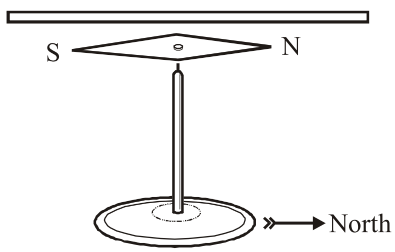
3A

MAGNETIC EFFECTS OF CURRENT

OERSTED EXPERIMENT

Oersted discovered a magnetic field around a conductor carrying electric current. Other related facts are as follows:

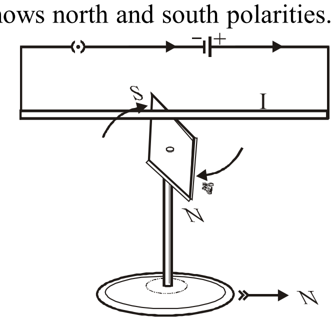
(a) A magnet at rest produces a magnetic field around it while an electric charge at rest produce an electric field around it.



(b) A current carrying conductor has a magnetic field and not an electric field around it. On the other hand, a charge moving with a uniform velocity has an electric as well as a magnetic field around it.

(c) An electric field cannot be produced without a charge whereas a magnetic field can be produced without a magnet.

(d) No poles are produced in a coil carrying current but such a coil shows north and south polarities.



Oersted's experiment. Current in the wire deflects the compass needle.

(e) All oscillating or an accelerated charge produces E.M. waves also in additions to electric and magnetic fields.

Magnetic induction $\vec{B}$ is a vector quantity :
Commonly it is given by the number of lines of induction threading a unit area normal to the surface.

Unit of $\vec{B}$: MKS weber/metre^2, SI tesla,
CGS maxwell/cm^2 or gauss.
One Tesla= one (weber/m^2) = 10^4 (maxwell/cm^2)= 10^4 gauss

BIOT-SAVART'S LAW

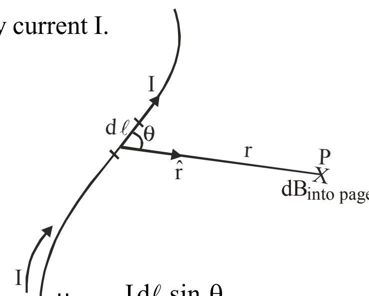
With the help of experimental results, Biot and Savart arrived at a mathematical expression that gives the magnetic field at some point in space in terms of the current that produces the field. That expression is based on the following experimental observations for the magnetic field $d\vec{B}$ at a point P associated with a length element $d\vec{\ell}$ of a wire carrying a steady current I.

$dB \propto I$

$dB \propto d\ell$

$dB \propto \frac{1}{r^2}$

$dB \propto \sin\theta$



Combining all these

$$dB \propto \frac{Id\ell \sin\theta}{r^2} \; ; \quad dB = \frac{\mu_0}{4\pi} \times \frac{Id\ell \sin\theta}{r^2}$$

μ_0 is called permeability of free space

$$\frac{\mu_0}{4\pi} = 10^{-7} \text{ henry/meter.}$$

$$1(\text{H/m}) = 1\frac{\text{T m}}{\text{A}} = 1\frac{\text{Wb}}{\text{Am}} = 1\frac{\text{N}}{\text{A}^2} = 1\frac{\text{Ns}^2}{\text{C}^2}$$

Dimensions of $\mu_0 = [M^1L^1T^{-2}A^{-2}]$

For vacuum : $\sqrt{\frac{1}{\mu_0\varepsilon_0}} = c = 3 \times 10^8$ m/s

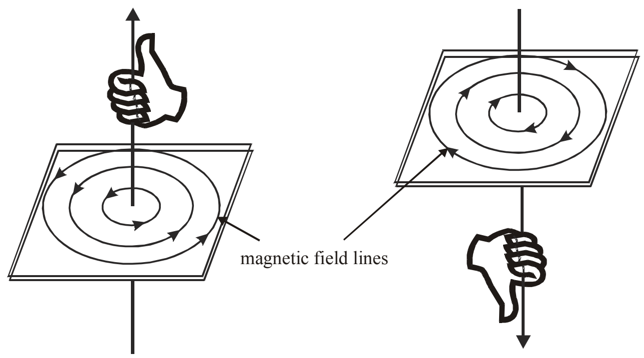
Biot-Savart law in vector form : $\vec{dB} = \frac{\mu_0 I}{4\pi}\frac{(\vec{d\ell} \times \vec{r})}{r^3}$

the direction of $\vec{dB}$ is perpendicular to the plane determined by $d\vec{\ell}$ and $\vec{r}$ (i.e. if $d\vec{\ell}$ and $\vec{r}$ lie in the plane of the paper then $\vec{dB}$ is $\perp$ to plane of the paper). In the figure, direction of $\vec{dB}$ is into the page. (Use right hand screw rule).

RULES TO FIND DIRECTION MAGNETIC FIELD

Right hand thumb rule. If we grasp the conductor in the palm of the right hand so that the thumb points in the direction of the flow of current, then the direction in which the fingers curl, gives the direction of magnetic field lines. For the current flowing through the conductor in the direction shown in fig. (a) or (b), both the rules predict that magnetic field lines will be in anticlockwise direction, when seen from above.

The magnetic field produced by a current-carrying straight conductor is of circular symmetry.

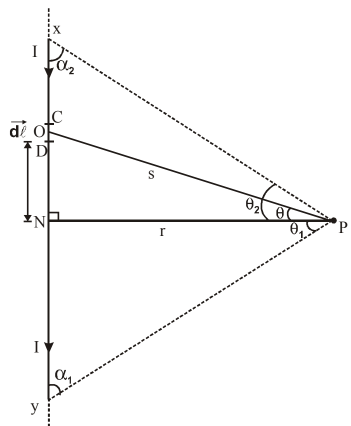


(a) (b)

The magnetic lines of force are concentric circles with the current carrying conductor passing through their common centre. The plane of the magnetic lines of force is perpendicular to the length of the conductor.

MAGNETIC FIELD DUE TO LONG STRAIGHT CONDUCTOR

Consider a long straight conductor XY through which current I is flowing from X to Y. Let P be the observation point at a distance 'r' from the conductor XY. Let us consider an infinitesimally small current element CD of length $d\ell$. Let s be the distance of P from the mid-point O of the current element.



