer :

Various methods can be used to measure the mass of an atom. One possibility is through the use of a mass spectrometer. The basic feature of a *Bainbridge* mass spectrometer is illustrated in Figure. A particle carrying a charge $+q$ is first sent through a velocity selector.

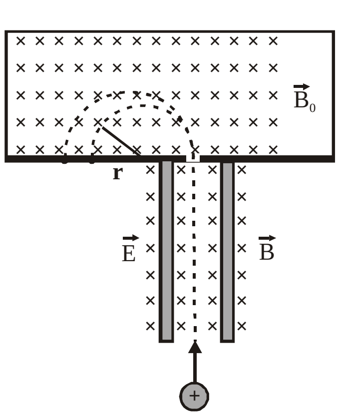


Figure : A Bainbridge mass spectrometer

The applied electric and magnetic fields satisfy the relation $E = vB$ so that the trajectory of the particle is a straight line. Upon entering a region where a second magnetic field $\vec{B}_0$ pointing into the page has been applied, the particle will move in a circular path with radius r and eventually strike the photographic plate. Using Eq., we have

$$r = \frac{mv}{qB_0}$$

Since v = E/B, the mass of the particle can be written as

$$m = \frac{qB_0 r}{v} = \frac{qB_0 Br}{E}$$

Ex. Particle A with charge q and mass m_A and particle B with charge $2q$ and mass m_B, are accelerated from rest by a potential difference ΔV, and subsequently deflected by a uniform magnetic field into semicircular paths. The radii of the trajectories by particle A and B are R and $2R$, respectively. The direction of the magnetic field is perpendicular to the velocity of the particle. What is their mass ratio?

Sol. The kinetic energy gained by the charges is equal to

$$\frac{1}{2}mv^2 = q\Delta V$$

which yields $v = \sqrt{\frac{2q\Delta V}{m}}$

The charges move in semicircles, since the magnetic force points radially inward and provides the source of the centripetal force :

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

The radius of the circle can be readily obtained as :

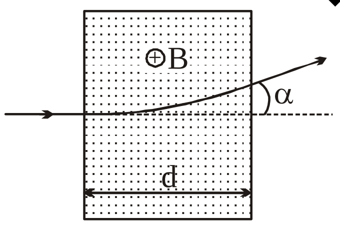
$$r = \frac{mv}{qB} = \frac{m}{qB}\sqrt{\frac{2q\Delta V}{m}} = \frac{1}{B}\sqrt{\frac{2m\Delta V}{q}}$$

which shows that r is proportional to $(m/q)^{1/2}$. The mass ratio can then be obtained from

$$\frac{r_A}{r_B} = \frac{(m_A/q_A)^{1/2}}{(m_B/q_B)^{1/2}} \Rightarrow \frac{R}{2R} = \frac{(m_A/q)^{1/2}}{(m_B/2q)^{1/2}}$$

which gives $\frac{m_A}{m_B} = \frac{1}{8}$

Ex. A proton accelerated by a potential difference V = 500 kV flies through a uniform transverse magnetic field with induction B = 0.51 T. The field occupies a region of space d = 10 cm in thickness (Fig.). Find the angle a through which the proton deviates from the initial direction of its motion.



Ans. $\alpha = \arcsin\left(dB\sqrt{\frac{q}{2mV}}\right) = 30°$

Sol. From the figure,

$$\sin\alpha = \frac{d}{R} = \frac{dqB}{mv}$$

As radius of the arc $R = \frac{mv}{qB}$, where v is the velocity of the particle, when it enters into the field.

From initial condition of the problem,

$$qV = \frac{1}{2}mv^2 \qquad \text{or, } v = \sqrt{\frac{2qV}{m}}$$

Hence, $\sin\alpha = \frac{dqB}{m\sqrt{2qV/m}} = dB\sqrt{\frac{q}{2mV}}$

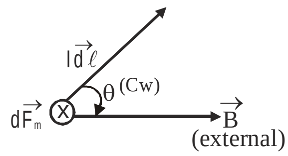
and $a = \sin^{-1}\left(dB\sqrt{\frac{q}{2mV}}\right) = 30°$, on putting the values.

CURRENT CARRYING CONDUCTOR IN MAGNETIC FIELD

When a current carrying conductor placed in magnetic field, a magnetic force exerts on each free electron which are present inside the conductor. The resultant of these forces on all the free electrons is called magnetic force on conductor.

- **Magnetic force on current element**

  Through experiments Ampere established that when current element $I\,d\vec{\ell}$ is placed in magnetic field $\vec{B}$, it experiences a magnetic force $d\vec{F}_m = I(d\vec{\ell} \times \vec{B})$



- Current element in a magnetic field does not experience any force if the current in it is parallel or anti–parallel with the field θ = 0° or 180°

  $dF_m = 0$ (min.)

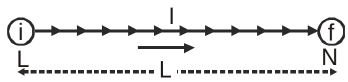
- Current element in a magnetic field experiences maximum force if the current in it is perpendicular with the field θ = 90°

  $dF_m = BId\ell$ (max.)

- Magnetic force on current element is always perpendicular to the current element vector and magnetic field vector. $d\vec{F}_m \perp Id\vec{\ell}$ and $d\vec{F}_m \perp \vec{B}$ (always)

- Total magnetic force on straight current carrying conductor in uniform magnetic field given as

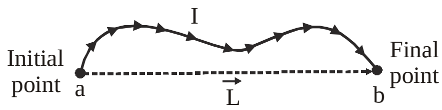
$$\vec{F}_m = \int_i^f d\vec{F}_m \left[\int_i^f d\vec{\ell}\right] = I \times \vec{B},\ \vec{F}_m = I(\vec{L} \times \vec{B})$$



Where $\vec{L} = \int_i^f \vec{d\ell}$, vector sum of all length elements from initial to final point, which is in accordance with the law of vector addition and $|\vec{L}|$ = length of the condutor.

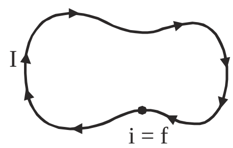
- Total magnetic force on arbitrary shape current carrying conductor in uniform magnetic field $\vec{B}$ is

$$\int_i^f d\vec{F}_m = I\left[\int_i^f d\vec{\ell}\right] \times \vec{B},\ \vec{F}_m = I(\vec{L} \times \vec{B})\ (L = ab)$$



Where $\vec{L} = \int_i^f d\vec{\ell}$, vector sum of all length elements from initial to final point or displacement between free ends of an arbitrary conducter from initial to final point.

- A current carrying closed loop (or coil) of any shape placed in uniform magnetic field then no net magnetic force act on it (Torque may or may not be zero)



$$\vec{L} = \int_i^f d\vec{\ell} = 0 \text{ or } \oint d\vec{\ell} = 0$$

So net magnetic force acting on a current carrying closed loop $\vec{F}_m = 0$ (always)

- When a current carrying closed loop (or coil) of any shape placed in non uniform magnetic field then net magnetic force is always acts on it (Torque may or may not be zero)

Ex. : Magnetic Force on a Semi-Circular Loop

Consider a closed semi-circular loop lying in the *xy* plane carrying a current *I* in the counterclockwise direction, as shown in Figure.

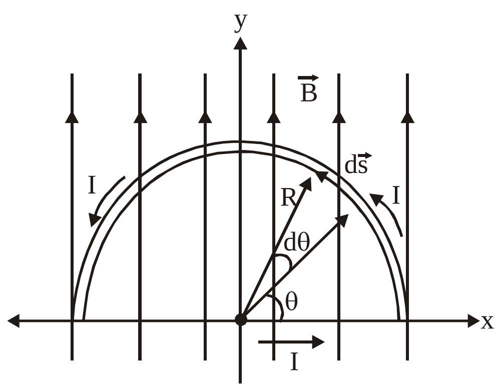


Figure 8.3.6 Semi-circular loop carrying a current *I*

A uniform magnetic field pointing in the +*y* direction is applied. Find the magnetic force acting on the straight segment and the semicircular arc.

Sol. Let $\vec{B} = B\hat{j}$ and $\vec{F}_1$ and $\vec{F}_2$ the forces acting on the straight segment and the semicircular parts, respectively. Using Eq. and noting that the length of the straight segment is 2*R*, the magnetic force is

$$\vec{F}_1 = I(2R\hat{i}) \times (B\hat{j}) = 2IRB\hat{k}$$

where $\hat{k}$ is directed out of the page.

To evaluate $\vec{F}_2$, we first note that the differential length element $d\vec{s}$ on the semicircle can be written as $d\vec{s} = ds\hat{\theta} = Rd\theta(-\sin\theta\hat{i} + \cos\theta\hat{j})$. The force acting on the length element is $d\vec{s}$ is :

$$d\vec{s} = Id\vec{s}\times\vec{B} = IRd\theta(-\sin\theta\hat{i}+\cos\theta\hat{j})\times(B\hat{j}) = -IBR\sin\theta d\theta\hat{k}$$

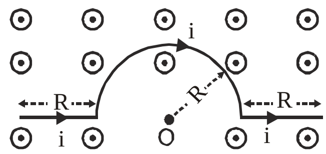
Here we see that $d\vec{F}_2$ points into the page. Integrating over the entire semi-circular arc, we have

Thus, the net force acting on the semi-circular wire is

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 = \vec{0}$$

This is consistent from our previous claim that the net magnetic force acting on a closed current-carrying loop must be zero.

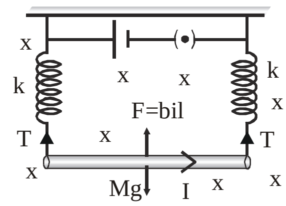
Ex. A wire bent as shown in fig carries a current i and is placed in a uniform field of magnetic induction $\vec{B}$ that emerges from the plane of the figure. Calculate the force acting on the wire.



Sol. The total force on the whole wire is

$F_m = I|\vec{L}|B = I(R + 2R + R)B = 4RIB$

Ex. A metal rod of mass 10 gm and length 25 cm is suspended on two springs as shown in figure. The springs are extended by 4 cm. When a 20 ampere current passes through the rod it rises by 1 cm. Determine the magnetic field assuming acceleration due to gravity to be 10 m/s^2.



Sol. Let tension in each spring is = T_0

Initially the rod will be in equilibrium if $2T_0 = Mg$

then $T_0 = kx_0$ ...(i)

Now when the current I is passed through the rod it will experience a force F = BIL vertically up; so in this situation for its equilibrium,

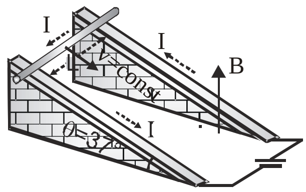
$2T + BIL = Mg$ with $T = kx$ ...(ii) $(x = 4 – 1 = 3\text{cm})$

So from eq. (i) and eq.(ii) $\dfrac{T}{T_0} = \dfrac{Mg - BIL}{Mg}$

$$\Rightarrow \frac{x}{x_0} = 1 - \frac{BIL}{Mg}$$

$$\Rightarrow B = \frac{Mg(x_0 - x)}{ILx_0} = \frac{10\times10^{-3}\times10\times3\times10^{-2}}{20\times25\times10^{-2}\times4\times10^{-2}} = 1.5 \times 10^{-2}\text{T}$$

Ex. Two conducting rails are connected to a source of e.m.f. and form an incline as shown in fig. A bar of mass 50 g slides without friction down the incline through a vertical magnetic field B. If the length of the bar is 50 cm and a current of 2.5 A is provided by the battery, for what value of B will the bar slide at a constant velocity ? [g = 10 m/s^2]

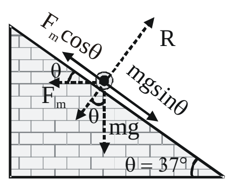


Sol. Force on current carrying wire F = BIL

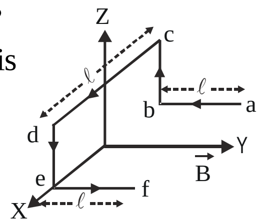
The rod will move down the plane with constant velocity only if

$F\cos\theta = mg\sin\theta \Rightarrow BIL\cos\theta = mg\sin\theta$

or, $B = \dfrac{mg}{IL}\tan\theta = \dfrac{50\times10^{-3}\times10}{2.5\times50\times10^{-2}}\times\dfrac{3}{4} = 0.3\text{ T}$



Ex. 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 field B parallel to +y direction. What is the force experienced by the wire.

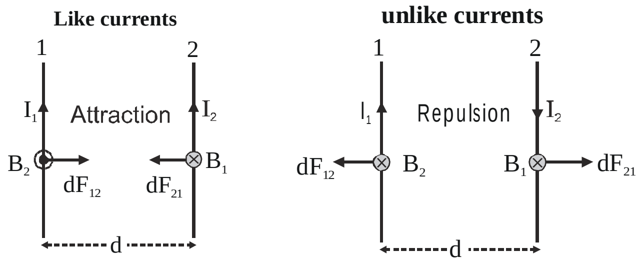


Sol. Magnetic force on wire abcdef in uniform magnetic field is $\vec{F}_m = I(\vec{L} \times \vec{B})$,

$\vec{L}$ is displacement between free ends of the conductor from initial to final point. $\vec{L} = (\ell)\,\hat{i}$ and $\vec{B} = (B)\,\hat{j}$

$F_m = I(\vec{L} \times \vec{B}) = BIL\,(\hat{i} \times \hat{j}) = BI\ell(\hat{k}) = BI\ell$, along +z direction

MAGNETIC FORCE BETWEEN TWO PARALLEL CURRENT CARRYING CONDUCTORS



The net magnetic force acts on a current carrying conductor due to its own field is zero. So consider two infinite long parallel conductors separated by distence 'd' carrying currents I_1 and I_2.

Magnetic field at each point on conductor (ii) due to current I_1 is $B_1 = \frac{\mu_0 I_1}{2\pi d}$

[uniform field for conductor (2)]

Magnetic field at each point on conductor (i) due to curent I_2 is $B_2 = \frac{\mu_0 I_2}{2\pi d}$

[Uniform field for conductor (1)]
consider a small element of length 'dℓ' on each conductor. These elements are right angle to the external magnetic field, so magnetic force experienced by elements of each conductor given as

$$dF_{12} = B_2 I_1 d\ell = \left(\frac{\mu_0 I_2}{2\pi d}\right) I_1\, d\ell \quad \text{...(i)} \qquad (\text{Where } I_1\, d\ell \perp B_2)$$

$$dF_{21} = B_1 I_2 d\ell = \left(\frac{\mu_0 I_1}{2\pi d}\right) I_2\, d\ell \quad \text{... (ii)} \qquad (\text{Where } I_2\, d\ell \perp B_1)$$

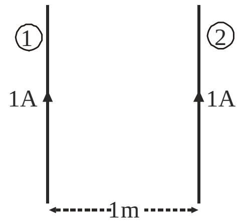
Where dF_{12} is magnetic force on element of conductor (i), due field of conductor (i) and dF_{21} is magnetic force on element of conductor (ii), due to field of conductor (i).

Magnetic force per unit length of each conductor is $\frac{dF_{12}}{d\ell} = \frac{dF_{21}}{d\ell} = \frac{\mu_0 I_1 I_2}{2\pi d}$

$$f = \frac{\mu_0 I_1 I_2}{2\pi d} \text{ N/m (in S.I.)} \qquad f = \frac{2 I_1 I_2}{d} \text{ dyne/cm (In C.G.S.)}$$

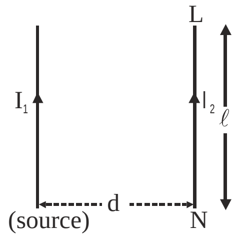
Definition of ampere :

Magnetic force/unit length for both infinite length conductor gives as



$$f = \frac{\mu_0 I_1 I_2}{2\pi d} = \frac{(4\pi\times10^{-7})(1)(1)}{2\pi(1)} = 2 \times 10^{-7}\ \text{N/m}$$

'Ampere' is the current which, when passed through each of two parallel infinite long straight conductors placed in free space at a distance of 1 m from each other, produces between them a force of 2×10^{-7} N/m



- Force scale $f = \dfrac{\mu_0 I_1 I_2}{2\pi d}$ is applicable when at least one conductor must be of infinite length so it behaves like source of uniform magnetic field for other conductor.

Magnetic force on conductor 'LN' is $F_{LN} = f \times \ell \Rightarrow F_{LN} = \left(\dfrac{\mu_0 I_1 I_2}{2\pi d}\right)\ell$

<u>Torque on a Current Loop :</u>

What happens when we place a rectangular loop carrying a current *I* in the *xy* plane and switch on a uniform magnetic field $\vec{B} = B\hat{i}$ which runs parallel to the plane of the loop, as shown in Figure (a)?

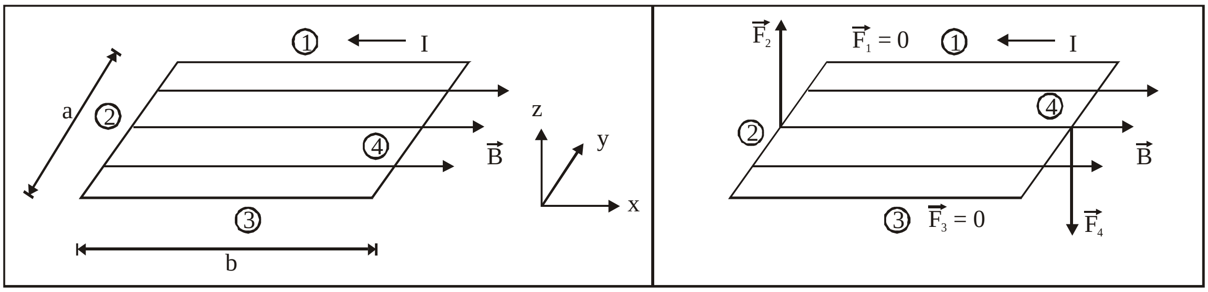


Figure : (a) A rectangular current loop placed in a uniform magnetic field.
(b) The magnetic forces acting on sides 2 and 4.

From Eq., we see the magnetic forces acting on sides 1 and 3 vanish because the length vectors $\vec{\ell}_1 = -b\hat{i}$ and $\vec{\ell}_3 = b\hat{i}$ are parallel and anti-parallel to $\vec{B}$ and their cross products vanish. On the other hand, the magnetic forces acting on segments 2 and 4 are non-vanishing:

$$\begin{cases} \vec{F}_2 = I(-a\hat{j})\times(B\hat{i}) = IaB\hat{k} \\ \vec{F}_4 = I(a\hat{j})\times(B\hat{i}) = -IaB\hat{k} \end{cases}$$

with $\vec{F}_2$ pointing out of the page and $\vec{F}_4$ into the page. Thus, the net force on the rectangular loop is

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \vec{F}_4 = \vec{0}$$

as expected. Even though the net force on the loop vanishes, the forces $\vec{F}_2$ and $\vec{F}_4$ will produce a torque which causes the loop to rotate about the *y*-axis (Figure). The torque with respect to the center of the loop is

$$\vec{\tau} = \left(-\frac{b}{2}\hat{i}\right)\times\vec{F}_2 + \left(\frac{b}{2}\hat{i}\right)\times\left(IaB\hat{k} + \left(\frac{b}{2}\hat{i}\right)\times\left(-IaB\hat{k}\right)\right)$$

$$= \left(\frac{IabB}{2} + \frac{IabB}{2}\right)\hat{j} = IabB\hat{j} = IAB\hat{j}$$

where A = ab represents the area of the loop and the positive sign indicates that the rotation is clockwise about the *y*-axis. It is convenient to introduce the area vector $\vec{A} = A\hat{n}$ where $\hat{n}$ is a unit vector in the direction normal to the plane of the loop. The direction of the positive sense of $\hat{n}$ is set by the conventional right-hand rule. In our case, we have $\hat{n} = +\hat{k}$. The above expression for torque can then be rewritten as

$$\vec{\tau} = I\vec{A}\times\vec{B}$$

Notice that the magnitude of the torque is at a maximum when $\vec{B}$ is parallel to the plane of the loop (or perpendicular to).

Consider now the more general situation where the loop (or the area vector $\vec{A}$) makes an angle θ with respect to the magnetic field.

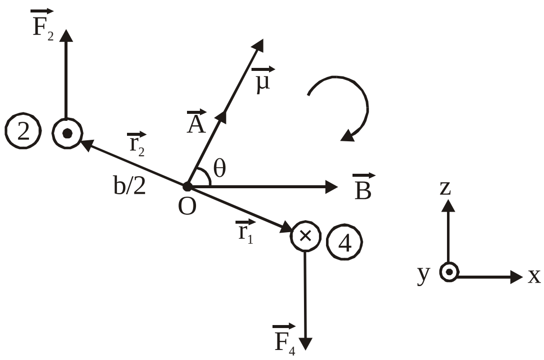


Figure : Rotation of a rectangular current loop

From Figure, the lever arms and can be expressed as:

$$\vec{r}_2 = \frac{b}{2}\left(-\sin\theta\hat{i} + \cos\theta\hat{k}\right) = -\vec{r}_4$$

and the net torque becomes

$$\vec{\tau} = \vec{r}_2\times\vec{F}_2 + \vec{r}_4 = 2\vec{r}_2\times\vec{F}_2 = 2.\frac{b}{2}\left(-\sin\theta\hat{i} + \cos\theta\hat{k}\right)\times\left(IaB\hat{k}\right)$$

$$jIabB\sin\theta\,\hat{j} = I\vec{A}\times\vec{B}$$

For a loop consisting of *N* turns, the magnitude of the toque is

$$\tau = NIAB\sin\theta$$

The quantity $NI\vec{A}$ is called the magnetic dipole moment $\vec{\mu}$

$$\vec{\mu} = NI\vec{A}$$

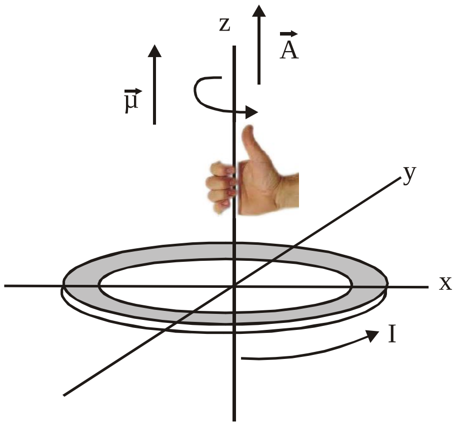


Figure : Right-hand rule for determining the direction of **μ**

The direction of $\vec{\mu}$ is the same as the area vector $\vec{A}$ (perpendicular to the plane of the loop) and is determined by the right-hand rule (Figure). The SI unit for the magnetic dipole moment is ampere-meter^2 (A•m^2).. Using the expression for $\vec{\mu}$, the torque exerted on a current-carrying loop can be rewritten as

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

The above equation is analogous to $\vec{\tau} = \vec{p} \times \vec{E}$ in Eq., the torque exerted on an electric dipole moment $\vec{p}$ in the presence of an electric field $\vec{E}$.

Configuratoin energy of current loop in uniform magnetic field.

Recalling that the potential energy for an electric dipole is $U = -\vec{p} \bullet \vec{E}$ [see Eq.], a similar form is expected for the magnetic case. The work done by an external agent to rotate the magnetic dipole from an angle θ_0 to θ is given by

$$W_{ext} = \int_{\theta_0}^{\theta} (\mu B \sin \theta')d\theta' = \mu B(\cos\theta_0 - \cos\theta)$$

$$= \Delta U = U - U_0$$

Once again, $W_{ext} = -W$, where W is the work done by the magnetic field. Choosing $U_0 = 0$ at $\theta_0 = \pi/2$, the dipole in the presence of an external field then has a potential energy os

$$U = -\mu B \cos \theta = -\vec{\mu} \bullet \vec{B}$$

The configuration is at a stable equilibrium when $\vec{\mu}$ is aligned parallel to $\vec{B}$, making U a minimum with $U_{min} = -\mu B$. On the other hand, when $\vec{\mu}$ and $\vec{B}$ are anti-parallel, $U_{max} = +\mu B$ is a maximum and the system is unstable.

Ex. A non-conducting thin disc of radius R charged uniformly over one side with surface density σ rotates about its axis with an angular velocity ω. Find:
(a) the magnetic induction at the centre of the disc;
(b) the magnetic moment of the disc.

Ans. (a) $B = 1/2\ \mu_0\sigma\omega R$; (b) $p_m = 1/4\ \pi\sigma\omega R^4$

Sol. (a) Let us take a ring element of radius r and thickness dr, then charge on the ring element.,

$$dq = \sigma 2\pi\ r\ dr$$

and current, due to this element, $di = \frac{(\sigma 2\pi r\,dr)\omega}{2\pi} = \sigma\omega r\,dr$

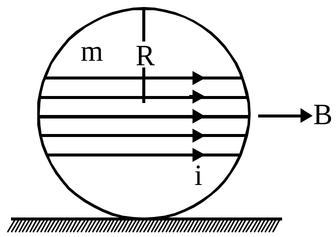
So, magnetic induction at the centre, due to this element : $dB = \frac{\mu_0}{2}\frac{di}{r}$

and hence, from symmetry : $B = \int dB = \int_0^R \frac{\mu_0 \sigma\omega\ r\,dr}{r} = \frac{\mu_0}{2}\sigma\omega R$

(b) Magnetic moment of the element, considered,
$dp_m = (di)\,\pi r^2 = \sigma\omega dr \pi\, r^2 = \sigma\pi\omega r^3\,dr$
Hence, the sought magnetic moment,

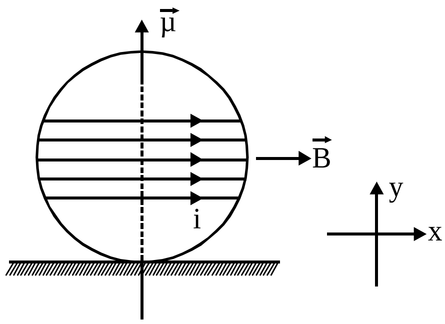
$$p_m = \int dp_m = \int_0^R \sigma\pi\omega r^3\,dr = \sigma\omega\pi\frac{R^4}{4}$$

Ex. A wire is wrapped N = 10 times over a solid sphere of mass m = 5kg, current I = 2A, which is placed on a smooth horizontal surface. A horizontal magnetic field of induction $|\vec{B}| = 10T$ is present. Find the angular acceleration experienced by the sphere. Assume that the mass of the wire is negligible compared to the mass of the sphere. If answer is 20nπ. Write value of n.