Let θ be the angle which OP makes with the direction of current. The magnetic field at P due to the current element

CD is $dB = \frac{\mu_0}{4\pi}\frac{I\,d\ell\sin\theta}{s^2}$ [Biot-Savart's law]

The mag. field at P due to the whole of the conductor XY

$$B = \int dB = \int_{-\theta_1}^{\theta_2} \frac{\mu_0 I}{4\pi r}\cos\theta\, d\theta$$

$$= \frac{\mu_0 I}{4\pi r}\int_{-\theta_1}^{\theta_2}\cos\theta\, d\theta = \frac{\mu_0 I}{4\pi r}[\sin\theta]_{-\theta_1}^{\theta_2}$$

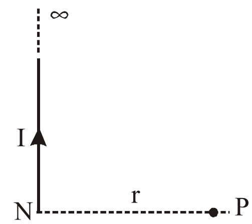
or $B = \frac{\mu_0 I}{4\pi r}[\sin\theta_2 - \sin(-\theta_1)] = \frac{\mu_0 I}{4\pi r}(\sin\theta_1 + \sin\theta_2)$

Case I : If the conductor is infinitely long, then $\theta_1 = 90°$ and $\theta_2 = 90°$

$$B = \frac{\mu_0 I}{4\pi r}\left[\sin\frac{\pi}{2} + \sin\left(\frac{\pi}{2}\right)\right] = \frac{\mu_0 I}{4\pi r}[1+1] = \frac{\mu_0}{4\pi}\frac{2I}{r}$$

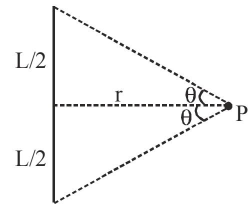
or $B = \frac{\mu_0 I}{2\pi r}$

Case II : If conductor is of infinite length but one end is in front of point P i.e. one end of conductor starts from point N then $\theta_1 = 0°$ and $\theta_2 = 90°$



$$B = \frac{\mu_0 I}{4\pi r}$$

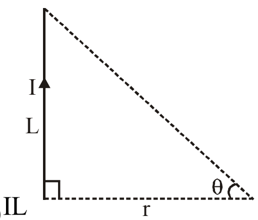
Case III : Conductor is finite length and point P is just in front of middle of the conductor



$$B = \frac{\mu_0 I}{4\pi r}(2\sin\theta)\,;\ \theta_1 = \theta_2 = \theta$$

$$B = \frac{\mu_0 IL}{2\pi r\sqrt{L^2 + r^2}}\ ;\ \sin\theta = \frac{L/2}{\sqrt{\left(\frac{L}{2}\right)^2 + r^2}}$$

Case IV : Conductor is of finite length and one end of it is in front of P.



$\theta_1 = 0\,;\quad \theta_2 = \theta$

$$B = \frac{\mu_0 I}{4\pi r}\times(\sin\theta)$$

$$\sin\theta = \frac{L}{\sqrt{L^2 + r^2}}\ ;\quad B = \frac{\mu_0 IL}{4\pi r\sqrt{L^2 + r^2}}$$

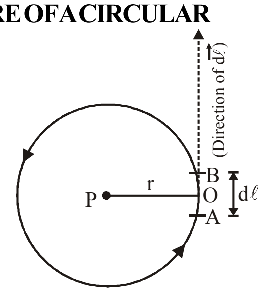
Case V : When point P is along the length of conductor.

$\theta_1 = \theta_2 = 0$

$\vec{B} = 0$

MAGNETIC FIELD AT THE CENTRE OF A CIRCULAR CURRENT-CARRYING COIL

Consider a circular coil of radius r through which current I is flowing. Let AB be an infinitesimally small element of length $d\ell$. According to Biot-Savart's law, the magnetic field dB at the centre P of the loop due to this small element $d\ell$ is



$dB = \frac{\mu_0}{4\pi}.\frac{I\,d\ell\sin\theta}{r^2}$, where θ is the angle between $\vec{d\ell}$ & $\vec{r}$.

$$\therefore\quad dB = \frac{\mu_0}{4\pi}\frac{I\,d\ell\sin 90°}{r^2} = \frac{\mu_0}{4\pi}\frac{I\,d\ell}{r^2}$$

(for circular loop, $\theta = 90°$)

The loop can be supposed to consists of a number of small elements placed side by side. The magnetic field due to all the elements will be in the same direction. So, the net magnetic field at P is given by

$$B = \sum dB = \sum \frac{\mu_0}{4\pi}\frac{I\,d\ell}{r^2} = \frac{\mu_0 I}{4\pi r^2}\sum d\ell$$

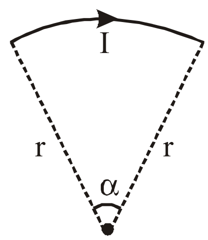
$$\therefore\quad B = \frac{\mu_0 I}{4\pi r^2}\times 2\pi r \quad \text{or} \quad B = \frac{\mu_0 I}{2r}$$

($\Sigma d\ell$ = circumference of the circle = $2\pi r$)

For a coil of n turns, $B = \frac{\mu_0 n I}{2r}$

Magnetic Field due to part of current carrying circular conductor (Arc) : Consider a circular arc shape current carrying thin wire. Let radius = r
Angle subtend by segment at the centre O = α
Current flowing through wire = I
Magnetic field at the centre O due to small element $d\ell$

$$dB = \frac{\mu_0}{4\pi}\frac{I d\ell \sin\theta}{r^2} \quad [\theta = \text{angle between } \vec{d\ell} \text{ and } \vec{r}\,]$$



$$B = \sum dB = \sum \frac{\mu_0}{4\pi}\frac{I d\ell}{r^2} \quad (\theta = 90°)$$

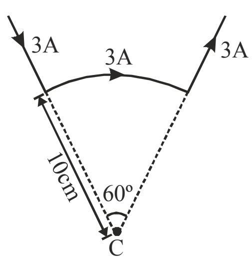
$$B = \frac{\mu_0 I}{4\pi r^2}\sum d\ell \quad \left(\because \frac{\sum d\ell}{r} = \alpha\right)$$

$$B = \frac{\mu_0 I}{4\pi r}\alpha$$

Example 1 :

A circular segment of radius 0.10 m subtends an angle of 60° at its centre. A current of 3 ampere is flowing through it. Find the magnitude and direction of the magnetic field at the centre C of the segment.

Sol. r = 0.10 m, I = 3 A, $\theta = 60° = \theta/3$



$$B = \frac{\mu_0}{4\pi}\cdot\frac{I}{r}\theta$$

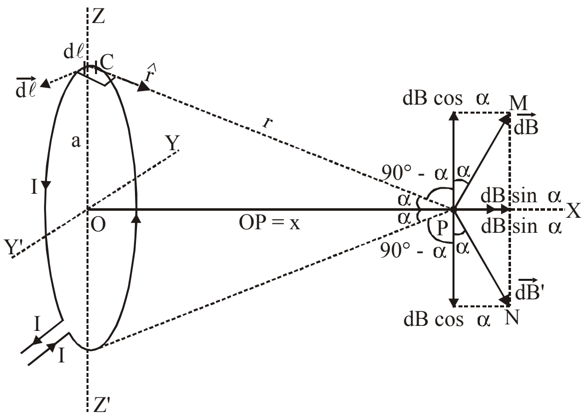
$$= \frac{4\pi\times10^{-7}}{4\pi}\times\frac{3}{0.10}\times\frac{\pi}{3}$$

or $\quad B = \frac{3.14}{0.10}\times10^{-7}\,T = 3.14\times10^{-6}\,T = 3.14\,\mu T$

Applying Right Hand Rule, we find that the direction of magnetic field is perpendicular to the plane of paper and directed inwards.

MAGNETIC FIELD ON THE AXIS OF A CIRCULAR COIL

Consider a circular loop of radius **a** through which current I is flowing as shown in fig. The point P lies on the axis of the circular current loop i.e., along the line perpendicular to the plane of the loop and passing through its centre. Let x be the distance of the observation point P from the centre O of the loop. Let us consider an infinitesimally small element AB of length $d\ell$.
Radius of the loop = a



According to Biot-Savart's law, the magnetic field at P due to this small element $\vec{dB} = \frac{\mu_0 I}{4\pi r^3}[\vec{d\ell}\times\vec{r}\,]$

$$dB = \frac{\mu_0\, I\, d\ell \sin\theta}{4\pi r^2} \quad \text{or} \quad dB = \frac{\mu_0 I\, d\ell}{4\pi r^2} \quad (\theta = 90°)$$

The direction of $\vec{dB}$ is perpendicular to the plane of the current element $d\vec{\ell}$ and $\vec{r}$ (CP) as shown in fig. by $\vec{PM}$. Similarly if we consider another small element just diametrically opposite to this element then magnetic field due to this at point P is $d\vec{B}'$, denoted by PN and of the same magnitude. dB = dB'

Both $\vec{dB}$ and $d\vec{B}'$ can be resolved into two mutually perpendicular components along PX and ZZ'.
The components along ZZ' [dB cosα and dB' cosα] cancel each other as they are equal and opposite in direction.
The same will hold for such other pairs of current elements over the entire circumference of the loop.
Therefore, due to the various current elements, the components of magnetic field is only along PX will contribute to the magnetic field due to the whole loop at point P.
Hence, net magnetic field at point P is

$$B = \sum dB\sin\alpha \ \ [\text{along OP}]\,; \quad B = \frac{\mu_0\, N\, I\, a^2}{2(a^2+x^2)^{3/2}}$$

Case I : At the centre of the loop, x = 0

$$B = \frac{\mu_0\, N\, I\, a^2}{2a^3} \quad \text{or} \quad B = \frac{\mu_0\, N\, I}{2a}$$

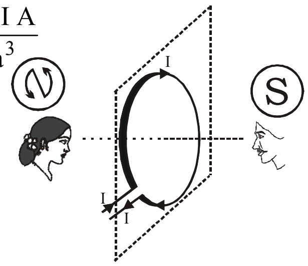
In terms area A (= πa^2) of the circular current loop,
The quantity N I A is known as the magnetic dipole moment M of the current loop.
The current loop can be regarded as a magnetic dipole which produces its magnetic field and magnetic dipole moment of the current loop is equal to the product of ampere turns and area of current loop.

we can write

$$B = \frac{\mu_0 \, N I A}{2 \, r(\pi a^2)} = \frac{\mu_0}{2\pi} \frac{N I A}{a^3}$$

or $B = \frac{\mu_0}{4\pi} \frac{2 N I A}{a^3}$

$\therefore \; B = \frac{\mu_0}{4\pi} \frac{2M}{a^3}$



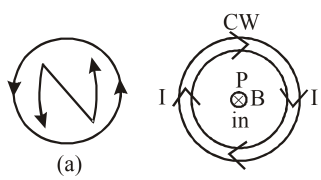
Case II : If the observation point is far way from the coil, then $a << x$. So, a^2 can be neglected in comparison to x^2.

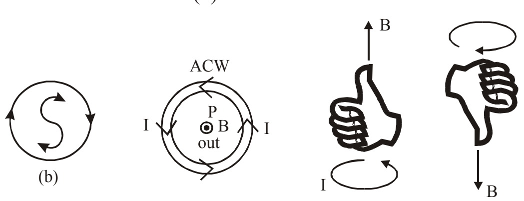
$\therefore \; B = \frac{\mu_0 \, N I a^2}{2x^3}$

In terms of magnetic dipole moment, $B = \frac{\mu_0}{4\pi} \frac{2M}{x^3}$

$$\left[B = \frac{\mu_0}{2\pi} \frac{N I A}{x^3} = \frac{\mu_0}{4\pi} \frac{2 N I A}{x^3} \right]$$

Right Hand Palm Rule. If we hold the thumb of right hand mutually perpendicular to the grip of the fingers such that the curvature of the finger represents the direction of current in the wire loop, then the thumb of the right hand will point in the direction of magnetic field near the centre of the current loop.

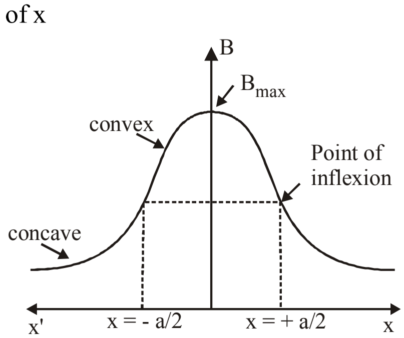




GRAPH OF B v/s x

As soon as x increases magnetic field B decreases, dependence of B on x is shown in figure

Rate of change of B with respect to x is different at different values of x



for $x < \pm\frac{a}{2}$ curve is convex & for $x > \pm\frac{a}{2}$ curve is concave

At $x = \pm\frac{a}{2}$ we get $\frac{dB}{dx} = \text{const.}$, and $\frac{d^2B}{dx^2} = 0$

So at $x = +\frac{a}{2}$ & $-\frac{a}{2}$ B varies linearly with x. These points are called point of inflexion.