Ans. 5

Sol. (a) The net torque acting on the sphere is



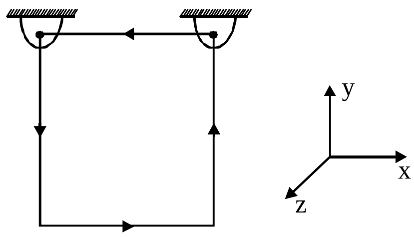
$\vec{\tau} = \vec{\mu}\times\vec{B} = \left(NiA\hat{j}\right)\times\left(B\hat{i}\right) = -NiAB\,\hat{k}$, where $A = \pi R^2$

or $\vec{\tau} = -N\pi R^2 iB\hat{k}$

(b) $\vec{\alpha} = \frac{\vec{\tau}}{I_C}$ ($\because$ the sphere is free to rotate, it must rotate about the centroidal axis)

$$= -\frac{N\pi R^2 iB}{\frac{2}{5}mR^2}\hat{k} \qquad \left(\because I_C = \frac{2}{5}mR^2\right) \qquad = \frac{5N\pi iB}{2m}\hat{k}$$

Ex. A current carrying uniform square frame is suspended from hinged supports as shown in the figure such that it can freely rotate about its upper side. The length and mass of each side of the frame is 2m and 4kg respectively. A uniform magnetic field $\vec{B}=\left(3\hat{i}+4\hat{j}\right)$ is applied. When the wire frame is rotated to 45° from vertical and released it remains in equilibrium. If the magnitude of current (in A) in the wire frame is I then find $\left(\frac{3}{5}\right)I$.



Ans. 6

Sol. $\vec{\mu}$ (Magnetic moment of loop) when it is lifted by 45° = $i\ell^2\left(\frac{\hat{j}+\hat{k}}{\sqrt{2}}\right)$

$\therefore$ $\vec{\tau}$ due to magnetic field = $\vec{\mu}\times\vec{B}$ = $\frac{i\ell^2}{\sqrt{2}}\left[\left(\hat{j}+\hat{k}\right)\times\left(3\hat{i}+4\hat{j}\right)\right]$

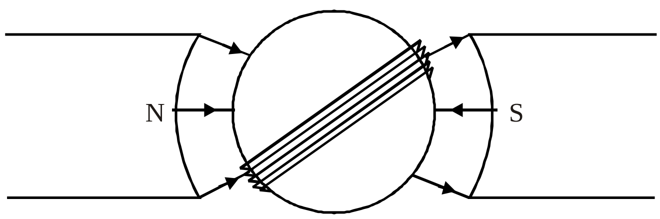
$\vec{\tau}$ due to mg (about top edge) = $4mg\frac{\ell}{2}\cos 45°\hat{i}$

$\therefore$ For equilibrium net torque along X-axis = 0

$$\therefore \quad \frac{4mg\ell}{2\sqrt{2}}=\frac{4i\ell^2}{\sqrt{2}} \Rightarrow i=\frac{mg}{2\ell}=10A$$

MOVING COIL GALVANOMETER :

The main parts of a moving-coil galvanometer are shown in figure.



The current to be measured is passed through the galvanometer. As the coil is in the magnetic field $\vec{B}$ of the permanent magnet, a torque $\vec{\Gamma}$ = $ni\vec{A}\times\vec{B}$ acts on the coil. Here n = number of turns, i = current in the coil $\vec{A}$ = area-vector of the coil and $\vec{B}$ = magnetic field at the site of the coil. This torque deflects the coil from its equilibrium position.

The pole pieces are made cylindrical. As a result, the magnetic field at the arms of the coil remains parallel to the plane of the coil everywhere even as the coil rotates. The deflecting torque is then $\Gamma = niAB$. As the upper end of the suspension strip W is fixed, the strip gets twisted when the coil rotates. This produces a restoring torque acting on the coil. If the deflection of the coil is θ and the torsional constant of the suspension strip is k, the restoring torque is kθ. The coil will stay at a deflection θ where

$$niAB = k\theta$$

or, $$i = \frac{k}{nAB}\theta$$

Hence, the current is proportional to the deflection. The constant $\frac{k}{n\,AB}$ is called the galvanometer constant.

We define the **current sensitivity** of the galvanometer as the deflection per unit current. From Eq. this current sensitivity is.

$$\frac{\phi}{I}=\frac{NAB}{k}$$

A convenient way for the manufacturer to increase the sensitivity is to increase the number of turns N. We choose galvanometers having sensitivities of value, required by our experiment.

We define the **voltage sensitivity** as the deflection per unit volt of applied potential difference

$$\frac{\phi}{I}=\left(\frac{NAB}{k}\right)\frac{I}{V}=\left(\frac{NAB}{k}\right)\frac{1}{R}$$

An interesting point to note is that increasing the current sensitivity may not necessarily increase the voltage sensitivity. If $N \to 2N$, i.e., we double the number of turns, then

$$\frac{\phi}{I}\to 2\frac{\phi}{I}$$

Thus, the current sensitivity doubles. However, the resistance of the galvanometer is also likely to double, since it is proportional to the length of the wire. In eq. $N \to 2N$, and $R \to 2R$, thus the voltage sensitivity,

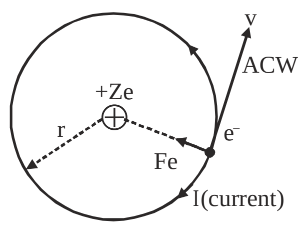
$$\frac{\phi}{V}\to\frac{\phi}{V}$$

remains unchanged.

ATOMIC MAGNETISM

An atomic orbital electron, which doing bounded uniform circular motion around nucleus. A current constitues with this orbital motion and hence orbit behaves like current carrying loop. Due to this magnetism produces at nucleus position. This phenomenon called as 'atomic magnetism.

Bohr's postulates :



(i) $\frac{mv^2}{r}=\frac{kze^2}{r^2}$ (ii) $L = mvr = n\left(\frac{h}{2\pi}\right)$, where n = 1, 2,3 ....

Basic elements of atomic magnetism :

(a) **Orbital current :-** $I = ef = \frac{e}{T} = \frac{ev}{2\pi r} = \frac{e\omega}{2\pi}$

(b) **Magnetic induction at nucleus position :-** As circular orbit behaves like current carrying loop, so magnetic induction at nucleus position $B_N=\frac{\mu_0 I}{2r}$

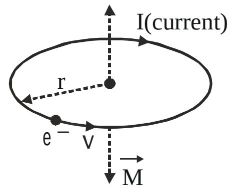
$$B_N=\frac{\mu_0 ef}{2r}=\frac{\mu_0 e}{2Tr}=\frac{\mu_0 ev}{4\pi r^2}=\frac{\mu_0 e\omega}{4\pi r}$$

(c) **Magnetic moment of circular orbit :-** Magnetic dipole moment of circular orbit

M = IA where A is area of circular orbit. $M = ef\left(\pi r^2\right) = \frac{\pi e r^2}{T} = \frac{evr}{2} = \frac{e\omega r^2}{2}$

- **Relation between magnetic moment and angular momentum of orbital electron**

Magnetic moment $M = \frac{evr}{2} \times \frac{m}{m} = \frac{eL}{2m}$ ($\because$ angular momentum L = mvr)



Vector form $\vec{M} = \frac{-e\vec{L}}{2m}$

For orbital electron its $\vec{M}$ and $\vec{L}$ both are antiparallel axial vectors.

A NONCONDUCTING CHARGED BODY IS ROTATED WITH SOME ANGULAR SPEED.

In this case the ratio of magnetic moment and angular momentum is constant which is equal to $\frac{q}{2m}$

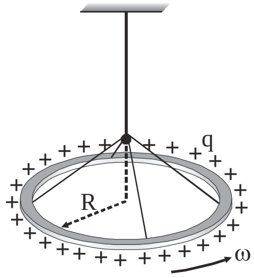
here q = charge and m = the mass of the body.

Ex. :- In case of a ring, of mass m, radius R and charge q distributed on it circumference.

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

Magnetic moment $M = iA = (qf)(\pi R^2)$

$$M = (q)\left(\frac{\omega}{2\pi}\right)(\pi R^2) = q\frac{\omega R^2}{2} \quad ...(ii)$$



$\because f = \frac{\omega}{2\pi}$ From Eqs. (i) and (ii) $\frac{M}{L} = \frac{q}{2m}$

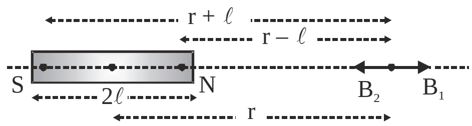
Although this expression is derived for simple case of a ring, it holds good for other bodies also. For example, for a disc or a sphere. $M = \frac{qL}{2m} \Rightarrow M = \frac{q(I\omega)}{2m}$, where $L = I\omega$

Rigid body	**Ring**	**Disc**	**Solid sphere**	**Spherical shell**
Moment of inertia (I)	mR^2	$\frac{mR^2}{2}$	$\frac{2}{5}mR^2$	$\frac{2}{3}mR^2$
Magnetic moment= $\frac{qI\omega}{2m}$	$\frac{q\omega R^2}{2}$	$\frac{q\omega R^2}{4}$	$\frac{q\omega R^2}{5}$	$\frac{q\omega R^2}{3}$

SUPPLEMENT FOR JEE-MAINS

MISCELLENEOUS

Magnetic field of long Bar magnet



(i) At Axial position :–

Magnetic field at point 'P' due to north pole $B_1 = \frac{\mu_0}{4\pi}\frac{m}{(r-\ell)^2}$ (away from north pole)

Magnetic field at point 'P' due to south pole $B_2 = \frac{\mu_0}{4\pi}\frac{m}{(r+\ell)^2}$ (towards north pole)

Net magnetic field at point 'P'

$$B_{axis} = B_1 - B_2\,,\ (\because\ B_1 > B_2) = \frac{\mu_0 m}{4\pi}\left[\frac{1}{(r-\ell)^2} - \frac{1}{(r+\ell)^2}\right] = \frac{\mu_0 m}{4\pi}\left[\frac{4r\ell}{(r^2-\ell^2)^2}\right]$$

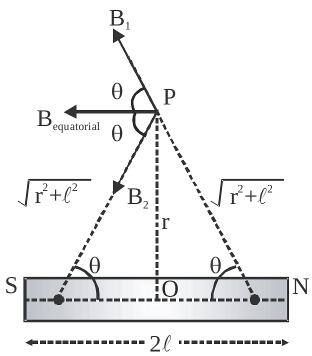
$$B_{axis} = \frac{\mu_0}{4\pi}\frac{2Mr}{(r^2-\ell^2)^2}\,, \text{ where } M = m\,(2\ell)$$

If magnet is short $r >> \ell$, then $B_{axis} \simeq \frac{\mu_0}{4\pi}\frac{2M}{r^3}$

(ii) At equatorial position :–

Magnetic field at point 'P' due to north pole :–

$$B_1 = \frac{\mu_0}{4\pi}\frac{m}{\left(\sqrt{r^2+\ell^2}\right)^2} \quad ..... (1) \qquad \text{(along NP line)}$$



Magnetic field at point 'P' due to south pole :–

$$B_2 = \frac{\mu_0}{4\pi}\frac{m}{\left(\sqrt{r^2+\ell^2}\right)^2} \quad ..... (2) \qquad \text{(along PS line)}$$

From equation (1) & (2) $B_1 = B_2 = \frac{\mu_0}{4\pi}\cdot\frac{m}{r^2+\ell^2} = B$ (Let)

Net magnetic field at point 'P'

$$B_{eq} = 2\,B\cos\theta = 2\cdot\frac{\mu_0}{4\pi}\frac{m}{(r^2+\ell^2)}\cos\theta\,, \qquad \left[\text{where } \cos\theta = \frac{\ell}{\sqrt{(r^2+\ell^2)}}\right]$$

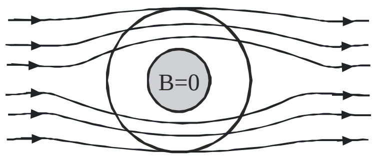
$$= 2\cdot\frac{\mu_0}{4\pi}\frac{m}{(r^2+\ell^2)}\frac{\ell}{\sqrt{(r^2+\ell^2)}}$$

$$B_{eq.} = \frac{\mu_0}{4\pi}\cdot\frac{M}{(r^2+\ell^2)^{3/2}},\qquad \text{where } M = m(2\ell)$$

If magnet is short $r >> \ell$, then $B_{eq.} \simeq \frac{\mu_0}{4\pi}\cdot\frac{M}{r^3}$

Magnetic shielding

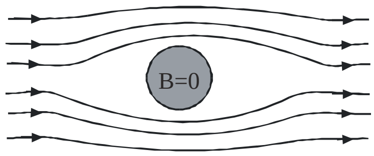
If a soft iron ring is placed in magnetic field, most of the lines are found to pass through the ring and no lines pass through the space inside the ring. The inside of the ring is thus protected against any external magnetic effect. This phenomenon is called magnetic screening or shielding and is used to protect costly wrist–watches and other instruments from external magnetic fields by enclosing them in a soft–iron case or box.



Iron ring in a field

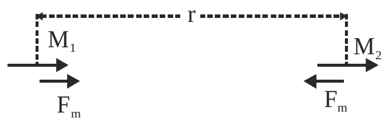
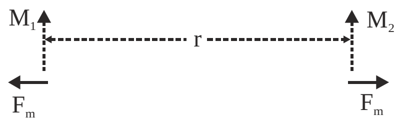
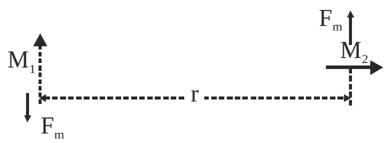
(i) Super conductors also provides perfect magnetic screening due to exclusion of lines of force. This effect is called **'Meissner effect'**

(ii) Relative magnetic premeability of super conductor is zero. So we can say that super conductors behaves like perfect dimagnetic.



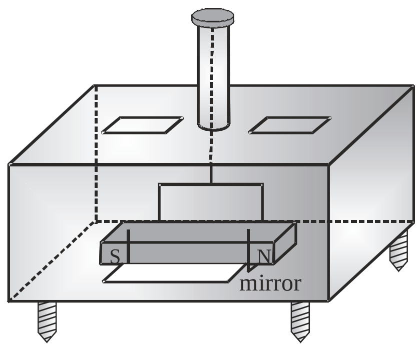
Super conductor in a field

Dipole - Dipole Interactions :

S.No.	**Relative position of dipoles**	**Magnetic force (F_m)**
(a)		$\frac{\mu_0}{4\pi}\cdot\frac{6M_1M_2}{r^4}$ (along r)
(b)		$\frac{\mu_0}{4\pi}\cdot\frac{3M_1M_2}{r^4}$ (along r)
(c)		$\frac{\mu_0}{4\pi}\cdot\frac{3M_1M_2}{r^4}$ (perpendicular to r)

VIBRATION MAGNETOMETER :

It is an instrument used to compare the horizontal components of magnetic field of earth of two different places, to compare magnetic fields and magetic moments of two bar magnets. It is also called oscillation magnetometer.

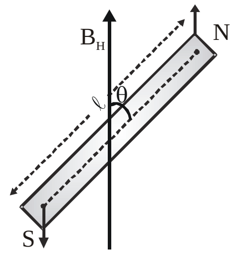


Principle **:** This device works on the principle, that whenever a freely suspended bar magent horizontal component in earth magnetic field (B_H) is slightly disturbed from its equilibrium position then, it will experience a torque and executes angular S.H.M. *Rotation is possible only in horizontal plane.

Angular S.H.M of magnetic dipole :- When a dipole is suspended in a uniform magnetic field it will align itself parallel to field. Now if it is given a small angular displacement θ about its equilibrium position. The restoring torque acts on it :

$\tau = -M B_H \sin\theta \Rightarrow I\alpha = -MB_H \sin\theta = -MB_H\,\theta$, $(\because \sin\theta \simeq \theta)$

$$\Rightarrow \alpha = \frac{MB_H}{I}(-\theta) \Rightarrow \alpha = \omega^2(-\theta) \Rightarrow \omega^2 = \frac{MB_H}{I}$$



The time period of angular S.H.M. $\Rightarrow T = 2\pi\sqrt{\frac{I}{MB_H}}$

M = magnetic moment of bar magnet

I = moment of inertia of bar magnet about its geometric axis

Comparision of magnetic moments of magnets of the same size

Let the two magnets of same size have moment of inertia I and magnetic moments M_1 and M_2. Suspend the two given magnets turn by turn in the metal stirrup of the vibration magnetometer and note the time period in each case.

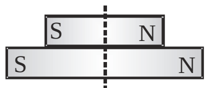
Then $T_1 = 2\pi\sqrt{\frac{I}{M_1B}}$ and $T_2 = 2\pi\sqrt{\frac{I}{M_2B}}$

Dividing, $\frac{T_1}{T_2} = \sqrt{\frac{M_2}{M_1}}$ or $\frac{M_1}{M_2} = \frac{T_2^2}{T_1^2}$

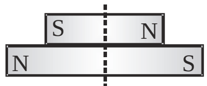
Since T_1 and T_2 are known therefore the ratio $\frac{M_2}{M_1}$ can be determined.

Comparision of magnetic moments of magnets of different sizes

Let the two magnets have moments of inertia I_1 and I_2 and magnetic moments M_1 and M_2 respectively. Place the two given magnets one upon the other as shown in Fig. (a). This combination is called sum combination'. It has moment of inertia $(I_1 + I_2)$ and magnetic moment $(M_1 + M_2)$. Put this combination in the magnetometer and set it into oscillations. The time period T_1 is determined.



(a) sum combination



(b) difference combination

$$T_1 = 2\pi\sqrt{\frac{I_1 + I_2}{(M_1 + M_2)B}} \qquad ....(1)$$

Now, the two magnets are placed as shown in Fig. (b). This combination is called 'difference combination'. It has moment of inertia $(I_1 + I_2)$ and magnetic moment $(M_1 - M_2)$. This combination is put in the magneto meter and its time period T_2 is determined.

$$T_2 = 2\pi\sqrt{\frac{I_1 + I_2}{(M_1 - M_2)B}} \qquad ......(2)$$

Dividing, $\frac{T_1}{T_2} = \sqrt{\frac{M_1 - M_2}{M_1 + M_2}}$ [from equation (1) and (2)]

knowing T_1 and T_2, we can determine $\frac{M_1}{M_2}$.

Comparision of earth's magnetic field at two different places

Let the vibrating magnet have moment of inertia I and magnetic moment M. Let it be vibrated in places where earth's magnetic field is B_{H_1} and B_{H_2} .

Then, $T_1 = 2\pi\sqrt{\frac{I}{MB_{H_1}}}$ and $T_2 = 2\pi\sqrt{\frac{I}{MB_{H_2}}}$

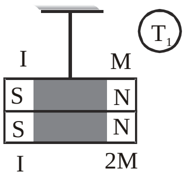
T_1 and T_2 are determined by placing magnetometer at two different places, turn by turn.

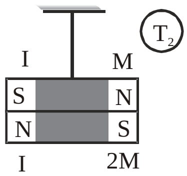
Dividing, $\frac{T_1}{T_2} = \sqrt{\frac{B_{H_2}}{B_{H_1}}}$ or $\frac{T_1^2}{T_2^2} = \frac{B_{H_2}}{B_{H_1}} = \frac{B_2 \cos\theta_2}{B_1 \cos\theta_1} \Rightarrow \frac{B_1}{B_2} = \frac{T_2^2 \cos\theta_2}{T_1^2 \cos\theta_1}$

Knowing T_1, T_2 and θ_1, θ_2 the ratio $\frac{B_1}{B_2}$ can be determined.

Ex. Magnetic moments of two identical magnets are M and 2M respectively. Both are combined in such a way that their similar poles are same side. The time period in this is case 'T_1'. If polrity of one of the magnets is reversed its period becomes 'T_2' then find out ratio of their time periods respectively.

Sol.





$M_{system} = 2M + M = 3M$
$I_{system} = 2I$

$M_{system} = 2M–M = M$
$I_{system} = 2I$

$T = 2\pi\sqrt{\frac{I}{MB_H}}$ ($I_{system} \rightarrow$ same, $B_H \rightarrow$ same) $\boxed{T \propto \frac{1}{\sqrt{M}}}$;

$$\frac{T_1}{T_2} = \sqrt{\frac{M_2}{M_1}} = \sqrt{\frac{M}{3M}} = \frac{1}{\sqrt{3}}$$

Ex. A magnet is suspended in such a way when it oscillates in the horizontal plane. It makes 20 oscillations per minute at a place where dip angle is 30° and 15 oscillations per min at a place where dip angle is 60°. Find the ratio of the total earth's magnetic field at the two places.

Sol. $f = \frac{1}{2\pi}\sqrt{\frac{MB_H}{I}}$

$\Rightarrow f^2 = \frac{1}{4\pi^2} \cdot \frac{MB\cos\theta}{I}$ I and M are same in given cases

$$\frac{B_1}{B_2} = \frac{f_1^2}{f_2^2} \times \frac{\cos\theta_2}{\cos\theta_1} = \frac{20 \times 20}{15 \times 15} \times \frac{\cos 60°}{\cos 30°} = \frac{16}{9\sqrt{3}}$$

NEUTRAL POINT

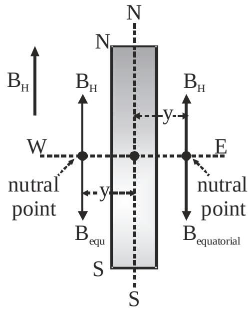
It is a point where net magnetic field is zero.

At this point magnetic field of bar magnet or current carrying coil or current carrying wire is just neutralised by magnetic field of earth. (B_H)

A compass needle placed at this neutral point can set itself in any direction.

Location of Neutral Points :

(a) **When N–pole of magnet directed towards North :-** Two neutral points symmetrically located on equatorial line of magnet. Let distance of each neutral point from centre of magnet is 'y' then

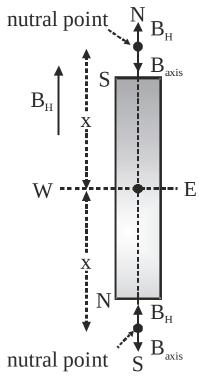


$$B_{eq} = B_H$$

$$B_H = \frac{\mu_0}{4\pi} \cdot \frac{M}{(y^2 + \ell^2)^{3/2}}$$

$$\frac{\mu_0}{4\pi} \cdot \frac{M}{y^3} = B_H \qquad \text{(If } y >>> \ell\text{)}$$

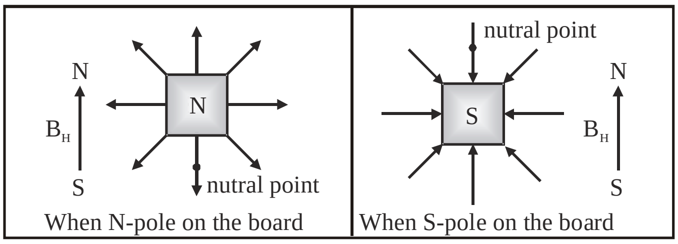
(b) **When S–pole of magnet directed towards North :-** Two neutral points symmetrically located on the axial line of magnet. Let distance of each neutral points from centre of the magnet is x, then



$$B_{axis} = B_H \Rightarrow B_H = \frac{\mu_0}{4\pi} \cdot \frac{2Mx}{(x^2 - \ell^2)^2}$$

$$\frac{\mu_0}{4\pi} \frac{2M}{x^3} = B_H \qquad \text{(If } x >>> \ell\text{)}$$

(c) If magnet is held vertically on the board, then only one neutral point is obtained on the horizontal board.



Ex. The magnetic field at a point x on the axis of a small bar magnet is equal to the field at a point y on the equator of the same magnet. Find the ratio of the distances of x and y from the centre of the magnet.

Sol. $B_{axis} = B_{equatorial} \Rightarrow \frac{\mu_0}{4\pi} \frac{2M}{x^3} = \frac{\mu_0}{4\pi} \frac{M}{y^3}$

$$\Rightarrow \frac{2}{x^3} = \frac{1}{y^3} \Rightarrow \frac{x^3}{y^3} = \frac{2}{1}$$

$$\Rightarrow \frac{x}{y} = 2^{1/3}$$

Ex. A coil of 0.1 m radius and 100 turns placed perpendicular magnetic meridian. When current of 2 ampere is flow through the coil then the neutral point is obtained at the centre. Find out magnetising field of earth.

Sol. Magnetic field at centre of coil $B = \dfrac{\mu_0 NI}{2R} = \mu_0 H_C$ $\qquad (\because H_C = H_e)$

Magnetising field of earth $H_e = \dfrac{NI}{2R} = \dfrac{100\times 2}{2\times 0.1} = 1000$ A/m

Ex. A short magnet of moment 6.75 A–m^2 produces a neutral point on its axis. If the horizontal component of earth's magnetic field 5×10^{-5} Wb/m^2, Calculate the distance of the neutral point from the centre.

Sol. $B_H = \dfrac{2KM}{d^3} \Rightarrow d = \left(\dfrac{2KM}{B_H}\right)^{1/3} = \left(\dfrac{2\times 10^{-7} \times 6.75}{5\times 10^{-5}}\right)^{1/3} = 0.3 \text{ m} = 30 \text{ cm}$

GEO-MAGNETISM

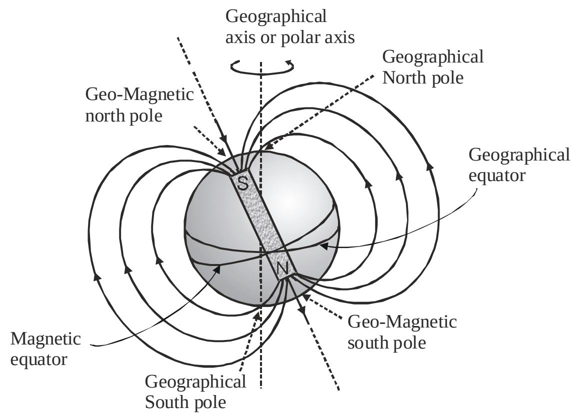
Important definitions :

(a) **Geographic axis** : It is a straight line passing through the geographical poles of the earth. It is also called axis of rotation or polar axis of the earth.

(b) **Geographic Meridian (GM)** : It is a vertical plane at any place which passing through geographical axis of the earth.

(c) **Geographic equator** : It is a great circle on the surface of the earth, in a plane perpendicular to the geographic axis. All the points on the geographic equator are at equal distance from the geographic poles.