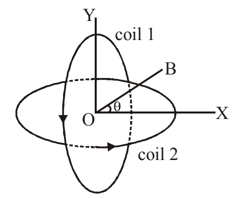
Distance in between these two points is equal to radius of the coil $B = \frac{B_C}{\left(1 + \frac{x^2}{a^2}\right)^{3/2}}$

$\because$ Magnetic field at the centre of coil $B_C = \frac{\mu_0 \, N I}{2 \, a}$

At $x = a/2$, $B = \frac{B_C}{\left(1 + \frac{1}{4}\right)^{3/2}}$ or $B = \frac{8}{5\sqrt{5}} \left(\frac{\mu_0 NI}{2a}\right)$

Example 2 :

For the arrangement made up of two identical coils of figure determine the magnetic field at the centre O.



Sol. The two coils are perpendicular to each other. Coil 1 produce field along X axis and coil 2 produce field along Y axis. Thus the resultant field will be $B = \sqrt{B_1^2 + B_2^2}$

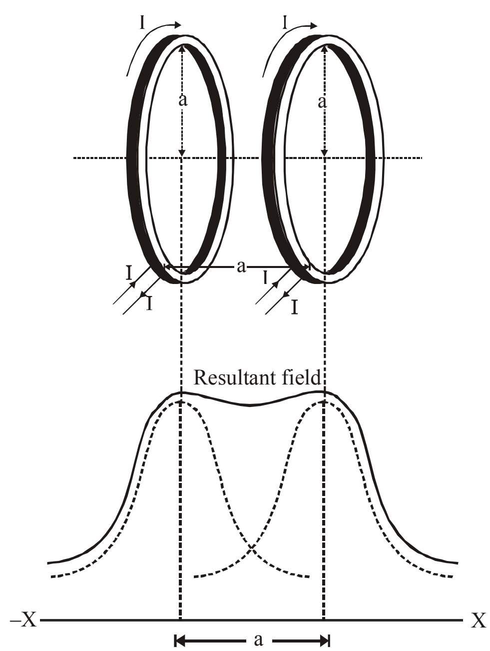
making an angle θ from x-axis $\tan\theta = \frac{B_2}{B_1}$

For identical coils,

$$B_1 = B_2 = \sqrt{2}\left(\frac{\mu_0 \, N I}{2a}\right) \text{ and hence } \theta = 45°$$

HELMHOLTZ COILS

The two coaxial coils of equal radii placed at distance equal to the radius of either of the coils and in which same current in same direction is flowing are known as Helmholtz coils. For these coils $x = a/2$, $I_1 = I_2 = I$, $a_1 = a_2 = a$



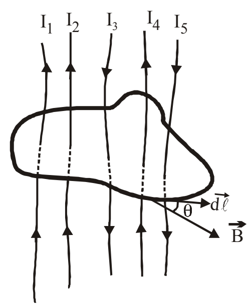
The two coils are placed mutually parallel to each other these coils are used to produce a uniform magnetic field. In between two coils along the axis at middle point rate of change of magnetic field is constant so if distance increases from a coil magnetic field decreases but distance from the another coil decreases so magnetic field due to second coil increases and hence the resultant magnetic field produced in the region between two coils remains uniform. Resultant magnetic field in between two coils

$$B = \frac{8\mu_0 nI}{5\sqrt{5}\,a} \quad \text{or } B = 0.76\frac{\mu_0 nI}{a} \quad \text{or } B = 1.423\,B_C$$

(B_C is magnetic field at the centre of a single coil.)

AMPERE'S CIRCUITAL LAW

Ampere's circuital law states that the line integral of magnetic field induction $\vec{B}$ around any closed path in vacuum is equal to μ_0 times the total current threading the closed path, i.e.,



$$\oint \vec{B}.\vec{d\ell} = \mu_0 \sum I \quad \text{here } \sum I = I_1 + I_2 - I_3 + I_4 - I_5$$

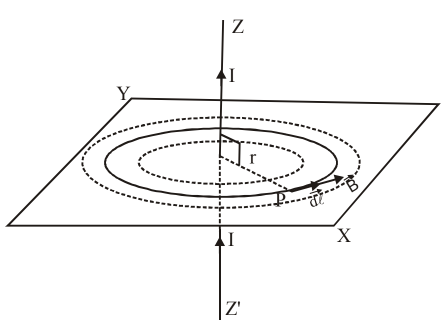
This result is independent of the size and shape of the closed curve enclosing a current. This is known as **Ampere's circuital law.** Ampere's law gives another method to calculate the magnetic field due to a given current distribution. Ampere's law may be derived from the Biot-Savart law and Biot-Savart law may be derived from the Ampere's law. Ampere's law is more useful under certain symmetrical conditions.

Biot-Savart law based on the experimental results whereas Ampere's law based on mathematical.

Applications of Ampere's Law :

(a) Magnetic induction due to a long current carrying wire. Consider a long straight conductor Z-Z' is along z-axis. Let I be the current flowing in the direction as shown in Fig. The magnetic field is produced around the conductor. The magnetic lines of force are concentric circles in the XY plane as shown by dotted lines. Let the magnitude of the magnetic field induction produced at a point P at distance r from the conductor is $\vec{B}$.

Consider a close circular loop as shown in figure.



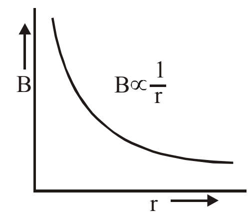
According to Ampere's law $\oint \vec{B}.\vec{d\ell} = \mu_0 \sum I$

The direction of $\vec{B}$ at every point is along the tangent to the circle. Consider a small element $d\vec{\ell}$ of the circle of radius r at P. The direction of $\vec{B}$ and $d\vec{\ell}$ is the same. Therefore, angle between them is zero.

Line integral of $\vec{B}$ around the complete circular path of radius r is given by

$$\oint \vec{B}.\vec{d\ell} = \oint B\,d\ell \cos 0^o$$

$$= B\oint d\ell = B \times 2\pi r$$



($\oint d\ell = 2\pi r =$ circumference of the circle.) and $\sum I = I$

So we get $B \times 2\pi r = \mu_0 I$

or $\quad B = \frac{\mu_0 I}{2\pi r} = \frac{\mu_0}{4\pi} \times \frac{2I}{r} \quad B \propto I$ and $B \propto \frac{1}{r}$

(b) Magnetic field created by a long current carrying conducting cylinder : A long straight wire of radius R carries a steady current I that is uniformly distributed through the cross-section of the wire.

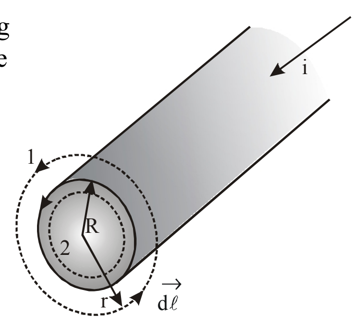
For finding the behavior of magnetic field due to this wire, let us divide the whole region into two parts.

(a) $r \geq R$ and (b) $r < R$.

r = distance from the centre of the wire.

For r ≥ R : For closed circular path denoted by (1) from symmetry $\vec{B}$ must be constant in magnitude and parallel to $\vec{d\ell}$ at every point on this circle. Because the total current passing through the plane of the circle is I.

From Ampere's Law



$$\oint \vec{B}.\vec{d\ell} = \mu_0 (I_{net})$$

or $\quad B(2\pi r) = \mu_0 I$

and $\quad B = \frac{\mu_0}{2\pi}\frac{I}{r}$

(for $r \geq R$) ......(a)

For r < R : The current I' passing through the plane of circle 2 is less than the total current I. Because the current is uniform over the cross-section of the wire.

Current through unit area = $I/\pi R^2$

So current through area enclosed by circle 2 is

$$I' = \frac{I\pi r^2}{\pi R^2} \quad \text{or } I' = \left(\frac{r^2}{R^2}\right) I$$

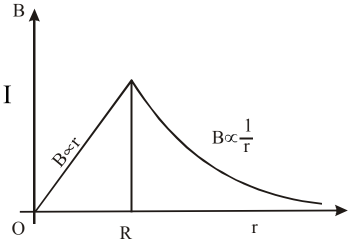
Now we apply Ampere's law for circle 2.

$$\oint \vec{B}.d\vec{\ell} = \mu_0 (I_{net})$$

$$\therefore \quad B(2\pi r) = \mu_0 \left(\frac{r^2}{R^2}\right) I$$

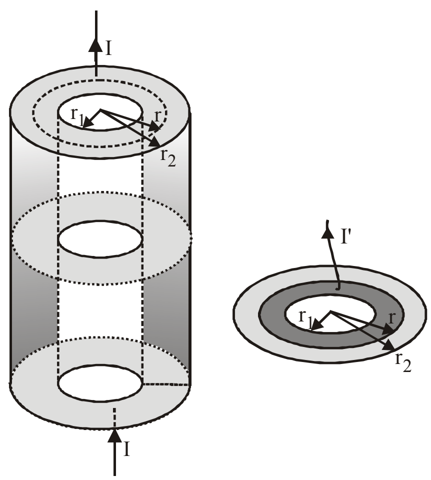
$$\text{or} \quad B = \left(\frac{\mu_0 I}{2\pi R^2}\right) r$$

(for $r < R$) ......(b)



The magnitude of the magnetic field versus r for this configuration is plotted in figure. Note that inside the wire $B \to 0$ as $r \to 0$. Note also that eq^n. (a) and eq^n (b) give the same value of the magnetic field at r = R, demonstrating that the magnetic field is continuous at the surface of the wire.

(c) Magnetic field due to a conducting current carrying hollow cylinder : Consider a conducting hollow cylinder with inner radius r_1 and outer radius r_2 &current I is flowing through it.



(I) **For $r < r_1$,** $\quad \Sigma I = 0$ and hence $B = 0$

(II) **For $r_1 < r < r_2$**

Now current I is flowing through area $[\pi r_2^2 - \pi r_1^2]$

So, current per unit area $= \dfrac{I}{\pi(r_2^2 - r_1^2)}$

$\therefore$ current flowing through area in bet^n $r_1 < r < r_2$ is

$$I' = \frac{I}{\pi(r_2^2 - r_1^2)} \times (\pi r^2 - \pi r_1^2)$$

by using ampere's law for circle of radius r

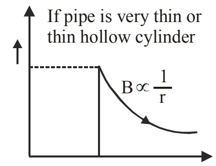
$$\oint \vec{B}.d\vec{\ell} = \mu_0 \Sigma I \quad \text{or} \quad \oint B\, d\ell \cos 0^\circ = \mu_0 \left[\frac{I(r^2 - r_1^2)}{r_2^2 - r_1^2}\right]$$

$$\text{or} \quad B \oint d\ell = \mu_0 I \left[\frac{r^2 - r_1^2}{r_2^2 - r_1^2}\right] \qquad [\because \oint d\ell = 2\pi r]$$

$$\text{or} \quad B = \frac{\mu_0 I}{2\pi r}\left[\frac{r^2 - r_1^2}{r_2^2 - r_1^2}\right]$$

(a) For $r = r_2$ (b) For $r > r_2$

$$B = \frac{\mu_0 I}{2\pi r_2} \qquad B = \frac{\mu_0 I}{2\pi r}$$



Example 3 :

A coaxial line carries the same current i up the inside conductor of radius a and down the outer conductor of inner radius b and outer radius c. Find the magnetic induction field at distance r from the centre of conductor (i) when $r > a$, (ii) $a < r < b$ (iii) $b < r < c$

Sol. Let the current be distributed uniformly over the cross-sections of outer and inner conductors.

current density in inner conductor $= \dfrac{i}{\pi a^2}$

current density in outer conductor $= \dfrac{i}{\pi(c^2 - b^2)}$

(i) When $r < a$: Consider a co-axial circular path of radius r. Let B be the magnetic of magnetic field at this distance then

B. $2\pi r = \mu_0 \times$ current enclosed by path

$$= \mu_0 \left(\frac{i}{\pi a^2} \times \pi r^2\right) = \frac{\mu_0 i r^2}{a^2} \quad \text{(using ampere's law)}$$

$$\therefore B = \frac{\mu_0}{4\pi} \times \frac{4 i r}{a^2} \frac{\text{weber}}{\text{metre}^2}$$

(ii) When $a < r < b$: In this case the circular path of radius r will enclose the current passing through inner conductor. Using Ampere's law

$$B.\, 2\pi r = \mu_0 i \quad \text{or} \quad B = \left(\frac{\mu_0 i}{2\pi r}\right) \frac{\text{weber}}{\text{metre}^2}$$

(iii) When $b < r < c$: Here, current enclosed by co-axial circular path of radius r = current passing through inner conductor – current passing through portions of outer conductor lying between radius = b and r

(Negative sign is used because the current in two conductor are in opposite directions) By Ampere's law