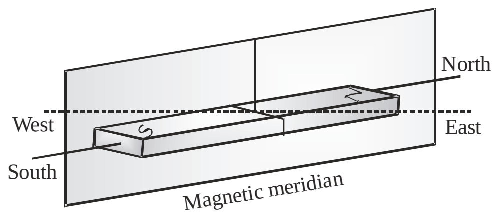
A great plane which passes through geographic equator and perpendicular to the geographic axis called **geographic equatorial plane**. This plane cuts the earth in two equal parts, a part has geographic north called **northen hemisphere** (NHS) and another part has geographic south called **southern hemi sphere** (SHS).



(d) **Magnetic axis** : It is a straight line passing through magnetic poles of the earth. It is inclined to the geographic axis at nearly 17°.

(e) **Magnetic Meridian (MM)** : (i) It is a vertical plane at any place which passing through magnetic axis of the earth. (ii) It is a vertical plane at any place which passing through axis of free suspended bar magnet or magetic needle.

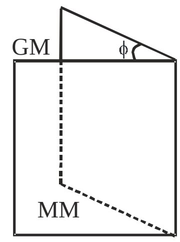
(iii) It is a vertical plane at any place which contains all the magnetic field lines of earth of that place.



(f) **Magnetic equator** : It is a great circle on the surface of the earth, in a plane perpendicular to the magnetic axis. All the points on the magnetic equator are at equal distance from the magnetic poles.

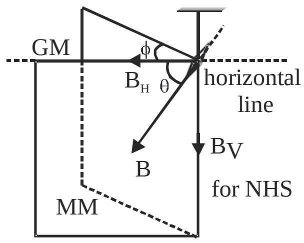
MAIN ELEMENTS OF EARTH'S MAGNETIC FIELD

Angle of declination (ϕ)



At a given place the acute angle between geographic meridian and the magnetic meridian is called angle of declination, i.e. at a given place it is the angle between the geographical north south direction and the direcation indicated by a agnetic compass needle in its equillibrium.

Angle of dip (θ)



(i) It is an angle which the direction of resultant magnetic field of the earth substends with the horizontal line in magnetic meridian at the given place.

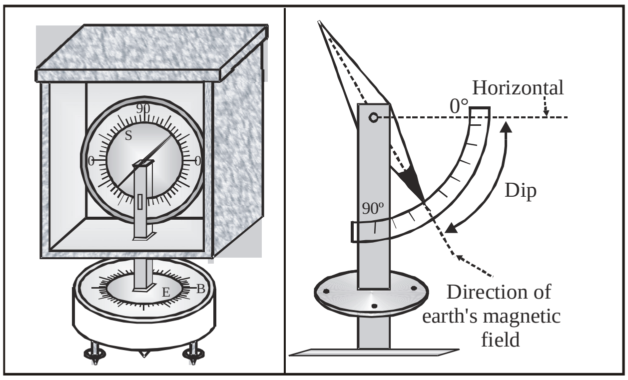
(ii) It is an angle which the axis of freely suspended magnetic needle (up or down) substends with the horizontal line in magnetic meridian at a given place.

In northen hemi sphere, north pole of freely suspended magnetic needle will dip downwards i.e. towards the earth surface. In southern hemi sphere, south pole of freely suspended magnetic needle will dip downwards i.e. towards the earth surface.

Dip circle : Angle of dip at a place is measured by the instrument called 'Dip-circle' in which a magnetic needle is free to rotate in vertical plane. About its horizontal axis. The ends of the needle move over a vertical scale graduated in degree.

Horizontal component of earth magnetic field (B_H)

Horizontal component of earth magnetic field at a given place is the component of resultant magnetic field of the earth along the horizontal line in magnetic meridian.



$B_H = B\cos\theta$ and $B_v = B\sin\theta$ ....(1)

so that $\tan\theta = \dfrac{B_V}{B_H}$ and $B = \sqrt{B_H^2 + B_V^2}$ ....(2)

At magnetic poles $\theta = 90°$ — $B_H = 0$ and only B_V exist

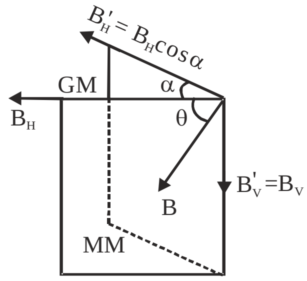
❖ At magnetic equator $\theta = 0°$ — $B_V = 0$ and only B_H exist

ϕ decides the plane in which magnetic field lies at any place, (ϕ) and (θ) decides the direction of magnetic field and (θ) and (B_H) decides the magnitude of the field.

Apparent angle of dip (θ') :

When the plane of vertical scale of dip circle is in the magnetic meridian, the needle rest in the direction of earth's magnetic field. The angle made by the needle with the horizontal is called true dip or actual dip. If the plane of vertical scale of dip circle not kept in magnetic meridian, then the needle will not indicate the correct direction of earth magnetic field.

In this situation the angle made by the needle with the horizontal is called the apparent angle of dip.Suppose the dip circle is set at an angle α to the magnetic meridian. Effective horizontal component in this plane will be $B_H \cos\alpha$ and no effect on vertical component B_V



Apparent angle of dip $\tan\theta' = \dfrac{B'_V}{B'_H}$

$$\Rightarrow \tan\theta' = \frac{B_V}{B_H\cos\alpha} \Rightarrow \tan\theta' = \frac{\tan\theta}{\cos\alpha}$$

❖ For a vertical plane other than magnetic meridian

$\alpha > 0 \Rightarrow \cos\alpha < 1 \Rightarrow \tan\theta' > \tan\theta \Rightarrow \theta' > \theta$,

so apparent angle of dip is always more than actual angle of dip at any place.

❖ For a vertical plane perpendicular to magnetic meridian

$$\alpha = 90° \Rightarrow \tan\theta' = \frac{\tan\theta}{\cos 90°} = \infty$$

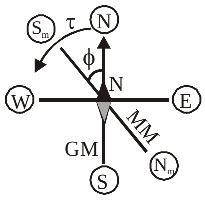
θ' = 90° , so in a plane perpendicular to magnetic meridian dip needle becomes just verticle.

Ex. At a certain place, the horizontal component of earth's magnetic field is $\sqrt{3}$ times of the vertical component. What the angle of dip at that place.

Sol. $B_H = \sqrt{3}\,B_V$, $\tan\theta = \dfrac{B_V}{B_H} = \dfrac{B_V}{\sqrt{3}B_v} = \dfrac{1}{\sqrt{3}} = \tan 30° \Rightarrow \theta = 30°$

Ex. A compass needle of magnetic moment is 60 A-m^2 pointing towards geographical north at a certain place where the horizontal component of earth's magnetic field is 40μT, experiences a torque 1.2×10^{-3} N-m. What is the declination of that place.

Sol. $\tau = MB\sin\phi$



$$\Rightarrow \sin\phi = \frac{\tau}{MB} = \frac{1.2\times10^{-3}}{24\times10^{-4}} = \frac{1}{2}$$

$\Rightarrow \phi = 30°$

Ex. If the dip circle is set at 45° to the magnetic meridian, then the apparent dip is 30°. Calculate the true dip.

Sol. $\tan\theta' = \dfrac{\tan\theta}{\cos\alpha}$

$\tan\theta = \tan\theta'\cos\alpha = \tan 30°\cos 45° = \dfrac{1}{\sqrt{3}}\times\dfrac{1}{\sqrt{2}}$

$\tan\theta = \dfrac{1}{\sqrt{6}} \Rightarrow \theta = \tan^{-1}\left(\dfrac{1}{\sqrt{6}}\right)$

Ex. A magnetic needle is free to rotate in a vertical plane and that plane makes an angle of 60^0 with magnetic meridian. If the needle stays in a direction making an angle of $\tan^{-1}\left(\dfrac{2}{\sqrt{3}}\right)$ with the horizontal direction, what would be the actual dip at that place ?

Sol. $\tan\theta = \tan\theta'\cos\alpha$ $\quad (\because\ \theta' = \tan^{-1}\left(\dfrac{2}{\sqrt{3}}\right),\ \alpha = 60°)$

$\therefore\ \tan\theta = \tan\left(\tan^{-1}\dfrac{2}{\sqrt{3}}\right)\cos 60°$

$\tan\theta = \dfrac{2}{\sqrt{3}}\times\dfrac{1}{2} = \dfrac{1}{\sqrt{3}} \Rightarrow \theta = 30°$

Ex. A 1-meter long narrow solenoid having 1000 turns is placed in magnetic meridian. Find the current in the solenoid which neutralises the earth's horizontal field of 0.36 oersted at the centre of the solenoid.

Sol. The magnetic field intensity at the centre of solenoid is $H = ni = 1000\ i$ A/m $= 4\pi i$ ovested
($\therefore$ 1 amp/meter $= 4\pi \times 10^{-3}$ oersted)
Since it neutralises the earth's field of 0.36 oersted, it is equal and opposite to the earth's field.
$\therefore\ 4\pi i = 0.36$

$\Rightarrow\ i = \dfrac{0.36}{4\times 3.14} = 0.0286$ ampere = 28.6 milli-ampere or 28.6 mA

Ex. If θ_1 and θ_2 are angles of dip in two vertical planes at right angle to each other and θ is true dip then prove $\cot^2\theta = \cot^2\theta_1 + \cot^2\theta_2$.

Sol. If the vertical plane in which dip is θ_1 subtends an angle α with meridian than other vertical plane in which dip is θ_2 and is perpendicular to first will make an angle of $90 - \alpha$ with magnetic meridian. If θ_1 and θ_2 are apparent dips than

$$\tan\theta_1 = \frac{B_V}{B_H\cos\alpha}$$

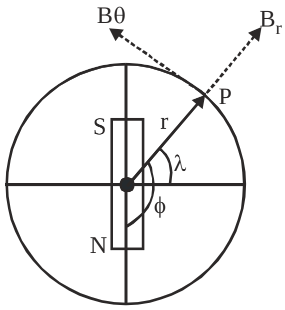
$$\tan\theta_2 = \frac{B_V}{B_H\cos(90-\alpha)} = \frac{B_V}{B_H\sin\alpha}$$

$$\cot^2\theta_1 + \cot^2\theta_2 = \frac{1}{(\tan\theta_1)^2} + \frac{1}{(\tan\theta_2)^2} = \frac{B_H^2\cos^2\alpha + B_H^2\sin^2\alpha}{B_V^2} = \frac{B_H^2}{B_V^2} = \left(\frac{B\cos\theta}{B\sin\theta}\right)^2 = \cot^2\theta$$

So $\cot^2\theta_1 + \cot^2\theta_2 = \cot^2\theta$

Ex. Considering earth as a short bar magnet show that the angle of dip θ is related to magnetic latitude λ as $\tan\theta = 2\tan\lambda$

Sol. For a magnetic dipole the field components at point P (r, ϕ) are given as



$$B_r = \frac{\mu_0}{4\pi}\frac{2M\cos\phi}{r^3} \quad B_\theta = \frac{\mu_0}{4\pi}\frac{M\sin\phi}{r^3}$$

$$\tan\theta = \frac{B_V}{B_H} = -\frac{B_r}{B_\theta} = -\frac{\mu_0}{4\pi}\frac{2M\cos\phi}{r^3}\frac{4\pi\ r^3}{\mu_0\ M\sin\phi}$$

or $\tan\theta = -2\cot\phi$

From figure $\phi = \frac{\pi}{2}+\lambda$ So $\tan\theta = -2\cot\left(\frac{\pi}{2}+\lambda\right)$ or $\tan\theta = 2\tan\lambda$

Ex. At a certain location in Africa, a compass points 12° west of the geographic north. The north tip of the magnetic needle of a dip circle placed in the plane of the magnetic meridian points 60° above the horizontal. The horizontal component of the earth's field is measured to be 0.16 G. Specify the direction and magnitude of the earth's field at the location.

Sol. From formula, $B_H = B\cos\theta$

$$B = \frac{B_H}{\cos\ \theta} = B_H\sec\theta = 0.16 \times 2 = 0.32\text{ G.}$$

The earth's field is 0.32 G, in direction 60° upwards from horizontal, in a plane (magnetic meridian) 12° West of geographical meridian.

Ex. A dip circle shows an apparent dip of 60° at a place where the true dip is 45°. If the dip circle is rotated through 90° what apparent dip will it show?

Sol. Let θ_1 and θ_2 be apparent dip shown by dip circle in two perpendicular positions then true dip θ is given by

$$\cot^2\theta = \cot^2\theta_1 + \cot^2\theta_2 \text{ or } \cot^2 45° = \cot^2 60° + \cot^2\theta_2$$

or $\cot^2\theta_2 = \frac{2}{3}$ or $\cot\theta_2 = 0.816$ giving $\theta_2 = 51°$

IMPORTANT DEFINATIONS AND RELATIONS

Magnetising field or Magnetic intensity $(\vec{H})$

Field in which a material is placed for magnetisation, called as magnetising field.

Magnetising field $\vec{H} = \frac{\vec{B}_0}{\mu_0} = \frac{\text{magnetic field}}{\text{permeability of free space}}$

SI Unit $\vec{H}$: ampere/meter

Intensity of magnetisation $(\vec{I})$

When a magnetic material is placed in magnetising field then induced dipole moment per unit volume of that material is known as intensity of magnetisation $\vec{I} = \frac{\vec{M}}{V}$

SI Unit : ampere/meter $[\because \frac{\vec{M}}{V} = \frac{I\vec{A}}{V} = \frac{\text{ampere} \times \text{meter}^2}{\text{meter}^3}]$

Magnetic susceptibility (χ_m)

$\chi_m = \frac{I}{H}$ [It is a scalar with no units and dimensions]

Physically it represent the ease with which a magnetic material can be magnetised
A material with more χ_m, can be change into magnet easily.

Magnetic permeability μ

$$\mu = \frac{B_m}{H} = \frac{\text{total magnetic field inside the material}}{\text{magnetising field}}$$

It measures the degree to which a magnetic material can be penetrated (or permeated) by the magnetic field lines

SI Unit of μ : $\mu = \frac{B_m}{H} \equiv \frac{Wb/m^2}{A/m} \equiv \frac{Wb}{A-m} \equiv \frac{H-A}{A-m} = \frac{H}{m}$

$[\because \phi = L\,I \therefore \text{weber} \equiv \text{henry} - \text{ampere}]$

Relative permeability $\mu_r = \frac{\mu}{\mu_0}$

It has no units and dimensions.

Relation between permeability and susceptibility

When a magnetic material is placed in magnetic field $\vec{B}_0$ for magnetisation then total magnetic field in material $\vec{B}_m = \vec{B}_0 + \vec{B}_i$, where $\vec{B}_i$ = induced field.

$\because \vec{B}_0 = \mu_0 \vec{H}$; $\vec{B}_i = \mu_0 \vec{I}$

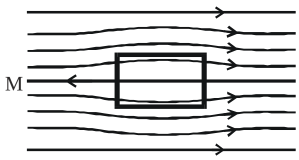
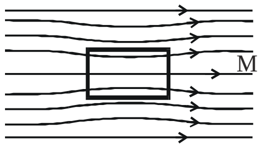
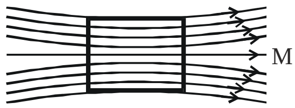
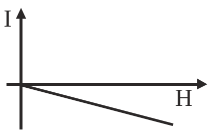
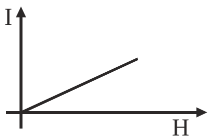
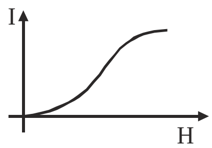
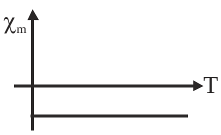
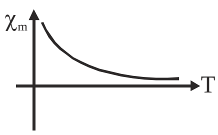
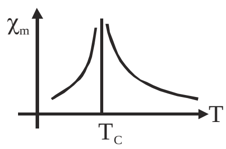
$\therefore \vec{B}_m = \mu_0 \vec{H} + \mu_0 \vec{I} \Rightarrow \vec{B}_m = \mu_0(\vec{H} + \vec{I}) = \mu_0 \vec{H}\left(1 + \frac{I}{H}\right)$

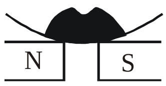
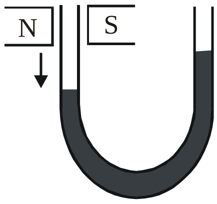
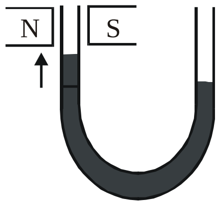
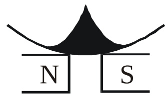
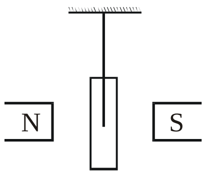
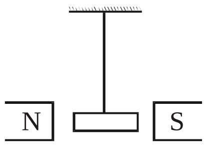
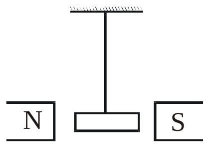
$\Rightarrow \frac{B}{H} = \mu_0\left(1 + \frac{I}{H}\right) \Rightarrow \mu = \mu_0(1 + \chi_m) \Rightarrow \mu_r = 1 + \chi_m$

for vacuum $\chi_m = 0, (\because \mu_r = 1)$
at STP for air $\chi_m = 0.04$
$(\because$ at S.T.P. for air $\mu_r = 1.04)$

CLASSIFICATION OF MAGNETIC MATERIALS

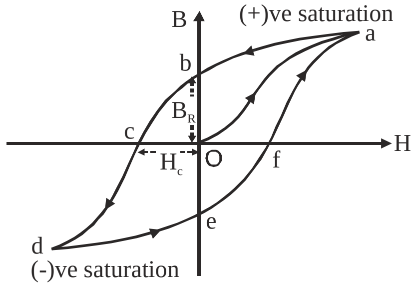
On the basis of magnetic properties of the materials [as magnetisation intensitily (I), Susceptibility (χ) and relative permeability (μ_r)] Faraday devide these materials in three classes –

PROPERTIES	DIAMAGNETIC	PARAMAGNETIC	FERROMAGNETIC
Cause of magnetism	Orbital motion of electrons	Spin motion of electrons	Formation of domains
Substance placed in uniform magnetic field.	Poor magnetisation in opposite direction. Here $B_m < B_0$ 	Poor magnetisation in same direction. Here $B_m > B_0$ 	Strong magnetisation in same direction. Here $B_m >>> B_0$ 
I – H curve	$I \rightarrow$ Small, negative, varies linearly with field 	$I \rightarrow$ Small, positive, varies linearly with field 	$I \rightarrow$ very large, positive & varies non–linearly with field 
χ_m – T curve	$\chi_m \rightarrow$ small, negative & temperature independent $\chi_m \propto T^{\circ}$ 	$\chi_m \rightarrow$ small, positive & varies inversely with temp. $\chi_m \propto \frac{1}{T}$ (Curie law) 	$\chi_m \rightarrow$ very large, positive & temp. dependent $\chi_m \propto \frac{1}{T - T_C}$ (Curie Weiss law) (for $T > T_C$) (T_C = Curie temperature)  $T_C(I_{iron})$=770°C or 1043K
μ_r	($\mu < \mu_0$) $1 > \mu_r > 0$	$2 > \mu_r > 1$ ($\mu > \mu_0$)	$\mu_r >>> 1$ ($\mu >>> \mu_0$)
Magnetic moment of single atom	Atoms donot have any permanent magnetic moment	Atoms have permanent megnetic moment which are randomly oriented. (i.e. in absence of external magnetic field the magnetic moment of whole material is zero)	Atoms have permanent megnetic moment which are organised in domains.

PROPERTIES	DIAMAGNETIC	PARAMAGNETIC	FERROMAGNETIC
Behaviour of substance in Nonuniform magnetic field	It moves from stronger to weaker magnetic field.  Weak Field  Strong Field  Level depressed in that limb	It moves with week force from weaker magnetic field to stronger magnetic field.  Weak Field  Strong Field  Level slightly rises	Strongly attract from weaker magnetic field to stronger magnetic field.  Weak Field  Strong Field
When rod of material is suspended between poles of magnet.	It becomes perpendicular to the direction of external magnetic field. 	If there is strong magnetic field in between the poles then rod becomes parallel to the magnetic field. 	Weak magnetic field between magnetic poles can made rod parallel to field direction. 
Magnetic moment of substance in presence of external magnetic field	Value $\vec{M}$ is very less and opposite to $\vec{H}$.	Value $\vec{M}$ is low but in direction of $\vec{H}$.	$\vec{M}$ is very high and in direction of $\vec{H}$.
Examples	Bi, Cu, Ag, Pb, H_2O, Hg, H_2, He, Ne, Au, Zn, Sb, NaCl, Diamond.(May be found in solid, liquid or gas).	Na, K, Mg, Mn, Sn, Pt, Al, O_2 (May be found in solid, liquid or gas.)	Fe,Co, Ni all their alloys, Fe_3O_4 Gd, Alnico, etc. (Normally found only in solids) (crystalline solids)

MAGNETIC HYSTERESIS

Only Ferromagnetic materials show magnetic hysteresis, when Ferromagnetic material is placed in external magnetic field for magnetisation then B increases with H non-linearly along Oa. If H is again bring to zero then it decreases along path ab. Due to lagging behind of B with H this curve is known as hysteresis curve. [Lagging of B behind H is called hysteresis]



Cause of hysteresis : By removing external magnetising field (H = 0), the magnetic moment of some domains remains aligned in the applied direction of previous magnetising field which results into a residual magnetism.

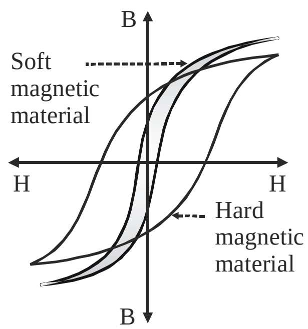
- **Residual magnetism (ob)** = $\mathbf{B_r}$ ≡ retentivity ≡ remanence
  Retentivity of a specimen is a measure of the magnetic field remaining in the ferromagnetic specimen when the magnetising field is removed.
- **Coercivity (oc)** : Coercivity is an measure of magnetising field required to destroy the residual magnetism of the ferromagnetic specimen.

Ferromagnetic materials

Soft magnetic materials	**Hard magnetic materials**
Low retentivity, low coercivity and small hysteresis loss.	High retentivity, high coercivity and large hysteresis loss
suitable for making electromagnets, cores of transformers etc. Ex. Soft iron, (used in magnetic shielding)	suitable for permanent magnet Ex. Steel, Alnico

HYSTERESIS LOSS

(i) The area of hystersis loop for a ferromagnetic material is equal to the energy loss per cycle of magnetisation and demagnetisation per unit volume.



$$W_H = \oint B.dH = \mu_0 \oint I.dH$$

(ii) Its value is different for different materials.

(iii) The work done per cycle per unit volume of material is equal to the area of hysteresis loop.

$\therefore$ Total energy loss in material $W_H = V A n t$ joule $= \dfrac{V A n t}{J}$ calorie

i.e W_H = volume of material × area of hysteresis curve × frequency × time.

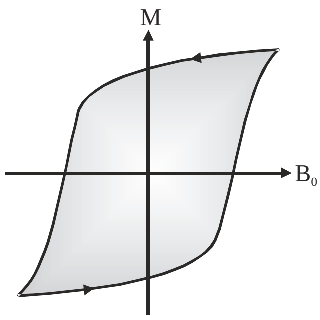


fig.(a)

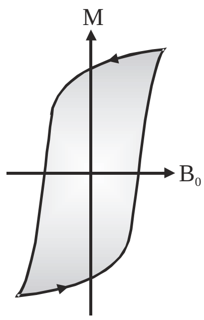


fig.(b)

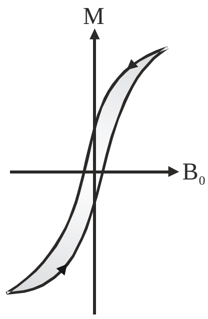


fig.(c)

The materials of both (a) and (b) remain strongly magnetized when B_0 is reduced to zero. The material of (a) is also hard to demagnetize, it would be good for permanent magnets.

The material of (b) magnetizes and demagnetizes more easily, it could be used as a computer memory material.

The material of (c) would be useful for transformers and other alternating-current devices where zero hysteresis would be optimal.

EXERCISE (S-1)

Biot savart law

1. Two long, straight wires, each carrying a current of 5 A, are placed along the X- and Y-axes respectively. The currents point along the positive directions of the axes. Find the magnetic field at the points (a) (1 m, 1 m), (b) (–1 m, 1 m), (c) (– 1 m, – 1 m) and (d) (1 m, – 1 m).

MG0001

2. A circular loop of radius 4.0 cm is placed in a horizontal plane and carries an electric current of 5.0 A in the clockwise direction as seen from above. Find the magnetic field

(a) At a point 3.0 cm above the centre of the loop.

(b) At a point 3.0 cm below the centre of the loop.

MG0002

3. Two concentric circular coils X and Y of radii 16 cm and 10 cm, respectively, lie in the same vertical plane containing the north to south direction. Coil X has 20 turns and carries a current of 16A ; coil Y has 25 turns and carries a current of 18 A. The sense of the current in X is anticlockwise, and clockwise in Y, 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. ***(NCERT)***

MG0003

4. A current element $\Delta\vec{\ell} = \Delta x\,\hat{i} - \Delta y\,\hat{j}$ carries 10 A current. It is placed at origin. Calculate magnetic field at point 'P' which is at position vector $\vec{r} = (\hat{i} + \hat{j})$ m with respect to origin. (where $\Delta x = \Delta y = 1$mm)

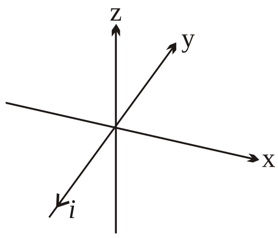
MG0004

5. A circular loop of radius r carries a current i. How should a long, straight wire carrying a current 4i be placed in the plane of the circle so that the magnetic field at the centre becomes zero ?

MG0005

6. A long straight wire carries a current of 10 A directed along the negative y-axis as shown in figure. A uniform magnetic field B_0 of magnitude 10^{-6} T is directed parallel to the x-axis. What is the resultant magnetic field at the following points?

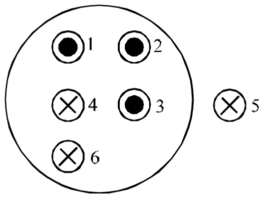
(a) x = 0, z = 2 m; (b) x = 2 m, z = 0; (c) x = 0, z = – 0.5 m



MG0006

Ampere's law

7. Six wires of current $I_1 = 1A, I_2 = 2A, I_3 = 3A, I_4 = 1A, I_5 = 5A$ and $I_6 = 4A$ cut the page perpendicularly at the points 1, 2, 3, 4, 5 and 6 respectively as shown in the figure. Find the value of the integral $\oint \vec{B}.d\vec{\ell}$ around the closed path.