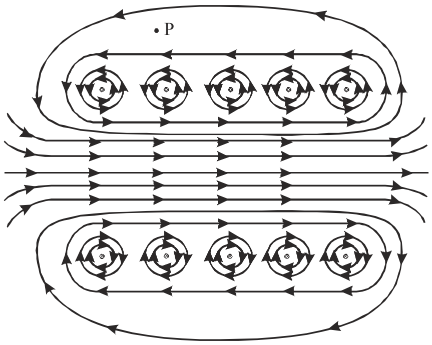
$$B.\, 2\pi r = \mu_0 \left[i - \frac{i}{\pi(c^2 - b^2)} \times \pi(r^2 - b^2)\right]$$

$$\therefore \quad B = \frac{\mu_0 i}{2\pi r}\left[1 - \frac{(r^2 - b^2)}{(c^2 - b^2)}\right]$$

MAGNETIC FIELD OF A SOLENOID

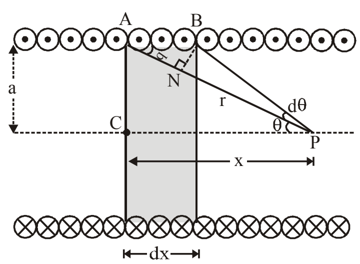
A solenoid is a long cylindrical helix. It is made by winding closely a large number of turns of insulated copper wire over a tube of card-board or china-clay. When electric current is passed through the solenoid, a magnetic field is produced around and within the solenoid.

Figure shows the lines of force of the magnetic field due to a solenoid. The lines of force inside the solenoid are nearly parallel which indicate that the magnetic field 'within' the solenoid is uniform and parallel to the axis of the solenoid.



Let there be a long solenoid of radius 'a' and carrying a current I. Let n be the number of turns per unit length of the solenoid. Let P be a point on the axis of the solenoid. Let us imagine the solenoid to be divided up into a number of narrow coils and consider one such coil AB of width δx. The number of turns in this coil is nδx. Let x be the distance of the point P from the centre C of this coil. The magnetic field at P due to this elementary coil is given by

$$\delta B = \frac{\mu_0 (n\,\delta x) I a^2}{2(a^2 + x^2)^{3/2}} \text{ N A}^{-1}\text{ m}^{-1} \quad ....(i)$$



Let average distance of circumference is r and δθ the angle subtended by the coil at P.

$$\sin\theta = \frac{BN}{AB} = \frac{r\,\delta\theta}{\delta x} \quad \text{or} \quad \delta x = \frac{r\,\delta\theta}{\sin\theta}$$

In Δ ACP, we have $a^2 + x^2 = r^2$

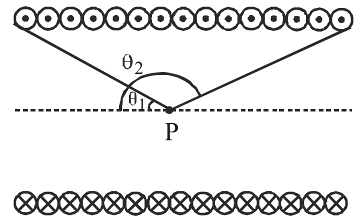
or $r^3 = (a^2 + x^2)^{3/2}$

Substituting these values of δx and $(a^2 + x^2)^{3/2}$ in eq. (i),

$$\text{we get } \delta B = \frac{\mu_0 (nr\,\delta\theta)\, I\, a^2}{2r^3 \sin\theta} = \frac{\mu_0\, n I a^2}{2\, r^2}\, \frac{\delta\theta}{\sin\theta}$$

$$\therefore \quad \delta B = \frac{1}{2}\mu_0 n I \sin\theta\,\delta\theta \qquad \left[\because \frac{a^2}{r^2} = \sin^2\theta\right]$$

The magnetic field B at P due to the whole solenoid can be obtained by integrating the above expression between the limits θ_1 and θ_2, where θ_1 and θ_2 are the semi-vertical angles subtended at P by the first and the last turn of the solenoid respectively. Thus



$$B = \int_{\theta_1}^{\theta_2} dB = \int_{\theta_1}^{\theta_2} \frac{1}{2}\mu_0 n I \sin\theta\, d\theta = \frac{1}{2}\mu_0 n I [-\cos\theta]_{\theta_1}^{\theta_2}$$

$$\text{or} \quad B = \frac{1}{2}\mu_0 n I [\cos\theta_1 - \cos\theta_2] \quad ....(ii)$$

If the observation point P is well inside a very long solenoid

Then, $\theta_1 \simeq 0^\circ$ and $\theta_2 \simeq 180^\circ$

$$\mathbf{B = \mu_0 n I}$$

Magnetic field at the ends of the solenoid :

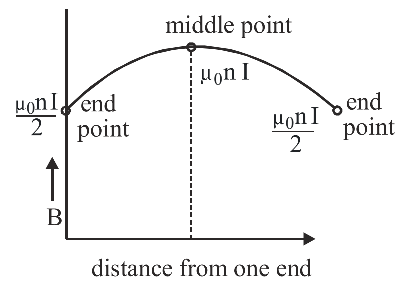
At the end of the last turn, $\theta_1 = 0$ and $\theta_2 = 90^\circ$

so that $\cos\theta_1 = 1$ and $\cos\theta_2 = 0$.

At the end of the first turn, $\theta_1 = 90^\circ$ and $\theta_2 = 180^\circ$

so that $\cos\theta_2 = -1$.

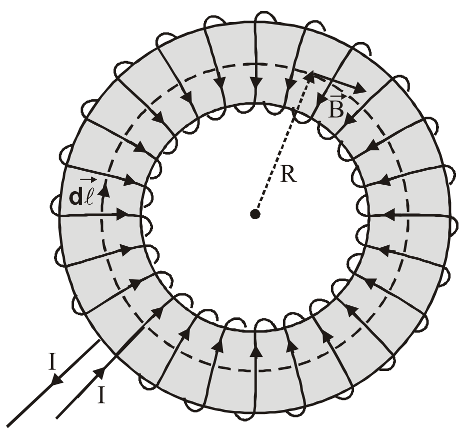
Hence from eq. (ii), $B = \frac{1}{2}\mu_0 n I$



Thus, the magnetic field at the ends of a 'long' solenoid is half of that at the centre. If the solenoid is sufficiently long, the field within it (except near the ends) in uniform. It does not depend upon the length and area of cross-section of the solenoid. Just as a parallel-plate capacitor produces uniform and known electric field, a solenoid produces a uniform and known magnetic field. The 'uniform' magnetic field within a long solenoid is parallel to the solenoid axis. Its direction along the axis is given by a curled-straight right-hand rule. "If we grasp the solenoid with our right hand so that our fingers follow the direction of the current in the windings, then out extended right thumb will point in the direction of the axial magnetic field".