MG0007

Motion of charged particle

8. A charged particle (charge q, mass m) has velocity v_0 at origin in +x direction. In space there is a uniform magnetic field B in – z direction. Find the y coordinate of particle when is crosses y axis.

MG0008

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

MG0009

10. 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 0.15 T. Determine the trajectory of the electron if the field (a) is transverse to its initial velocity, (b) makes an angle of 30°with the initial velocity. ***(NCERT)***

MG0010

Ampere force & torque

11. 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 5.0 A is set up in the rod through the wires. ***(NCERT)***

(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). $g = 9.8\ ms^{-2}$.

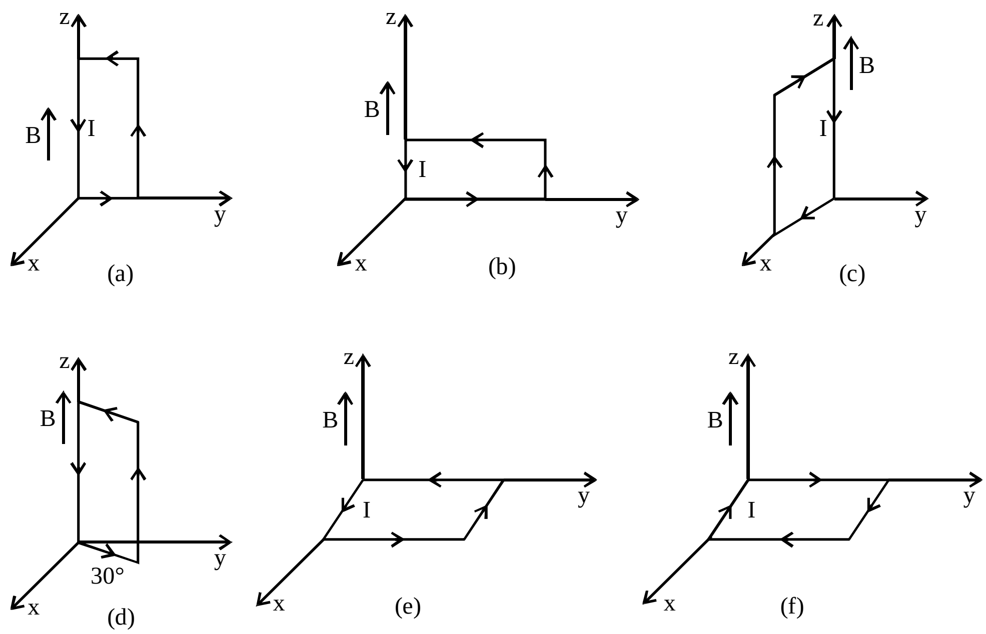
MG0011

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

(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? (All other particulars are also unaltered.)

MG0012

13. A uniform magnetic field of 3000 G is established along the positive z-direction. A rectangular loop of sides 10 cm and 5 cm carries a current of 12A. What is the torque on the loop in the different cases shown in figure. What is the force on each case ? Which case corresponds to stable equilibrium? ***(NCERT)***



MG0013

14. A circular coil of 20 turns and radius 10 cm is placed in a uniform magnetic field of 0.10 T normal to the plane of the coil. If the current in the coil is 5.0 A, what is the ***(NCERT)***

(a) total, torque on the coil,

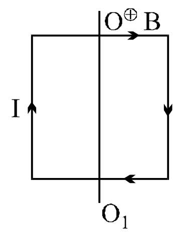
(b) total force on the coil,

(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}.)

MG0014

15. A square current carrying loop made of thin wire and having a mass m = 10g can rotate without friction with respect to the vertical axis OO_1, passing through the centre of the loop at right angles to two opposite sides of the loop. The loop is placed in a homogeneous magnetic field with an induction $B = 10^{-1}$ T directed at right angles to the plane of the drawing. A current I = 2A is flowing in the loop. Find the period of small oscillations that the loop performs about its position of stable equilibrium.



MG0015

16. Two moving coil meters. M_1 and M_2 have the following particulars : ***(NCERT)***

$R_1 = 10\ \Omega$, $N_1 = 30$,

$A_1 = 3.6 \times 10^{-3}\ m^2$. $B_1 = 0.25\ T$

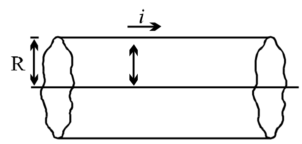
$R_2 = 14\ \Omega$, $N_2 = 42$ $A_2 = 1.8 \times 10^{-3}\ m^2$, $B_2 = 0.50\ T$

(The spring constants are identical for the two meters). Determine the ratio of (a) current sensitivity and (b) voltage sensitivity of M_2 and M_1.

MG0016

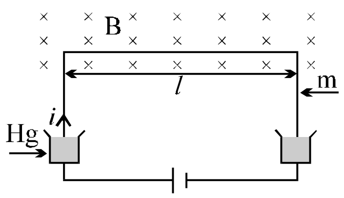
EXERCISE (S-2)

1. A cylindrical conductor of radius R carries a current along its length. The current density J, however, it is not uniform over the cross section of the conductor but is a function of the radius according to J = br, where b is a constant. Find an expression for the magnetic field B.
(a) at $r_1 < R$ & (b) at distance $r_2 > R$, measured from the axis



MG0017

2. A U-shaped wire of mass m and length l is immersed with its two ends in mercury (see figure). The wire is in a homogeneous field of magnetic induction **B**. If a charge, that is, a current pulse $q = \int idt$, is sent through the wire, the wire will jump up.
Calculate, the height h that the wire reaches, the size of the charge or current pulse, assuming that the time of the current pulse is very small in comparision with the time of flight. Make use of the fact that impulse of force equals $\int F\,dt$,which equals mv. Evaluate q for B = 0.1 Wb/m^2, m = 10gm, ℓ = 20cm & h = 3 meters. [g = 10 m/s^2]



MG0018

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

MG0019

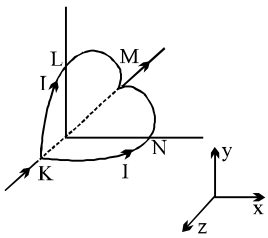
4. Two coils each of 100 turns are held such that one lies in the vertical plane with their centres coinciding. The radius of the vertical coil is 20 cm and that of the horizontal coil is 30 cm . How would you neutralize the magnetic field of the earth at their common centre ? What is the current to be passed through each coil ? Horizontal component of earth's magnetic induction = 3.49 x 10^{-5} T and angle of dip = 30°.

MG0020

5. 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 centers at the origin. Current I is flowing through each of the semicircles as shown in figure .

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

(ii) If an external uniform magnetic field $B\hat{j}$ is applied, determine the forces F_1 and F_2 on the semicircles KLM and KNM due to this field and the net force F on the loop . **[JEE 2000]**

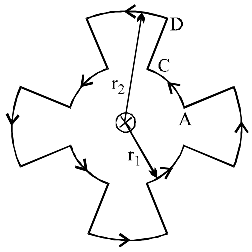


MG0021

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

(a) Find the magnetic field produced by this circuit at the centre.

(b) An infinitely long straight wire carrying a current of 10A is passing through the centre 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 centre 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 centre? **[JEE 2001]**



MG0022

7. A particle of charge +q and mass m moving under the influence of a uniform electric field $E\,\hat{i}$ and a magnetic field $B\,\hat{k}$ enters in I quadrant of a coordinate system at a point (0, a) with initial velocity $v\,\hat{i}$ and leaves the quadrant at a point (2a, 0) with velocity $-2v\,\hat{j}$. Find

(a) Magnitude of electric field

(b) Rate of work done by the electric field at point (0, a)

(c) Rate of work done by both the fields at (2a, 0).

MG0023

8. Electric charge q is uniformly distributed over a rod of length l. The rod is placed parallel to a long wire carrying a current i. The separation between the rod and the wire is a. Find the force needed to move the rod along its length with a uniform velocity v.

MG0024

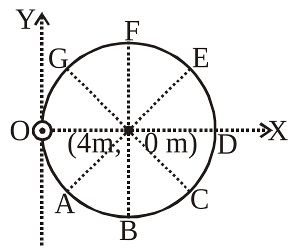
9. There exists a uniform magnetic and electric field of magnitude 1 T and 1 V/m respectively along positive y-axis. A charged particle of mass 1 kg and charge 1 C moving with velocity 1 m/sec along x-axis is at origin at t = 0. If the coordinates of particle at time **π seconds** is given as (X, Y, Z) in meter, then find the value of (XY + YZ + ZX) $\times \frac{5}{\pi^2}$.

MG0025

10. A proton beam passes without deviation through a region of space where there are uniform transverse mutually perpendicular electric and magnetic field with E and B. Then the beam strikes a grounded target. Find the force imparted by the beam on the target if the beam current is equal to I.

MG0026

11. An infinite uniform current carrying wire is kept along z-axis, carrrying current I_0 in the direction of the positive z-axis. OABCDEFG represents a circle (where all the points are equally spaced), whose centre at point (4m, 0 m) and radius 4 m as shown in the figure. If $\int_{DEF} \vec{B}.d\vec{\ell} = \frac{\mu_0 I_0}{k}$ in S.I. unit, then find the value of k.

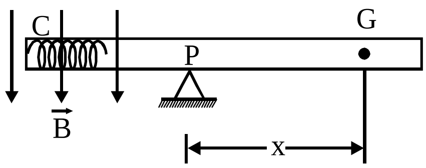


MG0027

12. A rod of length ℓ and total charge 'q' which is uniformly distributed is rotating with angular velocity ω about an axis passing through the centre of rod and perpendicular to rod. Find the magnitude of magnetic dipole moment (in Amp. m^2) of rod. (Take : q = 4C, ω = 6 rad/s and ℓ = 2m.)

MG0028

13. A uniform wooden bar of mass $\frac{\pi}{100}$ kg and radius of cross-section 10cm carries a light coil C of 100 turns. The bar is smoothly pivoted at P. If the coil carries a current 2A and subjected to an external magnetic field 10^{-2}T, the bar remains in equilibrium. Find the distance x (in cm) of the C.M. of the rod from the pivot.



MG0029

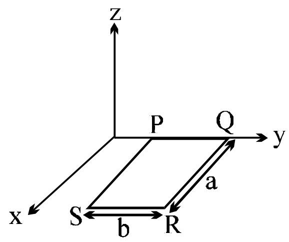
14. 3 infinitely long thin wires each carrying current *i* in the same direction , are in the x-y plane of a gravity free space . The central wire is along the y-axis while the other two are along $x = \pm d$.

(i) Find the locus of the points for which the magnetic field B is zero .

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

MG0030

15. A rectangular loop PQRS made from a uniform wire has length a, width b and mass m. It is free to rotate about the arm PQ, which remains hinged along a horizontal line taken as the y-axis (see figure). Take the vertically upward direction as the z-axis. A uniform magnetic field $\vec{B} = (3\hat{i} + 4\hat{k})B_0$ exists in the region. The loop is held in the x-y plane and a current I is passed through it. The loop is now released and is found to stay in the horizontal position in equilibrium. **[JEE 2002]**



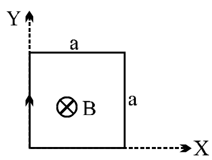
(a) What is the direction of the current I in PQ?

(b) Find the magnetic force on the arm RS.

(c) Find the expression for I in terms of B_0, a, b and m.

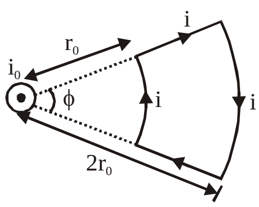
MG0031

16. A rectangular loop of wire is oriented with the left corner at the origin, one edge along X-axis and the other edge along Y-axis as shown in the figure. A magnetic field is into the page and has a magnitude that is given by $\beta = \alpha y$ where α is contant. Find the total magnetic force on the loop if it carries current i.



MG0032

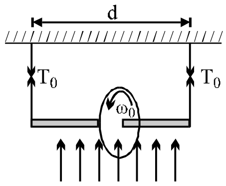
17. A closed loop carrying a current i is placed so that its plane is perpendicular to the long straight conductor which carries a current i_0 as shown in the figure. The torque acting on the current loop is $\alpha\mu_0$ N-m. Then find the value of α. (Given i = 2 A, i_0 = 2A, $r_0 = 2\pi$ m, $\phi = 60°$)



MG0033

18. 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 stringe 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 rotate.

[JEE 2003]



MG0034

19. In a moving coil galvanometer, torque on the coil can be expressed as τ = ki, where i is current through the wire and k is constant. The rectangular coil of the galvanometer having numbers of turns N, area A and moment of inertia I is placed in magnetic field B. Find

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

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

(c) the maximum angle through which coil is deflected, id charge Q is passed through the coil almost instantaneously. (Ignore the damping in mechanical oscillations) **[JEE 2005]**

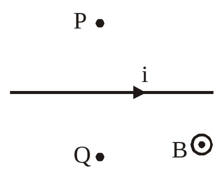
MG0035

EXERCISE (O-1)

SINGLE CORRECT TYPE QUESTIONS

Biot savart law

1. A long, straight wire carrying a current of 1.0 A is placed horizontally in a uniform magnetic field $B = 1.0 \times 10^{-5}$ T pointing vertically upward (figure). The magnitude of the resultant magnetic field at the points P and Q, both situated at a distance of 2.0 cm from the wire in the same horizontal plane are respectively



(A) zero, 20 μT (B) 20 μT, zero (C) zero, zero (D) 20 μT, 20 μT

MG0036

2. A horizontal overhead powerline is at a height of 4m from the ground and carries a current of 100 A from east to west. The magnetic field directly below it one the ground is($\mu_0 = 4\pi \times 10^{-7}$TmA^{-1})

(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

MG0037

3. Two parallel wires carry equal currents of 10 A along the same direction and are separated by a distance of 2.0 cm. Find the magnetic field at a point which is 2.0 cm away from each of these wires.

(A) 3.4×10^{-4} T in a direction parallel to the plane of the wires and perpendicular to the wires

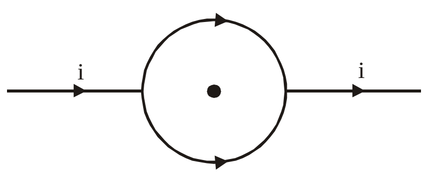
(B) 1.7×10^{-4} T in a direction parallel to the plane of the wires and parallel to the wires

(C) 1.7×10^{-4} T in a direction parallel to the plane of the wires and perpendicular to the wires

(D) 3.4×10^{-4} T in a direction parallel to the plane of the wires and parallel to the wires

MG0038

4. A conducting circular loop of radius a is connected to two long, straight wires. The straight wires carry a current i as shown in figure. Find the magnetic field B at the centre of the loop.



(A) zero (B) $\frac{\mu_0 I}{2a}$ (C) $\frac{\mu_0 I}{a}$ (D) $\frac{\mu_0 I}{a} + \frac{\mu_0 I}{2\pi a}$

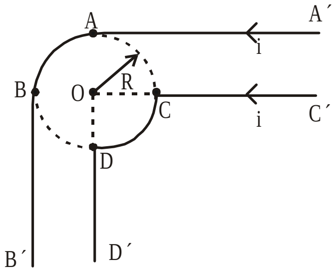
MG0039

5. A piece of wire carrying a current of 6.00 A is bent in the form of a circular arc of radius 10.0 cm, and it subtends an angle of 120° at the centre. Find the magnetic field B due to this piece of wire at the centre.

(A) zero (B) 1.26×10^{-5} T (C) 5×10^{-5} T (D) 7.2×10^{-5} T

MG0040

6. All straight wires are very long. Both AB and CD arc area of the same circle, both subtending right angles at the centre O. Then the magnetic field at O is



(A) $\frac{\mu_0 i}{4\pi R}$ (B) $\frac{\mu_0 i}{4\pi R}\sqrt{2}$ (C) $\frac{\mu_0 i}{2\pi R}$ (D) $\frac{\mu_0 i}{2\pi R}(\pi+1)$

MG0041

7. Two identical long 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-

(A) $\frac{\mu_0}{2\pi}\left(\frac{I_1+I_2}{d}\right)^{1/2}$ (B) $\frac{\mu_0}{2\pi d}\left(I_1^2+I_2^2\right)^{1/2}$ (C) $\frac{\mu_0}{2\pi d}(I_1+I_2)$ (D) $\frac{\mu_0}{2\pi d}\left(I_1^2+I_2^2\right)$

MG0042

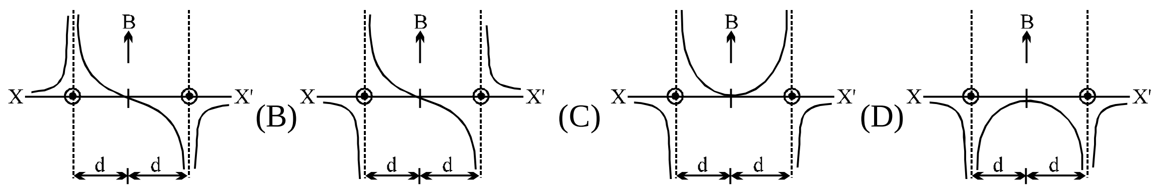
8. The magnetic field due to a current carrying circular loop of radius 3 cm at a point on the axis at a distance of 4 cm from the centre is 54 µT. What will be its value at the centre of the loop ?

(A) 250 µT (B) 150 µT (C) 125 µT (D) 75 µT

MG0043

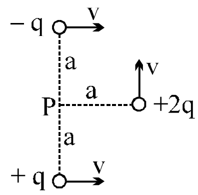
9. Two long parallel wires are at a distance 2d apart. They carry steady equal currents flowing out of the plane of the paper, as shown. The variation of the magnetic field B along the XX' is given by

(A) (B) (C) (D)



MG0044

10. A charge $+2q$ moves vertically upwards with speed v, a second charge $-q$ moves horizontally to the right with the same speed v, and a third charge $+q$ moves horizontally to the right with the same speed v. The point P is located a perpendicular distance a away from each charge as shown in the figure. The magnetic field at point P is



(A) Into the page with magnitude $\frac{\mu_0}{4\pi}\frac{2qv}{a^2}$

(B) Into the page with magnitude $\frac{\mu_0}{4\pi}\frac{4qv}{a^2}$

(C) Out of the page with magnitude $\frac{\mu_0}{4\pi}\frac{2qv}{a^2}$

(D) Out the page with magnitude $\frac{\mu_0}{4\pi}\frac{4qv}{a^2}$

MG0045

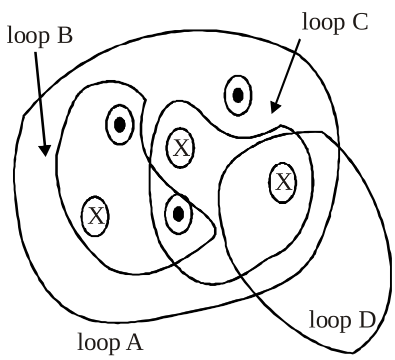
11. Considering magnetic field along the axis of a circular loop of radius 1 meter, at what distance from the centre of the loop the magnetic field is $\frac{1}{2\sqrt{2}}$ times of its value at the centre ?

(A) 1 m (B) 3 m (C) 5 m (D) 9 m

MG0046

Ampere's law

12. Consider six wires coming into or out of the page, all with the same current. Rank the line integral of the magnetic field (from most positive to most negative) taken counterclockwise around each loop shown.



(A) B > C > D > A (B) B > C = D > A (C) B > A > C = D (D) C > B = D > A

MG0047

13. **Statement-1 :** Ampere law can be used to find magnetic field due to finite length of a straight current carrying wire.

Statement-2 : The magnetic field due to finite length of a straight current carrying wire is symmetric about the wire.

(A) Statement-1 is true, statement-2 is true and statement-2 is correct explanation for statement-1.

(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the correct explanation for statement-1.

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true.

MG0048

14. A long, cylindrical wire of radius b carries a current i distributed uniformly over its cross-section. Find the magnitude of the magnetic field at a point inside the wire at a distance a from the axis.

(A) zero (B) $\frac{\mu_0 ib}{2\pi a^2}$ (C) $\frac{\mu_0 ia^2}{2\pi b^3}$ (D) $\frac{\mu_0 ia}{2\pi b^2}$

MG0049

15. A copper wire of diameter 1.6 mm carries a current of 20 A. Find the maximum magnitude of the magnetic field $\vec{B}$ due to this current.

(A) 5.0 mT (B) 10 mT (C) 15 mT (D) 15.5 mT

MG0050

16. A closely wound solenoid 80 cm long has 5 layers of windings of 400 turns each. The diameter of the solenoid is 1.8 cm. If the current carried is 8.0 A. estimate the magnitude of B inside the solenoid near its centre. ***(NCERT)***

(A) zero (B) $8\pi \times 10^{-3}$ T (C) $15\pi \times 10^{-3}$ T (D) $\pi \times 10^{-3}$ T

MG0051

17. 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/m^2. Another long solenoid has 100 turns per cm and it carries a current i/3. The value of the magnetic field at its centre is-

(A) 1.05×10^{-2} weber/m^2 (B) 1.05×10^{-5} weber/m^2

(C) 1.05×10^{-3} weber/m^2 (D) 1.05×10^{-4} weber/m^2

MG0052

18. 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 $\frac{a}{2}$ and 2a is-

(A) $\frac{1}{4}$ (B) 4 (C) 1 (D) $\frac{1}{2}$

MG0053

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

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

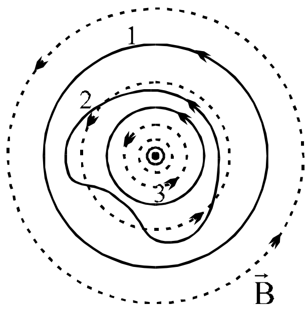
(B) the magnetic field is different at different points inside the pipe

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

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

MG0054

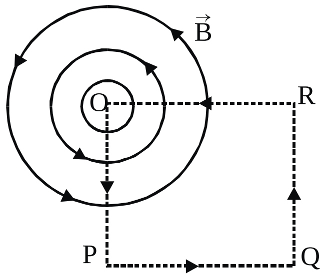
20. Consider the three closed loops drawn using solid line in the magnetic field (magnetic field lines are drawn using dotted line) of an infinite current-carrying wire normal to the plane of paper as shown. Rank the line integral of the magnetic field along each path in order of increasing magnitude



(A) 1 > 2 > 3 (B) 1 = 3 > 2 (C) 1 = 2 = 3 (D) 3 > 2 > 1

MG0055

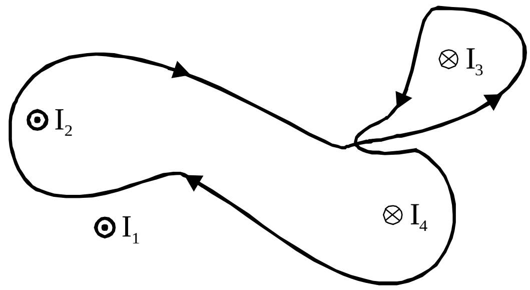
21. A current carrying wire (current = i) perpendicular to the plane of the paper produces a magnetic field, as shown in the figure. A square of side a is drawn with one of its vertices on the centre of the wire. The integral $\int \vec{B}.d\vec{r}$ along $OPQRO$ has the value



(A) $+\mu_0 i$ (B) $\frac{\mu_0 i}{8}$ (C) $\frac{\mu_0 i}{4}$ (D) $\frac{\mu_0 i}{2}$

MG0056

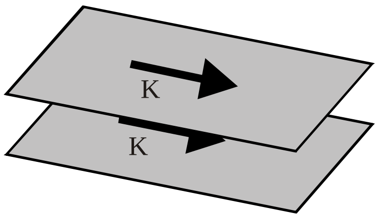
22. Four wires carrying current I_1 = 2A, I_2 = 4A, I_3 = 6A and I_4 = 8A respectively cut the page perpendicularly as shown in figure. The value of $\int \vec{B}.d\vec{\ell}$ for the loop shown would be :-



(A) +2 μ_0-wb/m (B) –2 μ_0-wb/m (C) + 10 μ_0-wb/m (D) – 10 μ_0-wb/m

MG0057

23. What are the directions of the magnetic field between and outside a pair of two parallel large sheets carrying currents in the same directions, as illustrated in Figure (from the side shown)?



(A) towards us between the plates and away from us above and below the plates.
(B) toward us above the plates and away from us below plates and zero between plates.
(C) towards us above and below the plates and zero between the plates
(D) towards us between the plates and zero above and below the plates.

MG0058

Motion of charge particle

24. A charged particle enters a non-uniform uni-directional field such that initial velocity is parallel to magnetic field, then the radius of curvature of its path is (in standard notation):
(A) mV/qB (B) 0 (C) ∞ (D) qB/mV

MG0059

25. A charge particle moves in a uniform magnetic field such that initial velocity is perpendicular to the magnetic field . No other force acts on the particle .
(A) the motion is uniform rectilinear
(B) the motion can be non uniform circular motion
(C) the motion can be uniform circular motion
(D) the motion must be uniform circular motion.

MG0060

26. A tightly-wound, long solenoid carries a current of 2.00 A. An electron is found to execute a uniform circular motion inside the solenoid with a frequency of 1.00×10^8 rev/s. Find the number of turns per metre in the solenoid.
(A) 500 Turns/m (B) 1020 Turns/m (C) 1232 Turns/m (D) 1420 Turns/m

MG0061

27. 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-

(A) helix (B) straight line (C) ellipse (D) circle

MG0062

28. An electron is moving along positive x-axis. A uniform electric field exists towards negative y-axis. What should be the direction of magnetic field of suitable magnitude so that net force of electron is zero

(A) positive z- axis (B) negative z-axis (C) positive y-axis (D) negative y-axis

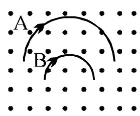
MG0063

29. An electron having kinetic energy T is moving in a circular orbit of radius R perpendicular to a uniform magnetic induction $\vec{B}$. If kinetic energy is doubled and magnetic induction tripled, the radius will become

(A) $\frac{3R}{2}$ (B) $\sqrt{\frac{3}{2}}\,R$ (C) $\sqrt{\frac{2}{9}}\,R$ (D) $\sqrt{\frac{4}{3}}\,R$

MG0064

30. 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 **[JEE, 2001 (Scr)]**



(A) $m_Av_A < m_Bv_B$ (B) $m_Av_A > m_Bv_B$

(C) $m_A < m_B$ and $v_A < v_B$ (D) $m_A = m_B$ and $v_A = v_B$

MG0065

31. A charged particle moves in a magnetic field $\vec{B} = 10\hat{i}$ with initial velocity $\vec{u} = 5\hat{i} + 4\hat{j}$. The path of the particle will be

(A) straight line (B) circle (C) helical (D) none

MG0066

32. An electron makes 3×10^5 revolutions per second in a circle of radius 0.5 angstrom. Find the magnetic field B at the centre of the circle.

(A) 6×10^{-10} T (B) 12×10^{-10} T (C) 18×10^{-10} T (D) 24×10^{-10} T

MG0067

33. Electrons moving with different speeds enter a uniform magnetic field in a direction perpendicular to the field. They will move along circular paths.

(A) of same radius

(B) with larger radii for the faster electrons

(C) with smaller radii for the faster electrons

(D) either (B) or (C) depending on the magnitude of the magnetic field

MG0068

34. In the previous question, time periods of rotation will be :

(A) same for all electrons

(B) greater for the faster electrons

(C) smaller for the faster electrons

(D) either (B) or (C) depending on the magnitude of the magnetic field

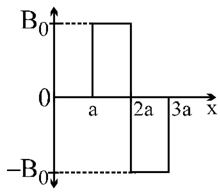
MG0069

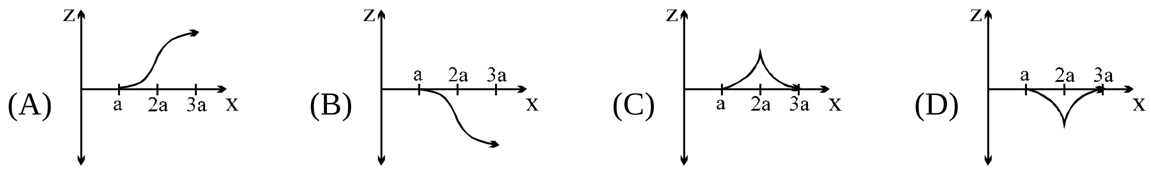
35. A particle of mass m and charge q moves with a constant velocity v along the positive x direction. It enters a region containing a uniform magnetic field B directed along the negative z direction, extending from x = a to x = b. The minimum value of v required so that the particle can just enter the region x > b is :- **JEE 2002 (screening)]**

(A) q b B/m (B) q(b – a) B/m (C) q a B/m (D) q(b + a) B/2m

MG0070

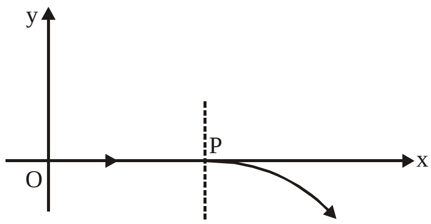
36. A magnetic field $\vec{B} = B_0\hat{j}$ exists in the region a < x < 2a and $\vec{B} = -B_0\hat{j}$, in the region 2a < x < 3a, where B_0 is a positive constant. A positive point charge moving with a velocity $\vec{v} = v_0\hat{i}$, where v_0 is a positive constant, enters the magnetic field at x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





MG0071

37. For a positively charged particle moving in a x – y plane initially along the x–axis, there is a sudden change in it path due to the presence of electric and/or magnetic field 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? **[JEE 2004]**



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

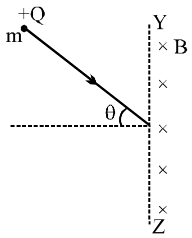
MG0072

38. A particle having charge of 1 C, mass 1 kg and speed 1 m/s enters a uniform magnetic field, having magnetic induction of 1 T, at an angle $\theta = 30°$ between velocity vector and magnetic induction. The pitch of its helical path is (in meters)

(A) $\frac{\sqrt{3}\pi}{2}$ (B) $\sqrt{3}\pi$ (C) $\frac{\pi}{2}$ (D) π

MG0073

39. A particle with charge +Q and mass m enters a magnetic field of magnitude B, existing only to the right of the boundary YZ. The direction of the motion of the particle is perpendicular to the direction of B. Let $T = 2\pi\frac{m}{QB}$. The time spent by the particle in the field will be



(A) $T\theta$ (B) $2T\theta$ (C) $T\left(\frac{\pi+2\theta}{2\pi}\right)$ (D) $T\left(\frac{\pi-2\theta}{2\pi}\right)$

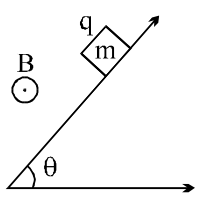
MG0074

40. In the previous question, if the particle has –Q charge, the time spend by the particle in the field will be :-

(A) $T\theta$ (B) $2T\theta$ (C) $T\left(\frac{\pi+2\theta}{2\pi}\right)$ (D) $T\left(\frac{\pi-2\theta}{2\pi}\right)$

MG0075

41. A block of mass m & charge q is released on a long smooth inclined plane magnetic field B is constant, uniform, horizontal and parallel to surface as shown. Find the time from start when block loses contact with the surface.



(A) $\frac{m\cos\theta}{qB}$ (B) $\frac{m\,\text{cosec}\,\theta}{qB}$ (C) $\frac{m\cot\theta}{qB}$ (D) none

MG0076

42. In a cyclotron, a charged particle

(A) undergoes acceleration all the time.

(B) speeds up between the dees because of the magnetic field.

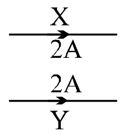
(C) speeds up in a dee.

(D) slows down within a dee and speeds up between dees.

MG0077

Ampere force & torque

43. In given figure, X and Y are two long straight parallel conductors each carrying a current of 2 A. The force on each conductor is F newtons. When the current in each is changed to 1 A and reversed in direction, the force on each is now



(A) F/4 and unchanged in direction (B) F/2 and reversed in direction
(C) F/2 and unchanged in direction (D) F/4 and reversed in direction

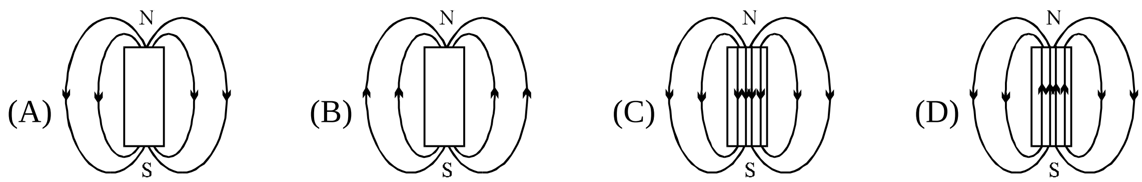
MG0078

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

(A) 2×10^{-5} N ; attractive force normal to B towards A.
(B) 2×10^{-5} N ; attractive force normal to A towards B.
(C) 5×10^{-5} N ; attractive force normal to A towards B.
(D) 5×10^{-5} N ; attractive force normal to B towards A.

MG0079

45. The magnetic field lines due to a bar magnet are correctly shown in:- **[JEE 2002 (screening)]**



MG0080

46. A wire of mass 100 g carrying a current of 2A towards increasing x is in the form of $y = x^2$ ($-2m \le x \le +2m$). This wire is placed in a magnetic field $B = -0.02\hat{k}$ Tesla & gravity free region. The acceleration of the wire (in m/s^2) is :-

(A) $-1.6\hat{j}$ (B) $-3.2\hat{j}$ (C) $1.6\hat{j}$ (D) $2.4\hat{j}$

MG0081

47. A circular loop of radius R carries a current I. Another circular loop of radius r(<<R) carries a current i and is placed at the centre of the larger loop. The planes of the two circles are at right angle to each other. Find the torque acting on the smaller loop.

(A) zero (B) $\frac{\mu_0 \pi i I r^2}{4R}$ (C) $\frac{\mu_0 \pi i I r^2}{2R}$ (D) $\frac{\mu_0 \pi i I r^2}{R}$

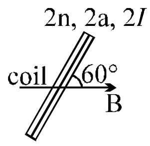
MG0082

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

(A) ω and q (B) ω, q and m (C) q and m (D) ω and m

MG0083

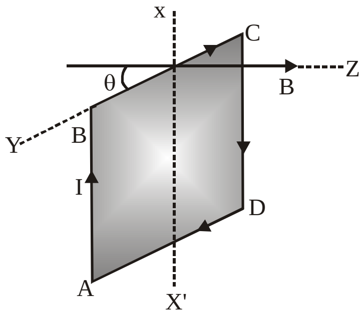
49. A rectangular coil PQ has 2n turns, an area 2a and carries a current 2*I*, (refer figure). The plane of the coil is at 60° to a horizontal uniform magnetic field of flux density B. The torque on the coil due to magnetic force is :-



(A) Bna*I* sin60° (B) 8Bna*I* cos60° (C) 4na*I* Bsin60° (D) none

MG0084

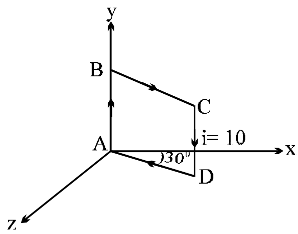
50. The square loop ABCD, carrying a current I, is placed in a uniform magnetic field B, as shown. The loop can rotate about the axis XX'. The plane of the loop makes an angle θ (θ < 90°) with the direction of B. Through what angle will the loop rotate by itself before the torque on it becomes zero–



(A) θ (B) 90° – θ (C) 90° + θ (D) 180° – θ

MG0085

51. Figure shows a square current carrying loop ABCD of side 10 cm and current i = 10A. The magnetic moment $\vec{M}$ of the loop is



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

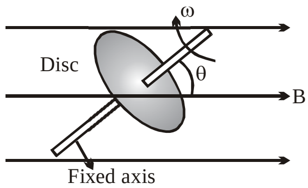
(B) (0.05) $\left(\hat{j}+\hat{k}\right)A-m^2$

(C) (0.05) $\left(\sqrt{3}\hat{i}+\hat{k}\right)A-m^2$

(D) $\left(\hat{i}+\hat{k}\right)A-m^2$

MG0086

52. A disc of radius r and carrying positive charge q is rotating with an angular speed ω in a uniform magnetic field B about a fixed axis as shown in figure, such that angle made by axis of disc with magnetic field is θ. Torque applied by axis on the disc is

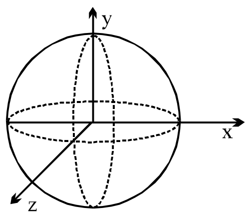


(A) $\frac{q\omega r^2 B\sin\theta}{2}$, clockwise (B) $\frac{q\omega r^2 B\sin\theta}{4}$, anticlockwise

(C) $\frac{q\omega r^2 B\sin\theta}{2}$, anticlockwise (D) $\frac{q\omega r^2 B\sin\theta}{4}$, clockwise

MG0087

53. Three rings, each having equal radius R, are placed mutually perpendicular to each other and each having its centre at the origin of co-ordinate system. If current I is flowing through each ring then the magnitude of the magnetic field at the common centre is



(A) $\sqrt{3}\frac{\mu_0 I}{2R}$ (B) zero (C) $\left(\sqrt{2}-1\right)\frac{\mu_0 I}{2R}$ (D) $\left(\sqrt{3}-\sqrt{2}\right)\frac{\mu_0 I}{2R}$

MG0088

54. Two mutually perpendicular long conducting wire carrying currents I_1 and I_2 lie in one plane. Locus of the point at which the magnetic induction is zero, is a

(A) circle with centre as the point of intersection of the wire.

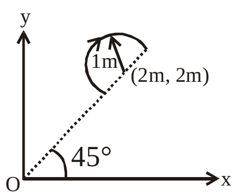
(B) parabola with vertex as the point of intersection of the wire

(C) straight line passing through the point of intersection of the wire

(D) rectangular hyperbola

MG0089

55. A uniform magnetic field $\vec{B}=\left(3\hat{i}+4\hat{j}+\hat{k}\right)$ Tesla exist in a region of space. A semicircular wire of radius 1 m carrying a current of 1A having its centre at (2,2,0) m is placed on the X-Y plane as shown. The force on the semicircular wire will be



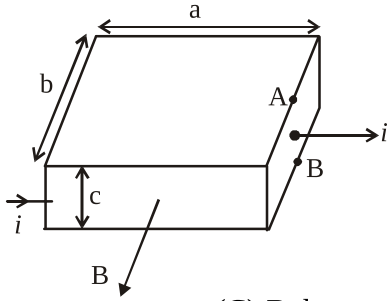
(A) $\frac{1}{\sqrt{2}}\left(\hat{i}-\hat{j}+\hat{k}\right)N$ (B) $\sqrt{2}\left(\hat{i}-\hat{j}+\hat{k}\right)N$ (C) $\frac{1}{\sqrt{2}}\left(\hat{i}+\hat{j}-\hat{k}\right)N$ (D) $\sqrt{2}\left(\hat{i}+\hat{j}-\hat{k}\right)N$

MG0090

56. A very long wire carrying current I is fixed along x-axis. Another parallel finite wire carrying a current in the opposite direction is kept at a distance d above the wire in xy plane. The second wire is free to move parallel to itself. The options available for its small displacements are in
(i) +ve x direction (ii) +ve y direction (iii) +ve z direction
Taking gravity in negative y direction, the nature of equilibrium of second wire is
(A) stable for movement in x direction, unstable for movement in y direction, neutral for movement in z direction
(B) stable for movement in y direction, unstable for movement in z direction, neutral for movement in x direction
(C) stable for movement in z direction, unstable for movement in y direction, neutral for movement in x direction
(D) stable for movement in y direction, unstable for movement in x direction, neutral for movement in z direction

MG0091

57. A current flows through a rectangular conductor in the presence of uniform magnetic field B pointing out of the page as shown. Then the potential difference $V_B - V_A$ is equal to
(Assume charge carries in the conductor to be positively charged moving with speed v)



(A) Bvc (B) –Bvc (C) Bvb (D) –Bvb

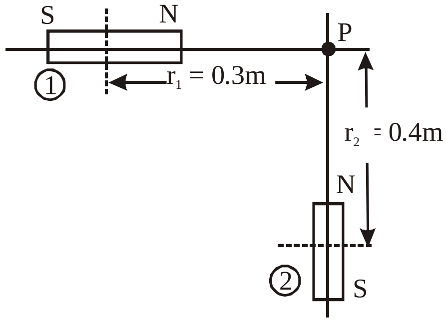
MG0092

58. A moving coil galvanometer has 150 equal divisions. Its current sensitivity is 10 divisions per milli ampere and voltage sensitivity is 2 divisions per millivolt. In order that each division reads 1 V, the resistance in Ohm's needed to be connected in series with the coil will be- **[AIEEE-2005]**
(A) 10^3 (B) 10^5 (C) 99995 (D) 9995

MG0093

SUPPLEMENT ON MAGNETIC PROPERTIES OF MATTER

59. Two short magnets of magnetic moment $2Am^2$ and $5Am^2$ respectively are placed along two lines drawn at right angle to each other on the sheet of paper as shown in the figure. What is the magnetic field at the point of intersection of their axis:



(A) 2.15×10^{-5} T (B) 215×10^{-5} T (C) 2.15×10^{-4} T (D) 21.5×10^{-5} T

MG0094

60. A steel wire of length L has a magnetic moment M. It is then bent into a semi-circular arc; the new magnetic moment will be :

(A) M (B) $2M/\pi$ (C) M/L (D) $M \times L$

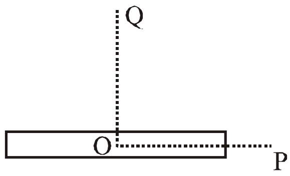
MG0095

61. Two bar magnets of the same mass, same length and breadth but having magnetic moments M and 2M are joined together north pole to north pole and suspended by a string . The time period of assembly in a magnetic field of strength H is 3 seconds. If now the polarity of one of the magnets is reversed and the combination is again made to oscillate in the same field, the time of oscillations is :

(A) $\sqrt{3}$ sec (B) $3\sqrt{3}$ sec (C) 3 sec (D) 6 sec

MG0096

62. When magnetic field at P and Q is same then OP/OQ = ?



(A) $\sqrt[3]{2}$ (B) $\frac{1}{\sqrt[3]{2}}$ (C) $2\sqrt{2}$ (D) $\frac{3}{2\sqrt{2}}$

MG0097

63. Similar pole each of pole strength m are placed at a distance of 1, 2,4, 8, ...meters from the origin on the x-axis. Where do you place a similar pole n the other side of the origin so that the origin becomes a neutral point :-

(A) 0.5 m (B) 0.5774 m (C) 0.86 m (D) 1m

MG0098

64. Two identical poles each of pole strength 4×10^{-3} amp-m placed at the two corners of an equilateral triangle of side 20 cm. The magnetic field at the third corner is :-

(A) $\sqrt{3}\times10^{-8}$ N/amp-m (B) $\frac{\sqrt{3}}{4} \times 10^{-8}$N/amp-m

(C) zero (D) 10^{-8} N/amp-m

MG0099

65. The magnetic field at a point on the axis of a dipole is 20 Wb/m^2 Northwards. What will be the magnetic induction at the point if the dipole be rotated anticlockwise by 90° :-

(A) 10 Wb/m^2 Eastwards (B) 10 Web/m^2 Southwards

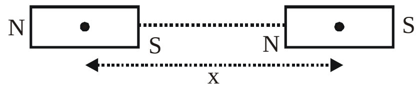
(C) 10 Wb/m^2 Northwards (D) 20 Wb/m^2 Southwards

MG0100

66. A bar magnet of magnetic moment $2A\text{-}m^2$ free to rotate about a vertical axis passing through its centre. The magnet is released from rest from east-west position. Then the kinetic energy of the magnet as it takes North-South position is (horizontal component of the earth's field is 25μT and angle of declination is zero :-

(A) 25 μJ (B) 50 μJ (C) 100 μJ (D) 125 μJ

67. The mid points of two small magnetic dipoles of length d in end-on positions, are separated by a distance x, (x >> d). The force between them is proportional to x^{-n} where n is :-



(A) 3 (B) 4 (C) 2 (D) 1

MG0102

68. A permanent magnet has shape of a thin disc with magnetic moment along its axis the radius of the disc is 1 cm. The magnetic field due to it can be assumed to be that due to molecular current I' flowing along the rim of the disc. If $\vec{B}$ at a distance of 10 cm from it's centre on the axis is 30μT, find I' (approximately) :-

(A) 1 kA (B) 0.5 kA (C) 2.5 kA (D) 3 kA

MG0103

69. The angle of dip at a place is 30° and the intensity of the vertical component of the earth's magnetic field $V = 6 \times 10^{-5}$T. The total intensity of the earth's magnetic field at this place is :

(A) 7×10^{-5} T (B) 6×10^{-5} T (C) 5×10^{-5} T (D) 12×10^{-5} T

MG0104

70. The total intensity of the earth's magnetic field at the magnetic equator is 5 units. What is its value at a magnetic latitude of 37 degree?

(A) $\sqrt{73}$ units (B) $\sqrt{52}$ units (C) 4 units (D) 3 units

MG0105

71. A magnet is suspended in the magnetic meridian with an untwisted wire. The upper end of wire is rotated through 180° to deflect the magnet by 30° from magnetic meridian. When the magnet is replaced by another magnet, the upper end of wire is rotated through 270° to deflect the magnet 30° from magnetic meridian. The ratio of magnetic moments of magnets is :-

(A) 1 : 5 (B) 1 : 8 (C) 5 : 8 (D) 8 : 5

MG0106

72. The imagined magnet makes an angle of 11.3° with earth's axis. On the earth, there are two points where magnetic equator and geographic equator meet let the angle of dip and angle of declination at these point be θ & φ respectively :-

(A) $\theta = \phi = 0°$ (B) $\theta = 11.3°,\ \phi = 0°$

(C) $\theta = 0°,\ \phi = 11.3°$ (D) $\theta = \phi = 11.3°$

MG0107

73. A specimen of iron of permeability 8×10^{-3} weber/ amp × metre is placed in a magnetic field of intensity 160 amp/metre. Then magnetic field in this iron is :

(A) 20×10^{3} Wb/m^2 (B) 1.28 Wb/m^2 (C) 5×10^{-5} Wb/m^2 (D) 0.8Wb/m^2

MG0108

74. Curie temperature is the temperature above which :

(A) a paramagnetic material becomes diamagnetic

(B) a ferromagnetic material becomes diamagnetic

(C) a paramagnetic material becomes ferromagnetic

(D) a ferromagnetic material becomes paramagnetic

MG0109

75. If a solution of ferromagnetic material is poured into a U-tube and one arm of this is placed between the poles of a strong magnet with the meniscus in line with the field, then the level of the solution will:

(A) Rise (B) Fall

(C) Rise till the liquid comes out (D) Remain unchanged

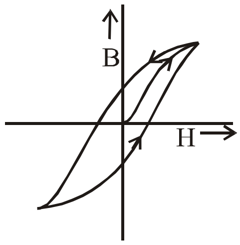
MG0110

76. A sample of paramagnetic salt contains 2.0×10^{24} atomic dipoles each of dipole moment $1.5 \times 10^{-23} J\ T^{-1}$. The sample is placed under a homogeneous magnetic field of 0.84T, and cooled to a temperature of 4.2K. The degree of magnetic saturation achieved is equal to 15%. What is the total dipole moment (approximate) of the sample for a magnetic field of 0.98 T and a temperature of 2.8K? (Assume Curie's law).

(A) $7.9\ JT^{-1}$ (B) $52.5\ J\ T^{-1}$ (C) $30\ J\ T^{-1}$ (D) $4.6J\ T^{-1}$

MG0111

77. The B-H curve for a certain specimen is schematically shown by the given diagram. Which one of the following is the correct magnetic nature of the specimen?



(A) Diamagnetic and not ferromagnetic or paramagnetic

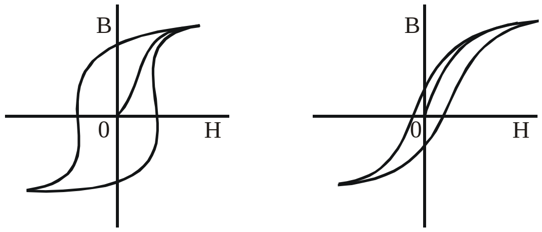
(B) Ferromagnetic and not diamagnetic or paramagnetic

(C) Paramagnetic and not diamagnetic or ferromagnetic

(D) Applicable to all the three types of magnetism mentioned above

MG0112

78. Two types of steel are characterized by the hysteresis loops shown in figure (a) and (b). The loops are obtained in the processes of magnetization and demagnetization of the steels. Which of the two types is best suited for using as the core of a transformer and which, for using as a permanent magnet ?



(A) Both are best suited for transformer
(B) Both are best suited for permanent magnet
(C) A is best suited for permanent magnet & B is best suited for core of transformer
(D) A is best suited for core of transformer & B is best suited for permanent magnet

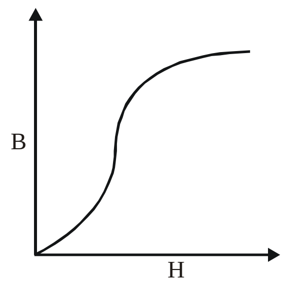
MG0113

79. A material satisfied the relation $\mu_0(H + M) = 0$, where H and M are magnetic intensity and magnetisation respectively, then material is :-

(A) nonmagnetic (B) paramagnetic (C) ferrormagnetic (D) diamagnetic

MG0114

80. The figure represent B-H curve for commercial iron. As H is increased, permeability :-



(A) increases and becomes constant
(B) increases, reaches a maximum and then decreases
(C) decreases continuously till it becomes very small
(D) decreases reaches a minimum and then increases

MG0115

81. **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.

(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

MG0116

82. Horizontal magnetic field of earth at Mumbai is 1.5×10^{-4} T in North direction. A small bar magnet of magnetic moment 10 Am^2 is kept on a horizontal table such that its North pole points due North. What is the magnetic field at 10 cm from centre of magnet at a point on its axis due North of it :-

(A) 3.5×10^{-4} T
(B) 5×10^{-5} T
(C) 2.15×10^{-3} T
(D) 1.15×10^{-3} T

MG0117

83. A compass needle kept on a horizontal table points in direction 30° west of north. A line is marked showing this direction and compass is now kept in vertical plane containing this line. The needle points in direction 30° below horizontal. If the plane of compass is still vertical but contains true north south direction at what angle to horizontal will needle point :-

(A) $\tan^{-1}\left(\frac{3}{2}\right)$
(B) $\tan^{-1}\left(\frac{2}{3}\right)$
(C) $\tan^{-1}(2)$
(D) $\tan^{-1}\left(\frac{1}{2}\right)$

MG0118

84. In a moving coil galvanometer the number of turns N = 24, area of the coil A = 2×10^{-3} m^2, and the magnetic field strength B = 0.2 T To increase its current sensitivity by 25% we :-

(A) increase B to 0.30 T
(B) decrease A to 1.5×10^{-3} m^2
(C) increase N to30
(D) none of the above

MG0119

85. 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 T'/T is- **[AIEEE - 2003]**

(A) $\frac{1}{2\sqrt{2}}$
(B) $\frac{1}{2}$
(C) 2
(D) $\frac{1}{4}$

MG0120

86. The magnetic lines of force inside a bar magnet: **[AIEEE - 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

MG0121

87. 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 three parts are then placed on each other with their like poles together. The time period of this combination will be- **[AIEEE - 2004]**

(A) 2s
(B) 2/3 s
(C) $2\sqrt{3}$ s
(D) $2/\sqrt{3}$ s

MG0122

88. The materials suitable for making electromagnets should have- **[AIEEE - 2004]**
(A) high retentivity and high coercivity
(B) low retentivity and low coercivity
(C) high retentivity and low coercivity
(D) low retentivity and high coercivity

MG0123

MULTIPLE CORRECT TYPE QUESTIONS

89. Consider three quantities x = E/B, y = $\sqrt{1/\mu_0\varepsilon_0}$ and z = $\frac{l}{CR}$. Here, l is the length of a wire, C is a capacitance and R is a resistance. All other symbols have standard meanings.
(A) x, y have the same dimensions
(B) y, z have the same dimensions
(C) z, x have the same dimensions
(D) none of the three pairs have the same dimensions.