TOROID

A toroid is an endless solenoid in the form of a ring, as shown in figure. A toroid is often used to create an almost uniform magnetic field in some enclosed area. The device consists of a conducting wire wrapped around a ring (a torus) made of a non-conducting material. Let a toroid having N closely spaced turns of wire, magnetic field in the region occupied by the torus = B. Radius of the Toroid ring = R



To calculate the field, we must evaluate $\oint \vec{B}.\vec{d\ell}$ over the circle of radius R. By symmetry magnitude of the field is constant at the circumference of the circle and tangent to it. So, $\oint \vec{B}.\vec{d\ell} = B\ell = B\,(2\pi R)$

The circular closed path surrounds N loops of wire, each of which carries a current I. So according to Ampere's law

$\oint \vec{B}.\vec{d\ell} = \mu_0\,(I_{net})$ or $B\,(2\pi R) = \mu_0\,N\,I$ or $B = \dfrac{\mu_0 NI}{2\,\pi\,R}$

This result shows that $B \propto \dfrac{1}{R}$ and hence is nonuniform in the region occupied by torus. However, if R is very large compared with the cross-sectional radius of the toroid, then the field is approximately uniform inside the torus.

Number of turns per unit length of torus $n = \dfrac{N}{2\,\pi\,R}$

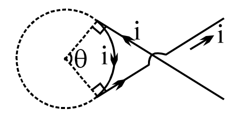
$\therefore\ B = \mu_0 nI$

For an ideal toroid, in which turns are closely spaced, the external magnetic field is zero. This is because the net current passing through any circular path laying outside the toroid is zero. Therefore, from Ampere's law we find that B = 0, in the regions exterior to the torus.

TRY IT YOURSELF-1

Q.1 Antiparallel currents are directed so that one is out of the page and the other is into the page. 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

Q.2 A wire carrying current I has the configuration shown in figure. Two semi-infinite straight sections, both tangent to the same circle, are connected by a circular arc, of central angle θ, along the circumference of the circle, with all sections lying in same plane. If magnetic field at centre 'O' of the circle is zero then θ is

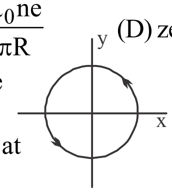


(A) 2 radian (B) 4 radian
(C) π /2 (D) π / 4

Q.3 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) all of the above

Q.4 An electron moving in a circular orbit of radius R makes n turns per second. The magnetic field at the centre has magnitude
(A) $\dfrac{2\mu_0 ne}{R}$ (B) $\dfrac{\mu_0 ne}{2R}$ (C) $\dfrac{\mu_0 ne}{\pi R}$ (D) zero

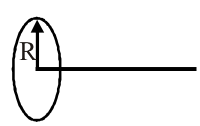
Q.5 Current i = 2.5 A flows along the circle $x^2 + y^2 = 9\ cm^2$ (here x & y are in cm) as shown. Magnetic field **(in Tesla)** at point (0, 0, 4 cm) is



(A) $(36\pi \times 10^{-7})\,\hat{k}$ (B) $(36\pi \times 10^{-7})\,(-\hat{k})$
(C) $\left(\dfrac{9\pi}{5} \times 10^{-7}\right)\hat{k}$ (D) $\left(\dfrac{9\pi}{5} \times 10^{-7}\right)(-\hat{k})$

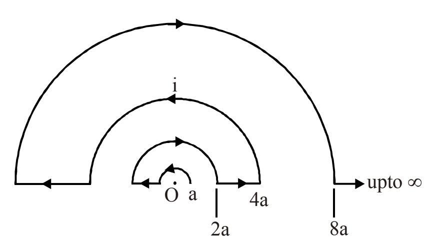
Q.6 Two long parallel straight conductors carry current i_1 and i_2 $(i_1 > i_2)$. When the currents are in the same direction, the magnetic field at a point midway between the wires is 20μT. If the direction of i_2 is reversed, the field becomes 50μT. The ratio of the currents i_1 / i_2 is :
(A) 5/2 (B) 7/3
(C) 4/3 (D) 5/3

Q.7 Constant current I is flowing through a circular coil of radius R. At what distance from the centre will the magnetic field (on the axis) be maximum :
(A) $\dfrac{R}{\sqrt{2}}$ (B) $\dfrac{R}{2}$
(C) R (D) zero



Q.8 There is a horizontal straight wire carrying current from West to East. Magnetic field due to this wire at a point :
(A) above it is towards South
(B) to the North of it is upwards
(C) below it is downwards
(D) below it is towards West

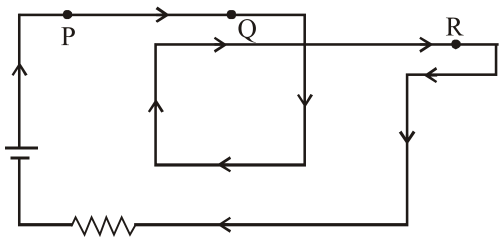
Q.9 A conductor carrying current ' i ' is bent in the form of concentric semicircles as shown in the figure. The magnetic field at the centre O is :



(A) zero (B) $\frac{\mu_0 i}{6a}$

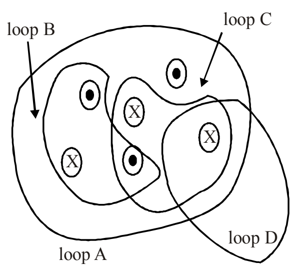
(C) $\frac{\mu_0 i}{a}$ (D) $\frac{\mu_0 i \ln 2}{4a}$

Q.10 A battery establishes a steady current around the circuit **shown**. A compass needle is placed successively at points P, Q, and R, just above the wire (slightly out of the plane of the page). The relative deflection of the needle, in descending order, is



(A) P, Q, R (B) Q, R, P
(C) R, Q, P (D) Q, P, R

Q.11 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 counter-clockwise around each loop shown.



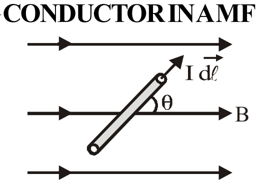
(A) B > C > D > A (B) B > C = D > A
(C) B > A > C = D (D) C > B = D > A

ANSWERS

(1) (C)	**(2)** (A)	**(3)** (D)
(4) (B)	**(5)** (A)	**(6)** (B)
(7) (D)	**(8)** (AB)	**(9)** (B)
(10) (D)	**(11)** (C)	

FORCE ON A CURRENT-CARRYING CONDUCTOR IN A MF

Current Element - Current element is defined as a vector having magnitude equal to the product of current with a small part of length of the conductor and the direction in which the current is flowing in that part of the conductor.