MG0124

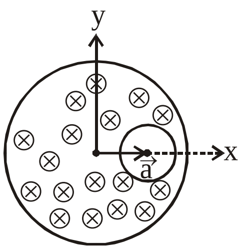
90. The magnetic lines of force due to a straight current carrying wire will be:
(A) circular for finite length of wire
(B) circular for semi-infinite wire
(C) circular for infinite wire
(D) Parabolic for finite wire

MG0125

91. A current I flows along the length of an infinitely long, straight, solid pipe. Then correct statement(s)-
(A) The magnetic field is zero only on the axis of the pipe
(B) The magnetic field is different at different points inside the pipe
(C) The magnetic field is maximum on surface
(D) The magnetic field at all points inside the pipe is the same, but not zero

MG0126

92. Figure shows cross-section view of a infinite cylindrical wire with a cylinderical cavity, current density is uniform $\vec{J} = -j_0\hat{k}$ as shown in figure.



(A) Field inside cavity is uniform

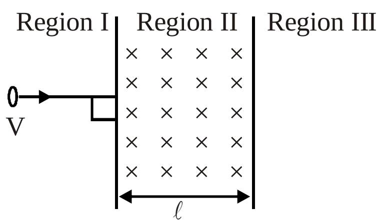
(B) Field inside cavity is along $\vec{a}$

(C) Field inside cavity is perpendicular to $\vec{a}$

(D) If an electron is projected with velocity $v_0\,\hat{j}$ it will move undeviated before colliding with cavity wall

MG0127

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



(A) The particle enters Region III only if its velocity $V > \dfrac{q\ell B}{m}$

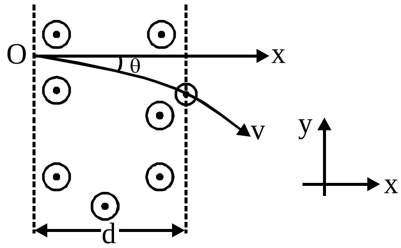
(B) The particle enters Region III only if its velocity $V < \dfrac{q\ell B}{m}$

(C) Path length of the particle in Region II is maximum when velocity $V = \dfrac{q\ell B}{m}$

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

MG0128

94. A particle of charge q is projected with a momentum $\vec{P} = P\hat{i}$ in the given region of magnetic field $\vec{B} = B\hat{k}$. It emerges from the magnetic field after deviating through an angle θ = 30°.



(A) The value of $\vec{P}$ is 2qBd

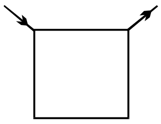
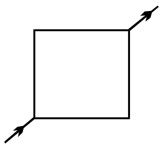
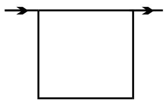
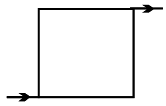
(B) The value of $\vec{P}$ is qBd

(C) Maximum change in momentum takes place for $d \geq \frac{P}{qB}$

(D) Maximum change in momentum takes place for $d \geq \frac{P}{2qB}$

MG0129

95. Current flows through uniform, square frames as shown. In which case is the magnetic field at the centre of the frame not zero. The wire current carrying shown outside coil and infinitely long.?

(A)  (B)  (C)  (D) 

MG0130

96. A long straight wire carries a current along the x-axis. Consider the points A(0, 1, 0), B(0, 1, 1), C(1, 0, 1) and D(1, 1, 1). Which of the following pairs of points will have magnetic fields of the same magnitude?

(A) A and B (B) A and C (C) B and C (D) B and D

MG0131

97. Two identical charged particles enter a uniform magnetic field with same speed but at angles 30° and 60° with field. Let a, b and c be the ratio of their time periods, radii and pitches of the helical paths than

(A) abc = 1 (B) abc > 1 (C) abc < 1 (D) a = bc

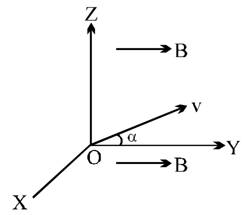
MG0132

98. An electron is moving along the positive X-axis. You want to apply a magnetic field for a short time so that the electron may reverse its direction and move parallel to the negative X–axis. This can be done by applying the magnetic field along :-

(A) Y-axis (B) Z-axis (C) Y-axis only (D) Z-axis only

MG0133

99. In a region of space, a uniform magnetic field B exists in the y-direction. A proton is fired from the origin, with its initial velocity v making a small angle α with the y-direction in the yz plane. In the subsequent motion of the proton,



(A) its x-coordinate can never be positive

(B) its x- and z-coordinates cannot both be zero at the same time

(C) its z-coordinate can never be negative

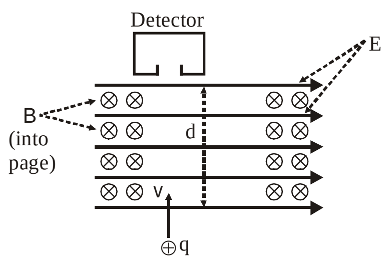
(D) its y-coordinate will be proportional to the square of its time elapsed

MG0134

COMPREHENSION TYPE QUESTIONS

Paragraph for Questions no. 100 to 103

A velocity filter uses the properties of electric and magnetic fields to select charged particles that are moving with a specific velocity. Charged particles with varying speeds are directed into the filter as shown in figure. The filter consists of an electric field E and a magnetic field B, each of constant magnitude, directed perpendicular to each other as shown. The particles that move straight through the filter with their direction unaltered by the fields have the specific filter speed, v_0. Those with speeds to v_0 may experience sufficiently little deflection that they also enter the detector.



The charged particle will experience a force due to the electric field given by the relationship $\vec{F} = q\vec{E}$, where q is the charge of the particle and $\vec{E}$ is the electric field. The moving particle will also experience a force due to the magnetic field. This force acts to oppose the force due to the electric field. The strength of the force due to the magnetic field is given by the relationship $\vec{F} = q(\vec{v} \times \vec{B})$, where q is the charge of the particle, $\vec{v}$ is the speed of the particle, and $\vec{B}$ is the magnetic field strength. When the forces due to the two fields are equal and opposite, the net force on the particle will be zero, and the particle will pass through the filter with its path unaltered. The electric and magnetic field strengths can be adjusted to choose the specific velocity to be filtered. The effects of gravity can be neglected.

100. The electric and magnetic fields in the filter of figure are adjusted to detect particles with positive charge q of a certain speed, v_0. Which of the following expressions is equal to this speed ?

(A) $B/(q^2E)$ (B) $E/(q^2B)$ (C) B/E (D) E/B

MG0135

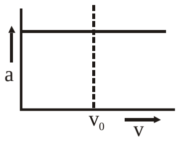
101. Which of the following is true about the velocity filter shown in figure ?
(A) It would not work with negatively charged particles
(B) The wider the detector entrance, the more narrow the range of speed detected
(C) The greater the distance d, the more narrow the range of speeds detected
(D) The detector may not detect a charged particle with the desired filter speed if its charge is too high

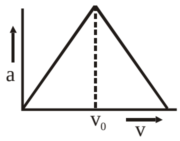
MG0136

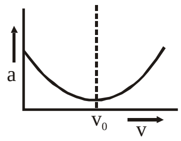
102. Which of the following statements is true regarding a charged particle that is moving through the filter at a speed that is less than the filter speed ?
(A) It experiences a greater force due to the magnetic field than due to the electric field
(B) It experiences a greater force due to the electric field than due to the magnetic field
(C) It experiences equal force due to both fields but greater acceleration due to the electric field
(D) It experiences equal force due to both fields but greater acceleration due to the magnetic field

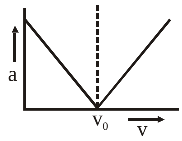
MG0137

103. Particles of identical mass and charge are sent through the filter at varying speeds, and the magnitude of acceleration of each particle is recorded as it first begins to be deflected. If the filter is set to detect particles of speed v_0, which one of the following is correct graph between acceleration and velocity of particle:

(A) 

(B) 

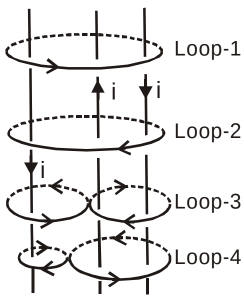
(C) 

(D) 

MG0138

MATRIX MATCH TYPE QUESTION

104. Three wires are carrying same constant current i in different directions. Four loops enclosing the wires in different manners are shown. The direction of $d\vec{\ell}$ is shown in figure.



	Column-I		Column-II
(A)	Along closed loop–1	(p)	$\oint \vec{B}.d\vec{\ell} = \mu_0 i$
(B)	Along closed loop–2	(q)	$\oint \vec{B}.d\vec{\ell} = -\mu_0 i$
(C)	Along closed loop–3	(r)	$\oint \vec{B}.d\vec{\ell} = 0$
(D)	Along closed loop–4	(s)	Net work done by the magnetic force to move a unit charge along the loop is zero

MG0139

105. **Column-I** (Magnetic moment of) **Column-II**

(A)	a uniformly charged ring rotating uniformly about its axis	(p)	$\frac{q\omega r^2}{5}$
(B)	a charged particle rotating uniformly about a point	(q)	$\frac{q\omega r^2}{4}$
(C)	a uniformly charged disk rotating uniformly about its axis	(r)	$\frac{q\omega r^2}{3}$
(D)	a uniformly charged spherical shell rotating uniformly about one of its diameter	(s)	$\frac{q\omega r^2}{2}$
(E)	a uniformly charged sphere rotating	(t)	$q\omega r^2$

MG0140

EXERCISE (O-2)

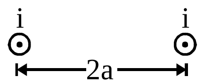
SINGLE CORRECT TYPE QUESTIONS

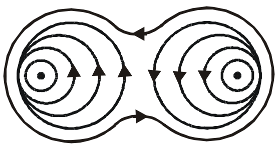
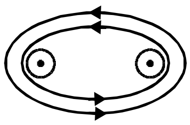
1. A ring like metallic conductor of resistance R and radius a, caries a constant current I. The ratio of the angular momentum L of the conduction electrons (about the axis of the ring) and the magnetic field B at the centre of the ring satisfy [where e and m represent the magnitudes of the electronic charge and mass]

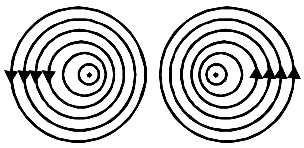
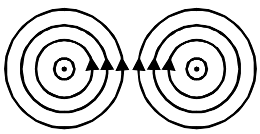
(A) $\frac{B}{L} \propto \frac{e^2}{m}$ (B) $\frac{B}{L} \propto e.m$ (C) $\frac{B}{L} \propto \frac{e}{m}$ (D) $\frac{B}{L} \propto \frac{m}{e}$

MG0141

2. Which of the following field patterns is correct for two long straight equal parallel current carrying wires ?

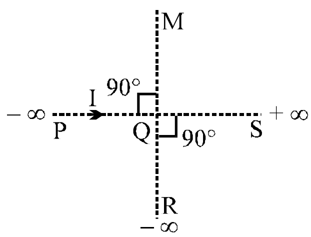


(A)  (B) 

(C)  (D) 

MG0142

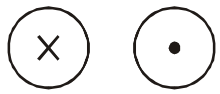
3. An infinitely long conductor PQR is bent to form a right angle as shown. A current I flows through PQR. The magnetic field due to this current at the point M is H_1. Now, another infinitely long straight conductor QS is connected at Q so that the current in PQ remaining unchanged. The magnetic field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



(A) 1/2 (B) 1 (C) 2/3 (D) 2

MG0143

4. Equal antiparallel currents are directed in two parallel wires so that one is out of the page and the other is into the page as shown. Compare the magnitude of the magnetic field B_2 at any arbitrary point equidistant from the wires to the magnitude of the field B_1 at that point from one wire alone :-



(A) $B_2 > B_1$ for all equidistant points
(B) $B_2 < B_1$ for all equidistant points
(C) $B_2 > B_1$ for closer equidistant points only
(D) $B_2 < B_1$ for closer equidistant points only

MG0144

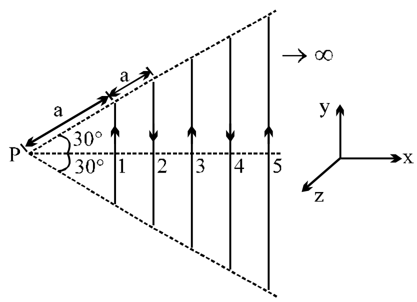
5. A long straight wire along the z-axis carries a current I in the negative z direction. The magnetic vector field $\vec{B}$ at a point having coordinates (x, y) in the z = 0 plane is :- **[JEE 2002 (screening)]**

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

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

MG0145

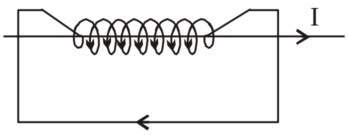
6. Infinite number of straight wires each carrying current I are equally placed as shown in the figure. Adjacent wires have current in opposite direction. Net magnetic field at point P is :-



(A) $\frac{\mu_0 I}{4\pi}\frac{\ln 2}{\sqrt{3}a}\hat{k}$ (B) $\frac{\mu_0 I}{4\pi}\frac{\ln 4}{\sqrt{3}a}\hat{k}$ (C) $\frac{\mu_0 I}{4\pi}\frac{\ln 4}{\sqrt{3}a}(-\hat{k})$ (D) Zero

MG0146

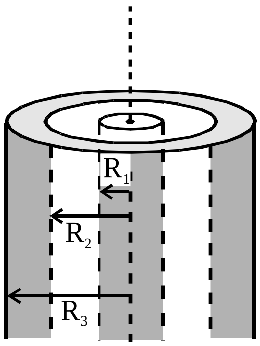
7. In the diagram shown, a wire carries current I. What is the value of the $\oint \vec{B}\cdot d\vec{s}$ (as in Ampere's law) on the helical loop shown in the figure? The integration in done in the sense shown. The loop has N turns and part of helical loop on which arrows are drawn is outside the plane of paper.

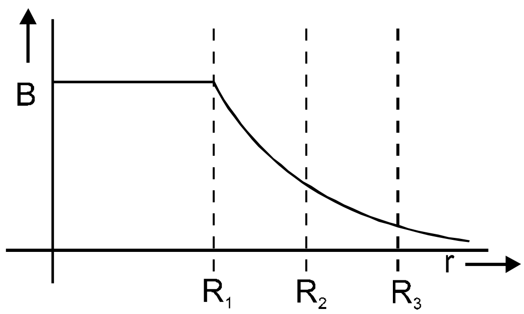


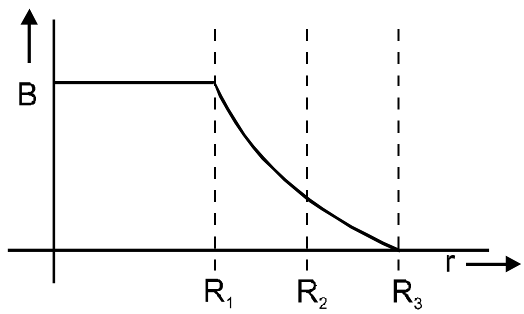
(A) – μ_0(NI) (B) μ_0(I) (C) μ_0(NI) (D) Zero

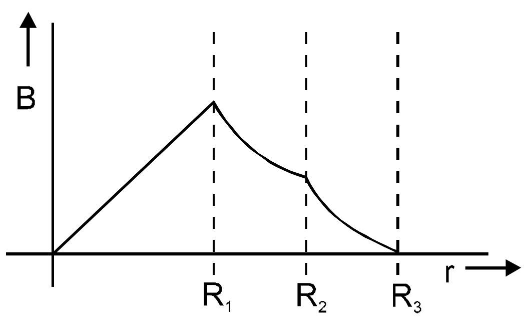
MG0147

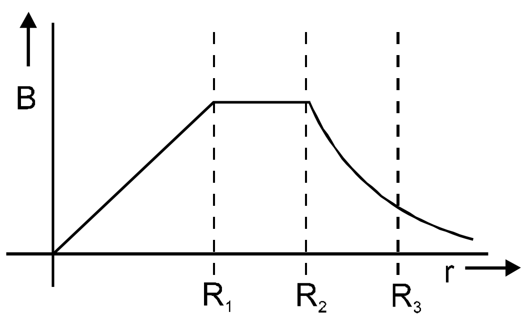
8. A coaxial cable is made up of two conductors. The inner conductor is solid and is of radius R_1 & the outer conductor is hollow of inner radius R_2 and outer radius R_3. The space between the conductors is filled with air. The inner and outer conductors are carrying currents of equal magnitudes and in opposite directions. Then the variation of magnetic field with distance from the axis is best plotted as:



(A)


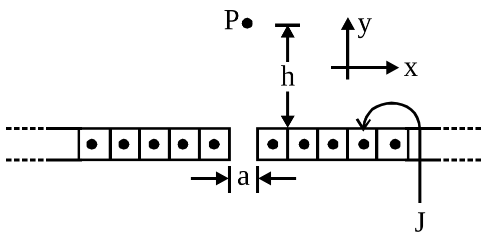
(B)


(C)


(D)


MG0148

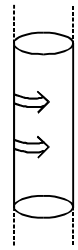
9. A small segment of length a is cut along z-axis from a infinite sheet having a surface current density J (current per unit width). The magnetic field at P is :-



(A) $2\mu_0 J\left(1-\frac{h}{a\pi}\right)\hat{i}$ (B) $\frac{\mu_0 Jh}{2a\pi}\hat{i}$ (C) $\frac{\mu_0 J}{2}\left(\frac{a}{h\pi}-1\right)\hat{i}$ (D) $-\frac{\mu_0 j}{2}\left(\frac{h}{a\pi}-1\right)\hat{i}$

MG0149

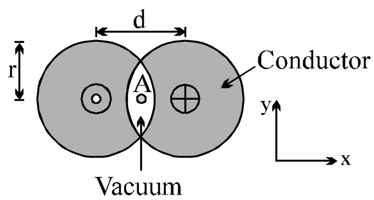
10. A hollow cylinder having infinite length and carrying uniform current per unit length λ along the circumference as shown. Magnetic field inside the cylinder is :-



(A) $\frac{\mu_0\lambda}{2}$ (B) $\mu_0\lambda$ (C) $2\mu_0\lambda$ (D) none

MG0150

11. Two long conductors are arranged as shown above to form overlapping cylinders, each of radius r, whose centers are separated by a distance d. Current of density J flows into the plane of the page along the shaded part of one conductor and an equal current flows out of the plane of the page along the shaded portion of the other, as shown. What are the magnitude and direction of the magnetic field at point A?



(A) $(\mu_0/2\pi)\pi dJ$, in the +y-direction (B) $(\mu_0/2\pi)d^2/r$, in the +y-direction
(C) $(\mu_0/2\pi)4d^2J/r$, in the –y-direction (D) $(\mu_0/2\pi)Jr^2/d$, in the –y-direction

MG0151

12. 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 **[JEE 2000 (Scr)]**

(A) positive ions deflect towards +y direction and negative ions towards –y direction

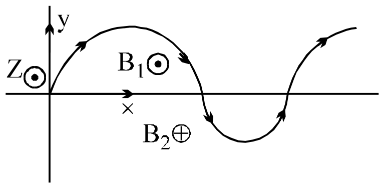
(B) all ions deflect towards +y direction.

(C) all ions deflect towards –y direction

(D) positive ions deflect towards –y direction and negative ions towards +y direction.

MG0152

13. At t = 0 a charge q is at the origin and moving in the y-direction with velocity $\vec{v} = v\hat{j}$. The charge moves in a magnetic field that is for y > 0 out of page and given by $B_1\hat{z}$ and for y < 0 into the page and given $-B_2\hat{z}$. The charge's subsequent trajectory is shown in the sketch. From this information, we can deduce that



(A) q > 0 and $|B_1| < |B_2|$ (B) q < 0 and $|B_1| < |B_2|$

(C) q > 0 and $|B_1| > |B_2|$ (D) q < 0 and $|B_1| > |B_2|$

MG0153

14. A particle of specific charge (charge/mass) α starts moving from the origin under the action of an electric field $\vec{E} = E_0\hat{i}$ and magnetic field $\vec{B} = B_0\hat{k}$. Its velocity at $(x_0, y_0, 0)$ is $(4\hat{i} - 3\hat{j})$. The value of x_0 is:

(A) $\frac{13}{2}\frac{\alpha E_0}{B_0}$ (B) $\frac{16\alpha B_0}{E_0}$ (C) $\frac{25}{2\alpha E_0}$ (D) $\frac{5\alpha}{2B_0}$

MG0154

15. A particle of specific charge (q/m) is projected from the origin of coordinates with initial velocity [u**i** – v**j**]. Uniform electric and magnetic fields exist in the region along the +y direction, of magnitude E and B. The particle will definitely return to the origin once if

(A) $[vB/2\pi E]$ is an integer (B) $(u^2 + v^2)^{1/2}$ $[B/\pi E]$ is an integer

(C) $[vB/\pi E]$ in an integer (D) $[uB/\pi E]$ is an integer

MG0155

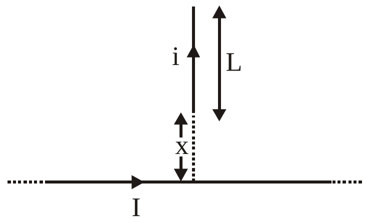
16. An electron moving with a velocity $\vec{V}_1 = 2\hat{i}$ m/s at a point in a magnetic field experiences a force $\vec{F}_1 = -2\hat{j}N$. If the electron is moving with a velocity $\vec{V}_2 = 2\hat{j}$ m/s at the same point, it experiences a force $\vec{F}_2 = +2\hat{i}\,N$. The force the electron would experience if it were moving with a velocity $\vec{V}_3 = 2\hat{k}$ m/s at the same point is

(A) zero (B) $2\hat{k}N$

(C) $-2\hat{k}N$ (D) information is insufficient

MG0156

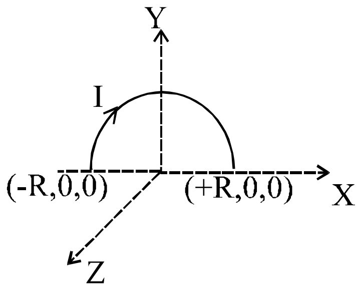
17. The magnetic force between wires as shown in figure is :-



(A) $\frac{\mu_0 i I^2}{2\pi}\ell n\left(\frac{x+\ell}{2x}\right)$ (B) $\frac{\mu_0 i I^2}{2\pi}\ell n\left(\frac{2x+\ell}{2x}\right)$ (C) $\frac{\mu_0 i I}{2\pi}\ell n\left(\frac{x+\ell}{x}\right)$ (D) None of these

MG0157

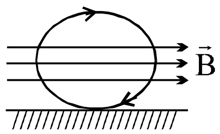
18. A semi circular current carrying wire having radius R is placed in x-y plane with its centre at origin 'O'. There is non-uniform magnetic field $\vec{B}=\frac{B_o x}{2R}\hat{k}$ (here B_o is +ve constant) is existing in the region. The magnetic force acting on semi circular wire will be along :-



(A) – x-axis (B) + y-axis (C) – y-axis (D) + x-axis

MG0158

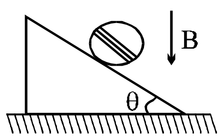
19. A conducting ring of mass 2 kg and radius 0.5 m is placed on a smooth horizontal plane. The ring carries a current i = 4A. A horizontal magnetic field B = 10T is switched on at time t = 0 as shown in figure. The initial angular acceleration of the ring will be :-



(A) 40 π rad/s² (B) 20 π rad/s² (C) 5 π rad/s² (D) 15 π rad/s²

MG0159

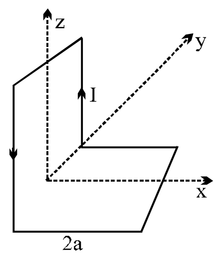
20. In the figure shown a coil of single turn is wound on a sphere of radius R and mass m. The plane of the coil is parallel to the plane and lies in the equatorial plane of the sphere. Current in the coil is i. The value of B if the sphere is in equilibrium is :-



(A) $\frac{mg\cos\theta}{\pi iR}$ (B) $\frac{mg}{\pi iR}$ (C) $\frac{mg\tan\theta}{\pi iR}$ (D) $\frac{mg\sin\theta}{\pi iR}$

MG0160

21. 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 :- **[JEE, 2001 (Scr)]**



(A) $\frac{1}{\sqrt{2}}(-\hat{j}+\hat{k})$ (B) $\frac{1}{\sqrt{3}}(-\hat{j}+\hat{k}+\hat{i})$ (C) $\frac{1}{\sqrt{3}}(\hat{i}+\hat{j}+\hat{k})$ (D) $\frac{1}{\sqrt{2}}(\hat{i}+\hat{k})$

MG0161

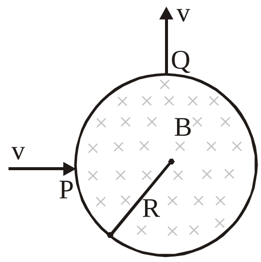
22. Two protons move parallel to each other, keeping distance r between them, both moving with same velocity $\vec{V}$. Then the ratio of the electric and magnetic force of interaction between them is :-

(A) c^2/V^2 (B) $2c^2/V^2$ (C) $c^2/2V^2$ (D) None

MG0162

MULTIPLE CORRECT TYPE QUESTIONS

23. A particle of charge 'q' and mass 'm' enters normally (at point P) in a region of magnetic field with speed v. It comes out normally from Q after time T as shown in figure. The magnetic field B is present only in the region of radius R and is uniform. Initial and final velocities are along radial direction and they are perpendicular to each other. For this to happen, which of the following expression(s) is/are **CORRECT** :-



(A) $B = \frac{mv}{qR}$ (B) $T = \frac{\pi R}{2v}$ (C) $T = \frac{\pi m}{2qB}$ (D) None of these

MG0163

24. A particle of mass m and charge q moving with velocity $\vec{v}$ enters a region of uniform magnetic field of induction $\vec{B}$. Then

(A) its path in the region of the field is always circular

(B) its path in the region of the field is circular if $\vec{v}.\vec{B}=0$

(C) its path in the region of the field is a straight line if $\vec{v}\times\vec{B}=0$

(D) distance travelled by the particle in time T does not depend on the angle between $\vec{v}$ and $\vec{B}$

MG0164

MATRIX MATCH TYPE QUESTION

25. A charged particle with some initial velocity is projected in a region where uniform electric and/or magnetic fields are present. In Column-I information about the existence of electric and/or magnetic field and direction of initial velocity of charged particle are given, while in column-II the possible paths of charged particle is mentioned. Match the entries of Column I with the entries of Column-II.

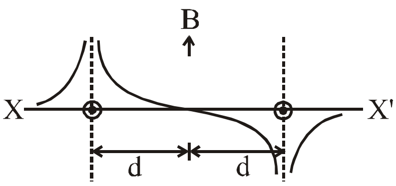
Column–I	**Column–II**
(A) $\vec{E} = 0, \vec{B} \neq 0$ and initial velocity is at an unknown angle with $\vec{B}$	(P) Straight line
(B) $\vec{E} \neq 0, \vec{B} = 0$ and initial velocity is at an unknown angle with $\vec{E}$	(Q) Parabola
(C) $\vec{E} \neq 0, \vec{B} \neq 0, \vec{E} \parallel \vec{B}$ and initial velocity is perpendicular to $\vec{E}$	(R) Circular
(D) $\vec{E} \neq 0, B \neq 0, \vec{E}$ is perpendicular to $\vec{B}$ and initial velocity is perpendicular to both $\vec{E}$ and $\vec{B}$	(S) Helical path with nonuniform pitch
	(T) Helical path with uniform pitch

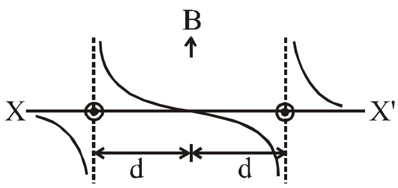
MG0165

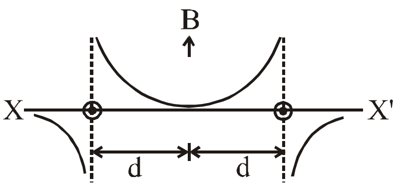
EXERCISE-JM

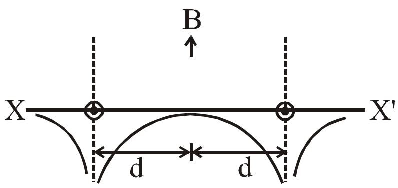
1. Two long parallel wires are at a distance 2d apart. They carry steady equal currents flowing out of the plane of the paper as shown. The variation of the magnetic field B along the line XX' is given by:-

[AIEEE - 2010]

(1) 

(2) 

(3) 

(4) 

MG0166

2. A current I flows in an infinity long wire with cross section in the from of a semicircular ring of radius R. the magnitude of the magnetic induction along its axis is :- **[AIEEE - 2011]**

(1) $\frac{\mu_0 I}{2\pi R}$ (2) $\frac{\mu_0 I}{4\pi R}$ (3) $\frac{\mu_0 I}{\pi^2 R}$ (4) $\frac{\mu_0 I}{2\pi^2 R}$

MG0167

3. An electric charge + q moves with velocity $\vec{V} = 3\hat{i} + 4\hat{j} + \hat{k}$, in an electromagnetic field given by $\vec{E} = 3\hat{i} + \hat{j} + 2\hat{k}$ $\vec{B} = \hat{i} + \hat{j} - 3\hat{k}$. The y-component of the force experienced by + q is :

[AIEEE - 2010]

(1) 2 q (2) 11 q (3) 5 q (4) 3q

MG0168

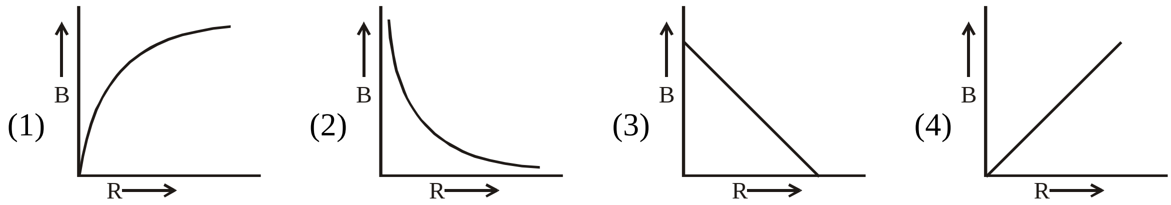
4. A thin circular disk of radius R is uniformly charged with density $\sigma > 0$ per unit area. The disk rotates about its axis with a uniform angular speed ω. The magnetic moment of the disk is :-

[AIEEE - 2011]

(1) $2\pi R^4\sigma\omega$ (2) $\pi R^4\sigma\omega$ (3) $\frac{\pi R^4}{2}\sigma\omega$ (4) $\frac{\pi R^4}{4}\sigma\omega$

MG0169

5. 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 :- **[AIEEE-2012]**



MG0170

6. 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 20.0cm. The value of the resultant horizontal magnetic induction at the midpoint O of the line joining their centres is close to :- (Horizontal component of earth's magnetic induction is 3.6×10^{-5} Wb/m^2)

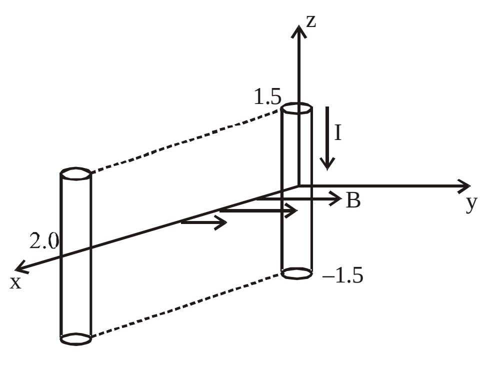
[JEE(Mains) - 2013]

(1) 3.6×10^{-5} Wb/m^2 (2) 2.56×10^{-4} Wb/m^2
(3) 3.50×10^{-4} Wb/m^2 (4) 5.80×10^{-4} Wb/m^2

MG0171

7. 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 $\vec{B} = 3.0 \times 10^{-4} e^{-0.2x} \hat{a}_y$ 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(Mains) - 2014]



(1) 14.85 W (2) 29.7 W (3) 1.57 W (4) 2.97 W

MG0172

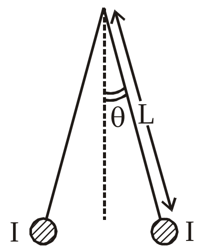
8. The coercivity of a small magnet where the ferromagnet gets demagnetized is 3×10^3 A m^{-1}. The current required to be passed in a solenoid of length 10 cm and number of turns 100, so that the magnet gets demagnetized when inside the solenoid, is : **[JEE(Mains) - 2014]**

(1) 3A (2) 6 A (3) 30 mA (4) 60 mA

MG0173

9. Two long current carrying thin wires, both with current I, are held by the 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 :- (g = gravitational acceleration)

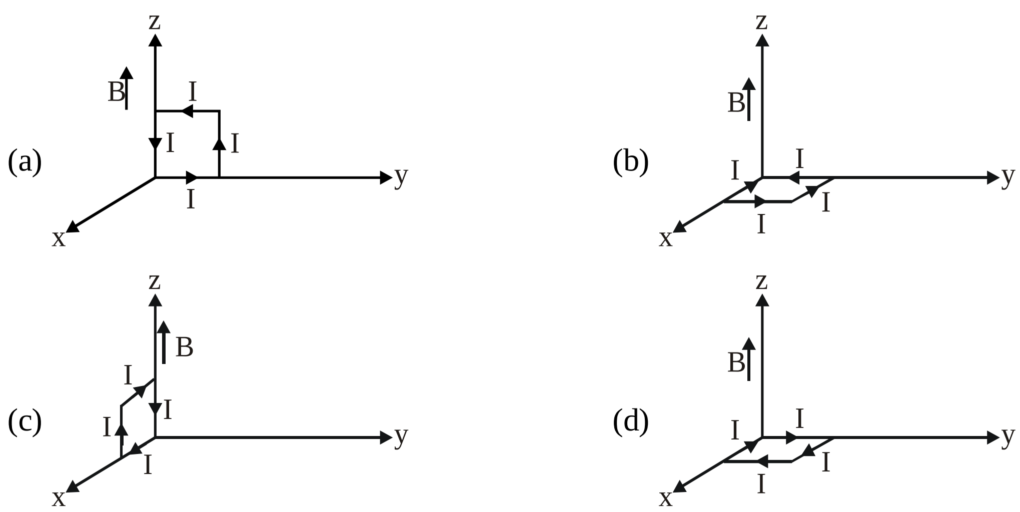
[JEE(Mains) - 2015]



(1) $2\sqrt{\frac{\pi g L}{\mu_0}\tan\theta}$ (2) $\sqrt{\frac{\pi\lambda g L}{\mu_0}\tan\theta}$ (3) $\sin\theta\sqrt{\frac{\pi\lambda g L}{\mu_0\cos\theta}}$ (4) $2\sin\theta\sqrt{\frac{\pi\lambda g L}{\mu_0\cos\theta}}$

MG0174

10. A rectangular loop of sides 10 cm and 5 cm carrying a current I of 12 A is place in different orientations as shown in the figures below : **[JEE(Mains) - 2015]**



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 ?

(1) (b) and (d), respectively
(2) (b) and (c), respectively
(3) (a) and (b), respectively
(4) (a) and (c), respectively

MG0175

11. Two coaxial solenoids of different radii carry current I in the same direction. Let $\vec{F_1}$ be the magnetic force on the inner solenoid due to the outer one and $\vec{F_2}$ be the magnetic force on the outer solenoid due to the inner one. Then : **[JEE Main-2015]**

(1) $\vec{F_1}$ is radially inwards and $\vec{F_2} = 0$

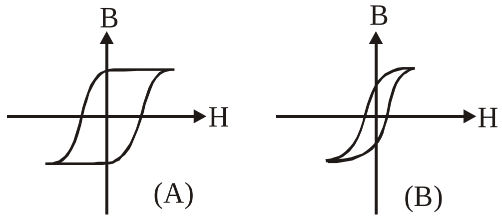
(2) $\vec{F_1}$ is radially outwards and $\vec{F_2} = 0$

(3) $\vec{F_1} = \vec{F_2} = 0$

(4) $\vec{F_1}$ is radially inwards and $\vec{F_2}$ is radially outwards.

MG0176

12. Hysteresis loops for two magnetic materials A and B are given below :



These materials are used to make magnets for electric generators, transformer core and electromagnet core. Then it is proper to use ; **[JEE Main-2016]**

(1) B for electromagnets and transformers.

(2) A for electric generators and transformers.

(3) A for electromagnets and B for electric transformers.

(4) A for transformers and B for electric generators.

MG0177

13. 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]**

(1) $\frac{\pi^2}{8\sqrt{2}}$ (2) $\frac{\pi^2}{8}$ (3) $\frac{\pi^2}{16\sqrt{2}}$ (4) $\frac{\pi^2}{16}$

MG0178

14. A magnetic needle of magnetic moment 6.7×10^{-2} Am^2 and moment of inertia 7.5×10^{-6} kg m^2 is performing simple harmonic oscillations in a magnetic field of 0.01 T. Time taken for 10 complete oscillations is : **[JEE Main-2017]**

(1) 6.98 s (2) 8.76 s (3) 6.65 s (4) 8.89 s

MG0179

15. An electron, a proton and an alpha particle having the same kinetic energy are moving in circular orbits of radii r_e, r_p, r_α respectively in a uniform magnetic field B. The relation between r_e, r_p, r_α is:- **[JEE Main-2018]**

(1) $r_e < r_p = r_\alpha$ (2) $r_e < r_p < r_\alpha$ (3) $r_e < r_\alpha < r_p$ (4) $r_e > r_p = r_\alpha$

MG0180

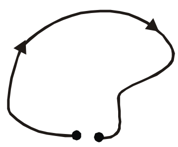
16. The dipole moment of a circular loop carrying a current I, is m and the magnetic field at the centre of the loop is B_1. When the dipole moment is doubled by keeping the current constant, the magnetic field at the centre of the loop is B_2. The ratio $\frac{B_1}{B_2}$ is : **[JEE Main-2018]**

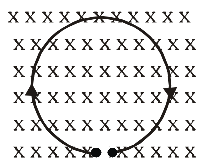
(1) $\sqrt{3}$ (2) $\sqrt{2}$ (3) $\frac{1}{\sqrt{2}}$ (4) 2

MG0181

EXERCISE-JA

1. A thin flexible wire of length L is connected to two adjacent fixed points and carries a current I in the clockwise direction, as shown in the figure. When the system is put in a uniform magnetic field of strength B going into the plane of the paper, the wire takes the shape of a circle. The tension in the wire is : **[2010, 3M]**



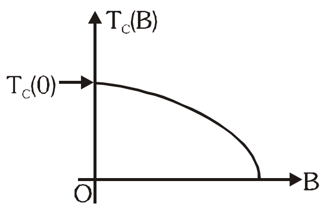


(A) IBL (B) $\frac{IBL}{\pi}$ (C) $\frac{IBL}{2\pi}$ (D) $\frac{IBL}{4\pi}$

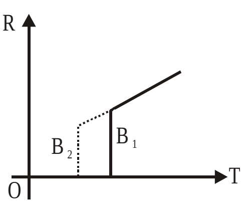
MG0182

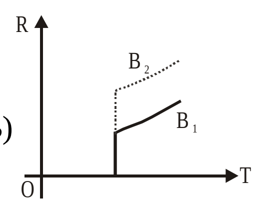
Paragraph for Question no. 2 and 3

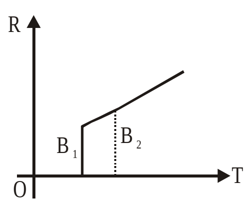
Electrical resistance of certain materials, known as superconductors, changes abruptly from a nonzero value to zero as their temperature is lowered below a critical temperature $T_C(0)$. An interesting property of superconductors is that their critical temperature becomes smaller than $T_C(0)$ if they are placed in a magnetic field, i.e., the critical temperature $T_C(B)$ is a function of the magnetic field strength B. The dependence of T_C (B) on B is shown in the figure. **[JEE2010]**

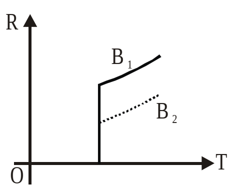


2. In the graphs below, the resistance R of a superconductor is shown as a function of its temperature T for two different magnetic fields B_1(sold line) and B_2 (dashed line). If B_2 is larger than B_1, which of the following graphs shows the correct variation of R with T in these fields?

(A) 

(B) 

(C) 

(D) 

MG0183

3. A superconductor has $T_C(0) = 100$ K. When a magnetic field of 7.5 Tesla is applied, its T_C decreases to 75 K. For this material one can definitely say that when

(A) B = 5 Tesla, T_C (B) = 80 K (B) B = 5 Tesla, 75 K < T_C(B) < 100 K

(C) B = 10 Tesla, 75 K < T_C(B) < 100K (D) B = 10 Tesla, T_C(B) = 70 K

MG0184

4. 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? **[IIT-JEE 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 of the same time

(D) they will come out at different times

MG0185

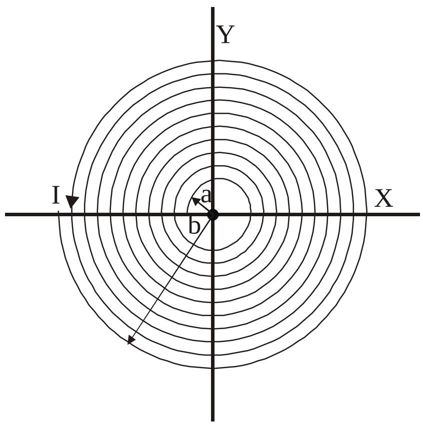
5. A long insulated copper wire is closely wound as a spiral of 'N' turns. The spiral has inner radius 'a' and outer radius 'b'. The spiral lies in the X-Y plane and a steady current '*I*' flows through the wire. The Z-component of the magnetic field at the center of the spiral is **[IIT-JEE 2011]**

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



MG0186

6. 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 x-y plane, making an angle θ with the x-axis. Which of the following option (s) is (are) correct for time t > 0? **[IIT-JEE 2012]**

(A) If θ = 0°, the charge moves in a circular path in the x-z plane.

(B) If θ = 0°, the charge undergoes helical motion with constant pitch along the y-axis.

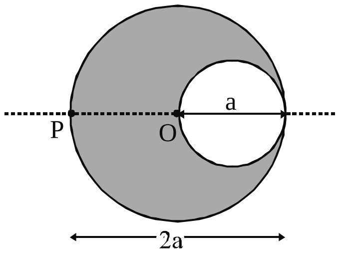
(C) If θ = 10°, the charge undergoes helical motion with its pitch increasing with time, along the y-axis

(D) If θ = 90°, the charge undergoes linear but accelerated motion along the y-axis

MG0187

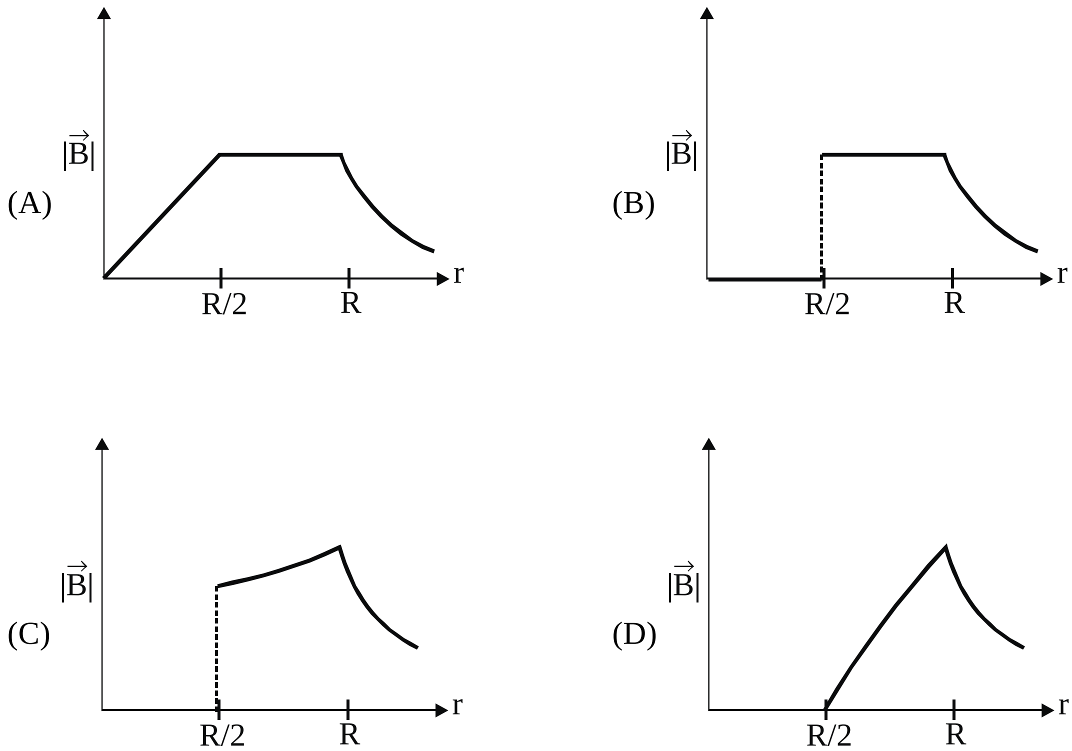
7. A cylindrical cavity of diameter a exists inside a cylinder of diameter 2a as shown in the figure. Both the cylinder and the cavity are infinitely long. A uniform current density J flows along the length. If the magnitude of the magnetic field at the point P is given by $\frac{N}{12}\mu_0 aJ$, then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

[IIT-JEE 2012]



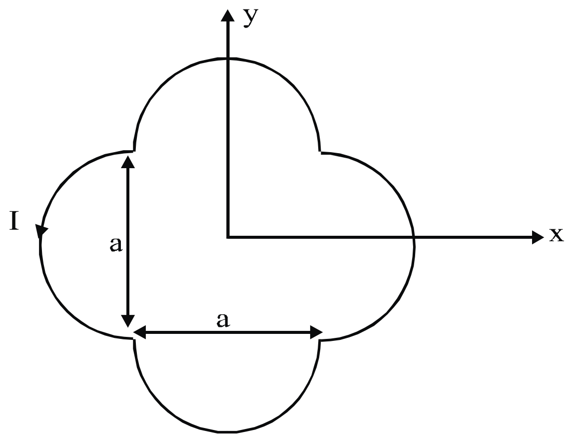
MG0188

8. 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 **[IIT-JEE 2012]**



MG0189

9. 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 **[JEE 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) $(2\pi+1)a^2 I\hat{k}$

MG0190

10. A particle of mass M and positive charge Q, moving with a constant velocity $\vec{u}_1 = 4\hat{i}\,ms^{-1}$, 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 from all values of y. After passing through this region, the particle emerges on the other side after 10 milliseconds with a velocity $\vec{u}_2 = 2\left(\sqrt{3}\hat{i}+\hat{j}\right)ms^{-1}$. The correct statements(s) is (are) :- **[IIT-JEE 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.

MG0191

11. 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-Advanced-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, centred on the axis

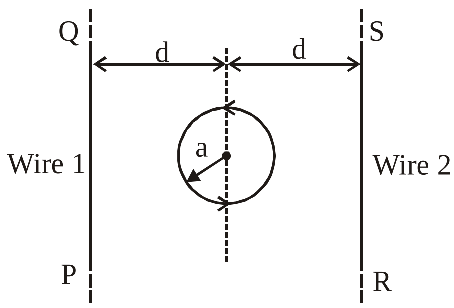
(D) In the region r > 2R, the magnetic field is non-zero

MG0192

12. 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 $\frac{X_0}{X_1} = 3$, and value of $\frac{R_1}{R_2}$ is:- **[JEE-Advanced-2014]**

Paragraph for Questions 13 & 14

The figure shows a circular loop of radius a with two long parallel wires (numbered 1 and 2) all in the plane of the paper. The distance of each wire from the centre of the loop is d. The loop and the wires are carrying the same current I. The current in the loop is in the counterclockwise direction if seen from above. **[JEE-Advanced-2014]**



MG0193

13. When d ≈ a but wires are not touching the loop, it is found that the net magnetic field on the axis of the loop is zero at a height h above the loop. In that case

(A) current in wire 1 and wire 2 is the direction PQ and RS, respectively and h ≈ a

(B) current in wire 1 and wire 2 is the direction PQ and SR, respectively and h ≈ a

(C) current in wire 1 and wire 2 is the direction PQ and SR, respectively and h ≈ 1.2 a

(D) current in wire 1 and wire 2 is the direction PQ and RS, respectively and h ≈ 1.2 a

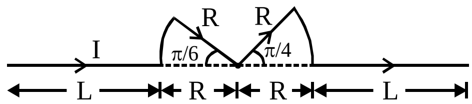
MG0194

14. 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-Advanced-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) $\frac{\sqrt{3}\mu_0 I^2 a^2}{2d}$

MG0195

15. A conductor (shown in the figure) carrying constant current I is kept in the x-y plane in a unfirom 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-Advanced-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 $\hat{z}$, $F = 0$

Answer Q.16, Q.17 and Q.18 by appropriately matching the information given in the three columns of the following table.

A charged particle (electron or proton) is introduced at the origin (x = 0, y = 0, z = 0) with a given initial velocity $\vec{v}$. A uniform electric field $\vec{E}$ and a uniform magnetic field $\vec{B}$ exist everywhere. The velocity $\vec{v}$, electric field $\vec{E}$ and magnetic field $\vec{B}$ are given in column 1, 2 and 3, respectively. The quantities E_0, B_0 are positive in magnitude. **[JEE-Advanced-2017]**

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

MG0196

16. In which case will the particle move in a straight line with constant velocity ?

(A) (II) (iii) (S) (B) (IV) (i) (S) (C) (III) (ii) (R) (D) (III) (iii) (P)

MG0197

17. In which case will the particle describe a helical path with axis along the positive z-direction ?

(A) (II) (ii) (R) (B) (IV) (ii) (R) (C) (IV) (i) (S) (D) (III) (iii) (P)

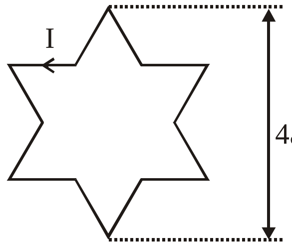
MG0198

18. In which case would the particle move in a straight line along the negative direction of y-axis (i.e., move along $-\hat{y}$) ?

(A) (IV) (ii) (S) (B) (III) (ii) (P) (C) (II) (iii) (Q) (D) (III) (ii) (R)

MG0199

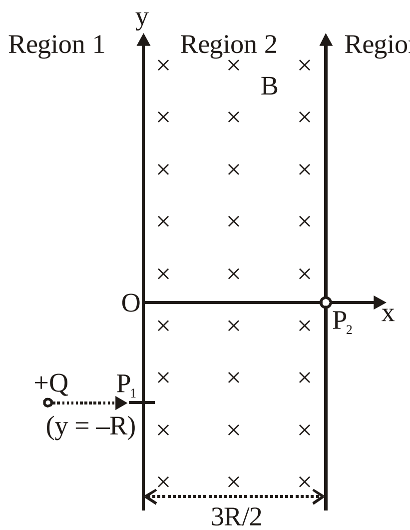
19. A symmetric star shaped conducting wire loop is carrying a steady state current I as shown in the figure. The distance between the diametrically opposite vertices of the star is 4a. The magnitude of the magnetic field at the center of the loop is : **[JEE-Advanced-2017]**



(A) $\frac{\mu_0 I}{4\pi a}3\left[\sqrt{3}-1\right]$ (B) $\frac{\mu_0 I}{4\pi a}6\left[\sqrt{3}-1\right]$ (C) $\frac{\mu_0 I}{4\pi a}6\left[\sqrt{3}+1\right]$ (D) $\frac{\mu_0 I}{4\pi a}3\left[2-\sqrt{3}\right]$

MG0200

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



(A) For $B=\frac{8}{13}\frac{p}{QR}$, the particle will enter region 3 through the point P_2 on x-axis

(B) For $B>\frac{2}{3}\frac{p}{QR}$, the particle will re-enter region 1

(C) For a fixed B, particle of same charge Q and same velocity v, the distance between the point P_1 and the point of re-entry into region 1 is inversely proportional to the mass of the particle.

(D) When the particle re-enters region 1 through the longest possible path in region 2, the magnitude of the chage in its linear momentum between point P_1 and the farthest point from y-axis is $\frac{p}{\sqrt{2}}$.

MG0201

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

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

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

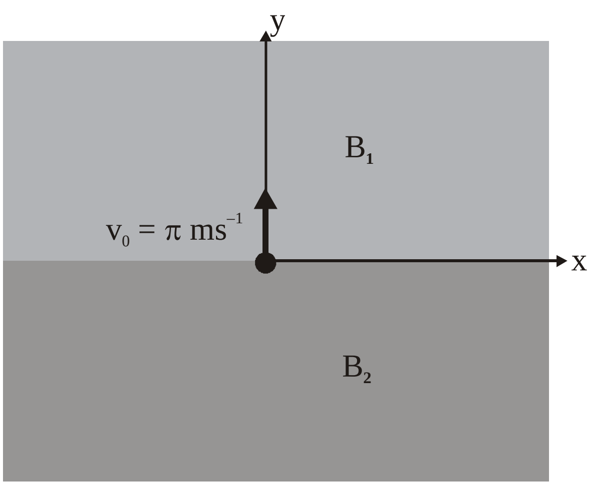
(C) If $I_1 < 0$ and $I_2 > 0$, then $\vec{B}$ can be equal to zero at the origin (0, 0, 0)

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

MG0202

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

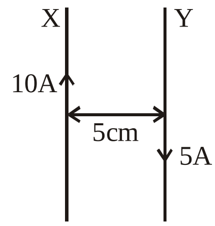
[JEE-Advanced-2018]



MG0203

MAGNETIC EFFECT OF CURRENT
(CBSE Previous Year's Questions)

1. Two long parallel straight wires X and Y separated by a distance of 5 cm in air carry currents of 10 A and 5 A respectively in opposite directions. Calculate the magnitude and direction of the force on a 20cm length of the wire Y.

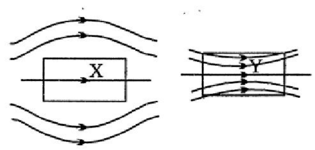


A circular coil of 100 turns, radius 10 cm carries a current of 5 A. it is suspended vertically in a uniform horizontal magnetic field of 0.5 T, the field lines making an angle of 60° with the of the plane of the coil. Calculate of the torque must be applied on it to prevent it from turning. **[2;CBSE-2004]**

2. Using Biot-Savart law, deduce an expression for the magnetic field on the axis of a circular current loop. Draw the magnetic field lines due to a circular current carrying loop. **[3; CBSE-2004]**

3. A hydrogen ion of mass 'm' and chargef 'q' travels with a speed 'v' in a circle of radius 'r' in a magnetic field of intensity 'B'. Write the equation in terms of these quantities only, relating the force on the ion to the required centripetal force. Hence derive an expression for its time period. **[3; CBSE-2004]**

4. A uniform magnetic field gets modified as shown below, when two specimens X and Y are placed in it



(i) Identify the two specimens X and Y.
(ii) State the reason for the behaviour of the field lines in X and Y. **[3; CBSE-2004]**

5. Two wires of equal lengths are bent in the form of two loops. One of the loops is square shaped whereas the other loop is circular. These are suspended in a uniform magnetic field and the same current is passed through them. Which loop will experience greater torque? Give reasons. **[1; CBSE-2005]**

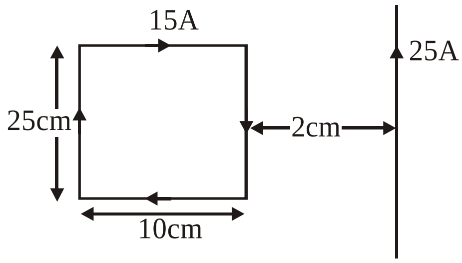
6. Write two characteristic properties to distinguish between diamagnetic and paramagnetic materials. **[2; CBSE-2005]**

7. Explain the principle and working of a cyclotron with the help of a Labeled diagram. A cyclotron's oscillator frequency is 10 Mhz. What should be the operating magnetic field for accelerating protons? If the radius of its 'dees' is 60 cm, what is the kinetic energy of the proton beam produced by the accelerator? Express your answer in units of Me V.
($e = 1.6 \times 10^{-19}$ C, $m_p = 1.67 \times 10^{-27}$ Kg, lMeV = 1.602×10^{-13} J) **[5; CBSE-2005]**

8. Depict the magnetic field lines due to two straight, long, parallel conductors carrying currents I_1 and I_2 in the same direction. Hence deduce an expression for the force acting per unit length on one conductor due to the other. Is this force attractive or repulsive?

Figure shows a rectangular current-carrying loop placed 2 cm away from a long, straight, current-carrying conductor. What is the direction and magnitude of the net force acting on the loop?

[5; CBSE-2005]



9. Steel is preferred for making permanent magnets whereas soft iron is preferred for making electromagnets. Give one reason. **[1; CBSE-2006]**

10. Draw a neat and labelled diagram of a cyclotron. State the underlying principle and explain how a positively charged particle gets accelerated in this machine. Show mathematically that the cyclotron frequency does not depend upon the speed of the particle. **[5; CBSE-2006]**

11. State the Biot - Savart law for the magnetic field due to a current carrying element. Use this law to obtain a formula for magnetic field at the centre of a circular loop of radius R carrying a steady current I. Sketch the magnetic field lines for a current loop clearly indicating the direction of the field.

[5; CBSE-2006]

12. An electron is moving along +ve x–axis in the presence of uniform magnetic field along +ve y-axis. What is the direction of the force acting on it ? **[1; CBSE-2007]**

13. Explain, with the help of a labelled diagram, the principle and construction of a cyclotron. Deduce an expression for the cyclotron frequency and show that it does not depend on the speed of the charged particle. **[3; CBSE-2007]**

14. Distinguish the magnetic properties of dia, para- and ferro-magnetic substances in terms of (i) susceptibility, (ii) magnetic permeability and (iii) coercivity. Give one example of each of these materials. Draw the field lines due to an external magnetic field near a (i) diamagnetic, (ii) paramagnetic substance. **[3; CBSE-2007]**

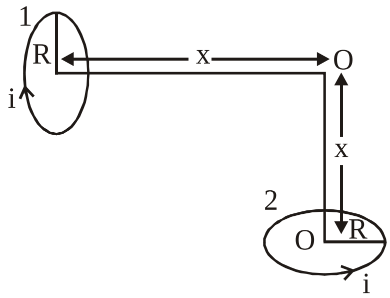
15. What is the direction of the force acting on a charged particle q, moving with a velocity $\vec{v}$ in a uniform magnetic field $\vec{B}$? **[1; CBSE-2008]**

16. Define magnetic susceptibility of a material Name two elements, one having positive susceptibility and the other having negative susceptibility. What does negative susceptibility signify ?

[2; CBSE-2008]

17. (a) Using Biot-Savart's law, derive an expression for the magnetic field at the centre of a circular coil of radius R, number of turns N, carrying current i.

(b) Two small identical circular coils marked 1,2 carry equal currents and are placed with their geometric axes perpendicular to each other as shown in the figure. Derive an expression for the resultant magnetic field at O.

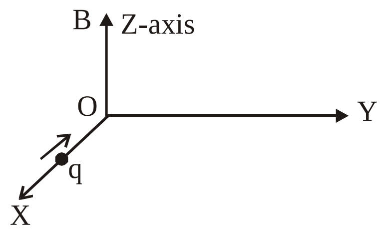


Draw a schematic diagram of a cyclotron. Explain its underlying principle and working, stating clearly the function of the electric and magnetic fields applied on a charged particle. Deduce an expression for the period of revolution and show that it does not depend on the speed of the charged particle.

[5; CBSE-2008]

18. Magnetic field lines can be entirely confined within the core of a toroid, but not within a straight solenoid. Why ? **[l; CBSE-2009]**

19. A charge 'q' moving along the X-axis with a velocity v is subjected to a uniformmagnetic field B acting along the Z-axis as it crosses the origin O.



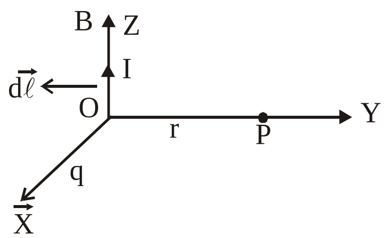
(i) Trace its trajectory.

(ii) Does the charge gain kinetic energy as it enters the magnetic field? Justify your answer.

[2; CBSE-2009]

20. State Biot-Savart law.

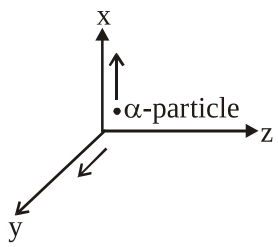
A current I flows in a conductor placed perpendicular to the plane of the paper. Indicate the direction of the magnetic field due to a small element $d\vec{\ell}$ at point P situated at a distance $\vec{r}$ from the element as shown in the figure.



21. Derive the expression for force per unit length between two long straight parallel current carrying conductors. Hence define one ampere. **[3; CBSE-2009]**

22. Explain the principle and working of a cyclotron with the help of a schematic diagram. Write the expression for cyclotron frequency. **[3; CBSE-2009]**

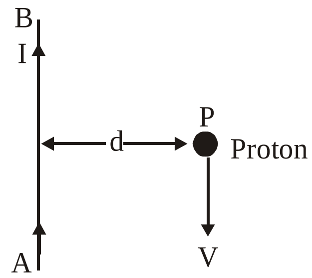
23. A beam of α particle projected along +x-axis, experiences a force due to a magnetic field along the +y – axis. What is the direction of the magnetic field? **[1; CBSE-2010]**



24. Deduce the expression for the magnetic dipole moment of an electron orbiting around the central nucleus. **[2; CBSE-2010]**

25. (a) With the help of a diagram, explain the principle and working of a moving coil galvanometer.
(b) What is the importance of a radial magnetic field and how is it produced ?
(c) Why is it that whil using a moving coil galvanometer as a voltmeter a high resistance in series is required whereas in an ammeter a shunt is used ? **[5; CBSE-2010]**

26. (a) Derive an expression for the force between two long parallel current carrying conductors.
(b) Use this expression to define S.I. unit of current.
(c) A long straight wire AB carries a current I. A proton P travels with a speed v, parallel to the wire, at a distance d from it in a direction opposite to the current as shown in the figure. What is the force experienced by the proton and what is its direction ? **[5; CBSE-2010]**



27. Where on the surface ofEarth is the angle of dip 90° ? **[1;CBSE-2011]**

28. Write the expression for Lorentz magnetic force on a particle of charge 'q' moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$. Show that no work is done by this force on the charged particle. **[2; CBSE-2011]**

29. A steady current (I_1) flows through a long straight wire. Another wire carrying steady current (I_2) in the same direction is kept close and parallel to the first wire. Show with the help of a diagram how the magnetic field due to the current I_1 exerts a magnetic force on the second wire. Write the expression for this force. **[2; CBSE-2011]**

30. (a) State the principle of the working of moving coil galvanometer, giving its labelled diagram.
(b) "Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity. "Justify this statement.
(c) Outline the necessary steps to convert a galvanometer of resistance R_G into an ammeter of a given range. **[5; CBSE-2011]**

31. (a) Using Ampere's circuital law, obtain the expression for the magnetic field due to a long solenoid at a point inside the solenoid on its axis.
(b) In what respect is a toroid different from a solenoid ? Draw and compare the pattern of the magnetic field lines in the two cases.
(c) How is the magnetic field inside a given solenoid made strong ? **[5; CBSE-2011]**

32. A circular coil of N turns and radius R carries a current I. It is unwound and rewound to make another coil of radius R/2, current I remaining the same. Calculate the ratio of the magnetic moments of the new coil and original coil. **[2; CBSE-2012]**

33. (a) Write the expression for the force, F, acting on a charged particle of charge 'q', moving with a velocity $\vec{v}$ in the presence of both electric field $\vec{E}$ and magnetic field $\vec{B}$. Obtain the condition under which the particle moves undeflected through the fields.
(b) A rectangular loop of size $l \times b$ carrying a steady current I is placed in uniform magnetic field $\vec{B}$. Prove that the torque $\vec{\tau}$ acting on the loop is given by $\vec{\tau} = \vec{m} \times \vec{B}$, where m is the magnetic moment of the loop.

OR

(a) Explain, giving reason, the basic difference in converting a galvanometer into (i) a voltmeter and (ii) an ammeter
(b) Two long straight parallel conductors carrying steady current I_1 and I_2 are separated by a distance 'd' Explain briefly, with the help of a suitable diagram, how the magnetic field due to one conductor acts on the other. Hence deduce the expression for the force acting between the two conductors. Mention the nature of this force. **[5; CBSE-2012]**

34. A wire AB is carrying a steady current of 12 A and is lying on the table. Another wire CD carrying 5 A is held directly above AB at a height of 1 mm. Find the mass per unit length of the wire CD so that it remains suspended at its position when left free. Give the direction of the current flowing in CD with respect to that in AB. [Take the value of g = 10 ms^{-2}] **[CBSE-2013]**

35. (a) Using Biot - Savatfs law, derive the expression for the magnetic field in the vector form at a point on the axis of a circular current loop.
(b) What does a toroid consist of? Find out the expression for the magnetic field inside a toroid for N turns of the coil having the average radius r and carrying a current I. Show that the magnetic field in the open space inside and exterior to the toroid is zero.

OR

(a) Draw a schematic sketch of a cyclotron. Explain clearly the role of crossed electric and magnetic field in accelerating the charge. Hence derive the expression for the kinetic energy acquired by the particles.
(b) An α-particle and a proton are released from the centre of the cyclotron and made to accelerate.
(i) Can both be accelerated at the same cyclotron frequency ? Give reason to justify your answer.
(ii) When they are accelerated in turn, which of the two will have higher velocity at the exit slit of the dees? **[CBSE-2013]**

36. Using the concept of force between two infinitely long parallel current carrying conductors, define one ampere of current. **[CBSE-2014]**

37. Show diagrammatically the behaviour of magnetic field lines in the presence of (i) paramagnetic and (ii) diamagnetic substances. How does one explain this distinguishing feature ? **[CBSE-2014]**

38. (a) Deduce an expression for the frequency of revolution of a charged particle in a magnetic field and show that it is independent of velocity or energy of the particle.

(b) Draw a schematic sketch of a cyclotron. Explain, giving the essential details of its construction, how it is used to accelerate the charged particles.

OR

(a) Draw a labelled diagram of a moving coil galvanometer. Describe briefly its principle and working.

(b) Answer the following:

(i) Why is it necessary to introduce a cylindrical soft iron core inside the coil of a galvanometer ?

(ii) Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity. Explain, giving reason. **[CBSE-2014]**

39. A cyclotron's oscillator frequency is 10 MHz. What should be the operating magneticf field for accelerating protons ? If the radius of its 'dees' is 60 cm, calculate the kinetic energy (in MeV) of the proton beam produced by the accelerator. **[3; CBSE-2015]**

40. Deduce the expression for the torque $\vec{\tau}$ acting on a planar loop of area $\vec{A}$ and carryig current I placed in a uniform magnetic field $\vec{B}$. **[3; CBSE-2015]**

If the loop is free to rotate, what would be its orientation is stable equilibrium ?

41. What can be the cause of helical motion of a charged particle ? **[1; CBSE-2016]**

42. State Ampere's circuital law. Use this law to find magnetic field due to straight infinite current carrying wire. How are the magnetic field lines different from the electrostatic field lines ? **[3; CBSE-2016]**

OR

State the principle of a cyclotron. Show that the time period of revolution of particles in a cyclotron is independent of their speeds. Why is this property neccessary for the operation of a cyclotron ?

43. Seema's uncle was advised by his doctor to have an MRI (Magnetic Resonance Imaging) scan of his brain. Her uncle felt it to be expensive and wanted to postpone it. **[4; CBSE-2016]**

When Seema learnt about this, she took the help of her family and also approached the doctor, who also offered a substantial discount. She then convinced her uncle to undergo the test to enable the doctor to know the condition of his brain. The information thus obtained greatly helped the doctor to treat him properly.

Based on the above paragraph, answer the following questions :

(a) What according to you are the values displayed by Seems, her family and the doctor ?

(b) What could be the possible reason for MRI test to be so expensive ?

(c) Assuming that MRI test was performed using a magnetic field of 0.1 T., find the minimum and maximum values of the force that the magnetic field could exert on a proton (charge = 1.6×10^{-19} C) moving with a speed of 10^4 m/s.

44. (a) When a bar magnet is pushed towards (or away) from the coil connected to a galvanometer, the pointer in the galvanometer deflects. Identify the phenomenon causing this deflection and write the factors on which the amount and direction of the deflection depends. State the laws describing this phenomenon. **[5; CBSE-2016]**

45. Find the condition under which the charged particles moving with different speeds in the presence of electric and magnetic field vectors can be used to select charged particles of a particular speed. **[2; CBSE-2017]**

46. Write two properties of a material suitable for making (a) a permanent magnet, and (b) an electromagnet. **[2; CBSE-2017]**

47. (a) State Biot – Savart law and express this law in the vector form. **[3; CBSE-2017]**

(b) Two identical circular coils, P and Q each of radius R, carrying currents 1A 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.

48. A proton and an electron travelling along parallel paths enter a region of uniform magnetic field, acting perpendicular to their paths. Which of them will move in a circular path with higher frequency? **[3; CBSE-2018]**

49. A bar magnet of magnetic moment of 6J/T is aligned at 60° with a uniform external magnetic field of 0.44 T. Calculate (a) the work done in turning the magnet to align its magnetic moment (i) normal to the magnetic field, (ii) opposite to the magnetic field, and (b) the torque on the magnet in the final orientation in case (ii). **[3; CBSE-2018]**

50. (a) An iron ring of relative permeability μ_r has windings of insulated copper wire of n turns per metre. When the current in the windings is I, find the expression for the magnetic field in the ring.

(b) The susceptibility of a magnetic material is 0.9853. Identify the type of magnetic material. Draw the modification of the field pattern on keeping a piece of this material in a uniform magnetic field. **[3; CBSE-2018]**

ANSWER KEY

EXERCISE (S-1)

1. Ans. (a) zero (b) 2μT along the Z-axis (c) zero and (d) 2μT along the negative Z-axis

2. Ans. 4.0×10^{-5} T, downwards in both the cases

3. Ans. $5\pi \times 10^{-4}$ T = 1.6×10^{-3} T towards west.

4. Ans. $7.07\times 10^{-10}\ \hat{k}T$

5. Ans. At a distance of $\frac{4r}{\pi}$ from the centre in such a way that the direction of the current in it is opposite to that in the nearest part of the circular wire.

6. Ans. (a) 0 (b) 1.41×10^{-6} T, 45° in xz-plane, (c) 5×10^{-6} T, +x-direction]

7. Ans. μ_0 weber.m^{-1}

8. Ans. $\frac{2mv_0}{qB}$

9. Ans. 1.2×10^{-2}m, 4.37×10^{-2}m

10. Ans. (a) Circular trajectory of radius 1.0 mm normal to B.
(b) Helical trajectory of radius 0.5 mm with velocity component 2.3×10^{7} ms^{-1} along B.

11. Ans. (a) A horizontal magnetic field of magnitude 0.26 T normal to the conductor in such a direction that Fleming a left-hand rule gives a magnetic force upward.
(b) 1.176 N.

12. Ans. (a) 3.1 Nm, (b) No, the answer is unchanged because the formula τ = N I A × B is true for a planar loop of any shape.

13. Ans. Use τ = IA × B and F = I1 × B
(a) 1.8×10^{-2} N m along –y direction
(b) same as in (a)
(c) 1.8×10^{-2} N m along –x direction
(d) 1.8×10^{-2} N m at an angle of 240° with the +x direction
(e) zero
(f) zero
Force is zero in each case. Case (e) corresponds to stable, and case (f) corresponds to unstable equilibrium

14. Ans. (a) Zero, (b) zero, (c) force on each electron is evB = IB/(nA) = 5×10^{-25}N. Note : Answer (c) denotes only the magnetic force.

15. Ans. $T_0 = 2\pi\sqrt{\frac{m}{6IB}}$ = 0.57 s

16. Ans. (a) 1.4, (b) 1

EXERCISE (S-2)

1. Ans. $B_1 = \frac{\mu_0 b r_1^2}{3}$, $B_2 = \frac{\mu_0 b R^3}{3r_2}$

2. Ans. $\sqrt{15}$ C

3. Ans. (6.4 m, 0,0) (6.4m, 0, 2m)

4. Ans. i_1 = 0.1110 A, i_2 = 0.096 A

5. Ans. (i) $-\frac{\mu_0 I}{4R} q v_0\ \hat{k}$ (ii) F_1 = 2 I R B F_2 = 2 I R B, Net force = $F_1 + F_2$ = 4 I R B $\hat{i}$

6. Ans. (a) 6.6×10^{-5}T, (b) 0, 0, $2 \times 10^{-5} \ell n\left(\frac{3}{2}\right)$N **7. Ans.** (a) $\frac{3mv^2}{4qa}$, (b) $\frac{3mv^3}{4a}$, (c) zero

8. Ans. $\frac{\mu_0 iqv}{2\pi a}$ **9. Ans.** 5 **10. Ans.** $\frac{mEI}{Be}$ **11. Ans.** 8

12. Ans. 4 **13. Ans.** 020 **14. Ans.** z = 0 , $x = \pm \frac{d}{\sqrt{3}}$, (ii) $\frac{I}{2\pi d}\sqrt{\frac{\mu_0}{\pi\lambda}}$

15. Ans. (a) current in loop PQRS is clockwise from P to QRS., (b) $\vec{F} = BI_0b\,(3\hat{k}-4\hat{i})$, (c) $I = \frac{mg}{6bB_0}$

16. Ans. $F = \alpha a^2 i\ \hat{j}$ **17. Ans.** 4 **18. Ans.** $\omega = \frac{dT_0}{QR^2B}$

19. Ans. (a) k = NAB, (b) $C = \frac{2i_0NAB}{\pi}$, (c) $Q \times \sqrt{\frac{NAB\pi}{2li_0}}$

EXERCISE (O-1)

1. Ans. (B)	**2. Ans. (C)**	**3. Ans. (C)**	**4. Ans. (A)**	**5. Ans. (B)**	**6. Ans. (C)**
7. Ans. (B)	**8. Ans. (A)**	**9. Ans. (B)**	**10. Ans. (D)**	**11. Ans. (A)**	**12. Ans. (C)**
13. Ans. (D)	**14. Ans. (D)**	**15. Ans. (A)**	**16. Ans. (B)**	**17. Ans. (A)**	**18. Ans. (C)**
19. Ans. (C)	**20. Ans. (C)**	**21. Ans. (C)**	**22. Ans. (B)**	**23. Ans. (B)**	**24. Ans. (C)**
25. Ans. (D)	**26. Ans. (D)**	**27. Ans. (B)**	**28. Ans. (B)**	**29. Ans. (C)**	**30. Ans. (B)**
31. Ans. (C)	**32. Ans. (A)**	**33. Ans. (B)**	**34. Ans. (A)**	**35. Ans. (B)**	**36. Ans. (A)**
37. Ans. (B)	**38. Ans. (B)**	**39. Ans. (C)**	**40. Ans. (D)**	**41. Ans. (C)**	**42. Ans. (A)**
43. Ans. (A)	**44. Ans. (B)**	**45. Ans. (D)**	**46. Ans. (C)**	**47. Ans. (C)**	**48. Ans. (C)**
49. Ans. (B)	**50. Ans. (C)**	**51. Ans. (A)**	**52. Ans. (D)**	**53. Ans. (A)**	**54. Ans. (C)**
55. Ans. (B)	**56. Ans. (B)**	**57. Ans. (A)**	**58. Ans. (D)**	**59. Ans. (A)**	**60. Ans. (B)**
61. Ans. (B)	**62. Ans. (A)**	**63. Ans. (C)**	**64. Ans. (A)**	**65. Ans. (A)**	**66. Ans. (B)**
67. Ans. (B)	**68. Ans. (B)**	**69. Ans. (D)**	**70. Ans. (B)**	**71. Ans. (C)**	**72. Ans. (C)**
73. Ans. (B)	**74. Ans. (D)**	**75. Ans. (A)**	**76. Ans. (A)**	**77. Ans. (B)**	**78. Ans. (C)**
79. Ans. (D)	**80. Ans. (B)**	**81. Ans. (C)**	**82. Ans. (C)**	**83. Ans. (B)**	**84. Ans. (C)**
85. Ans. (B)	**86. Ans. (D)**	**87. Ans. (A)**	**88. Ans. (B)**	**89. Ans. (A,B,C)**	

90. Ans. (A,B,C) **91. Ans. (A,B,C)** **92. Ans. (A, C, D)** **93. Ans. (A,C,D)**

94. Ans. (A, C) **95. Ans. (C)** **96. Ans. (B,D)** **97. Ans. (A,D)**

98. Ans. (A,B) **99. Ans. (A)** **100. Ans. (D)** **101. Ans. (C)**

102. Ans. (B) **103. Ans. (D)** **104. Ans. (A)-q,s; (B)-p,s; (C)-q,s; (D)-p,s**

105. Ans. (A)-s; (B)-s; (C)-q; (D)-r; (E)-p

EXERCISE (O-2)

1. Ans. (C) **2. Ans. (A)** **3. Ans. (C)** **4. Ans. (C)** **5. Ans. (A)** **6. Ans. (B)**
7. Ans. (C) **8. Ans. (C)** **9. Ans. (C)** **10. Ans. (B)** **11. Ans. (A)** **12. Ans. (C)**
13. Ans. (A) **14. Ans. (C)** **15. Ans. (C)** **16. Ans. (A)** **17. Ans. (C)** **18. Ans. (A)**
19. Ans. (A) **20. Ans. (B)** **21. Ans. (D)** **22. Ans. (A)** **23. Ans. (A,B,C)**
24. Ans. (B,C,D) **25. Ans. (A) $\rightarrow$ (P,R, T) ; (B) $\rightarrow$ (P,Q) ; (C) $\rightarrow$ (S) ; (D) $\rightarrow$ (P)**

EXERCISE (JM)

1. Ans. (2) **2. Ans. (3)** **3. Ans. (2)** **4. Ans. (4)** **5. Ans. (2)** **6. Ans. (2)**
7. Ans. (4) **8. Ans. (1)** **9. Ans. (4)** **10. Ans. (1)** **11. Ans. (2)** **12. Ans. (1)**
13. Ans. (1) **14. Ans. (3)** **15. Ans. (1)** **16. Ans. (2)**

EXERCISE (JA)

1. Ans. (C) **2. Ans. (A)** **3. Ans. (B)** **4. Ans. (BC,BD, BCD)** **5. Ans. (A)**
6. Ans. (C,D) **7. Ans. 5** **8. Ans. (D)** **9. Ans. (B)** **10. Ans. (A, C)**
11. Ans. (A, D) **12. Ans. 3** **13. Ans. (C)** **14. Ans. (B)** **15. Ans. (A,B,C)**
16. Ans. (A) **17. Ans. (C)** **18. Ans. (D)** **19. Ans. (B)** **20. Ans. (A) (B)**
21. Ans. (A,B,D) **22. Ans. 2 [1.99, 2.01]**