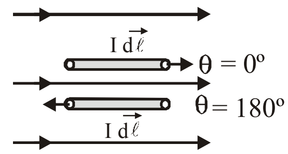
$0° < \theta < 90°$
$dF = B\,I\,d\ell \sin\theta$
Directed into the page

With the help of experiments Ampere established that when a current element $I\vec{d\ell}$ is placed in a magnetic field $\vec{B}$, it experiences a force $\vec{dF} = I\,\vec{d\ell} \times \vec{B}$

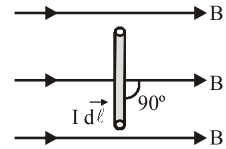
The magnitude of force is $dF = B\,I\,d\ell \sin\theta$

[θ is the angle between the $\vec{d\ell}$ and $\vec{B}$]

(i) When $\sin\theta = \min = 0$, i.e., $\theta = 0°$ or $180°$,
Then force on a current element = 0 (minimum)



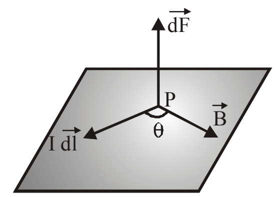
$\theta = 0$ or $180°$
$dF = \min = 0$

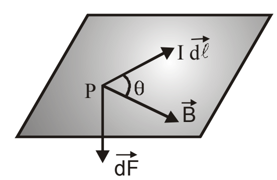


$\theta = 90°$
$dF = \max = B\,I\,d\ell$
Directed out of page

A current element in a magnetic field does not experience any force if the current in it is collinear with the field.

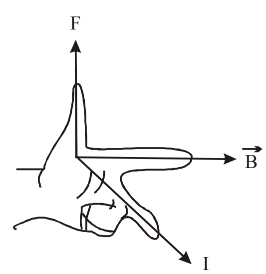
(ii) When $\sin\theta = \max = 1$, i.e., $\theta = 90°$
The force on the current will be maximum ($= BI\,d\ell$)
Force on a current element in a magnetic field is maximum ($= BI\,d\ell$). When it is perpendicular to the field.
The direction of force is always perpendicular to the plane containing $I\,d\vec{\ell}$ and $\vec{B}$.



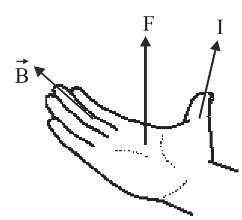


The direction of force on current element $I\,d\vec{\ell}$ and $\vec{B}$ are perpendicular to each other can also be determined by applying either of the following rules:

Fleming's Left-hand Rules
Stretch the forefinger, central finger and thumb of left hand mutually perpendicular.
Then if the forefinger points in the direction of field $(\vec{B})$, the central finger in the direction of current I, the thumb will point in the direction of force.



Right-hand Palm Rule : Stretch the fingers and thumb of right hand at right angles to each other. Then if the fingers point in the direction of field $\vec{B}$ and thumb in the direction of current I, the normal to palm will point in the direction of force.



Regarding the force on a current-carrying conductor in a magnetic field it is worth mentioning that :

(a) As the force $BI\,d\ell \sin\theta$ is not a function of position r, the magnetic force on a current element is non-central
[a central force is of the form $F = Kf(r)\,\vec{n}_r$].

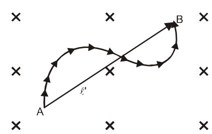
(b) The force $d\vec{F}$ is always perpendicular to both $\vec{B}$ and $I\,d\vec{\ell}$ though $\vec{B}$ and $I\,d\vec{\ell}$ may or may not be perpendicular to each other.

(c) In case of current-carrying conductor in a magnetic field if the field is uniform i.e., $\vec{B}$ = constt.,

$$\vec{F} = \int I\,d\vec{\ell} \times \vec{B} = I\left[\int d\vec{\ell}\right] \times \vec{B}$$

and as for a conductor $\int d\vec{\ell}$ represents the vector sum of all the length elements from initial to final point, which in accordance with the law of vector addition is equal to the length vector $\vec{\ell}'$ joining initial to final point, so a current-carrying conductor of any arbitrary shape in a uniform field experience a force

$$\vec{F} = I\left[\int d\vec{\ell}\right] \times \vec{B} = I\,\vec{\ell}' \times \vec{B}$$



where $\vec{\ell}'$ is the length vector joining initial and final points of the conductor as shown in fig.

(d) If the current-carrying conductor in the form of a loop of any arbitrary shape is placed in a uniform field,

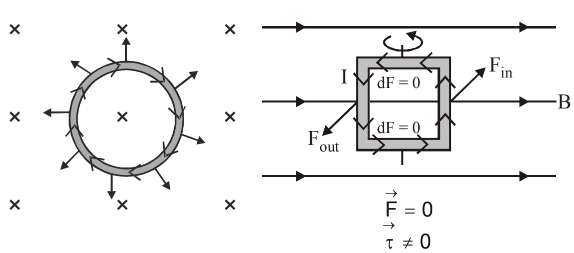
$\vec{F} = \oint I\,d\vec{\ell} \times \vec{B} = I\,[\oint d\vec{\ell}\,] \times \vec{B}$ and as for a closed loop,

$\oint d\vec{\ell}$ is always zero. [vector sum of all $d\vec{\ell}$]

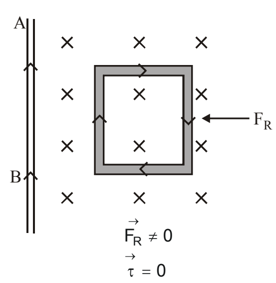
So, $\vec{F} = 0$ [as $\oint I\,d\vec{\ell} = 0$]

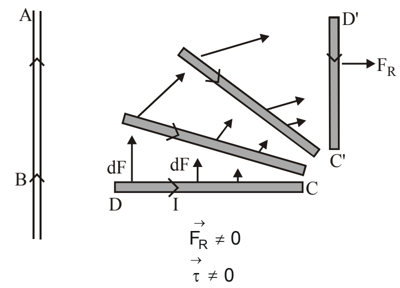
i.e., the net magnetic force on a current loop in a uniform magnetic field is always zero as shown in fig.

Here it must be kept in mind that in this situation different parts of the loop may experience elemental force due to which the loop may be under tension or may experience a torque as shown in fig.



(e) If a current-carrying conductor is situated in a non-uniform field, its different elements will experience different forces; so in this situation, $\vec{F}_R \neq 0$ but $\vec{\tau}$ may or may not be zero





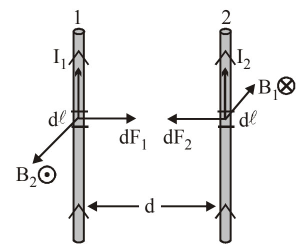
A current carrying rod CD in the field of current carrying wire AB

FORCE BETWEEN PARALLEL CURRENT CARRYING WIRES

Consider two long wires W_1 and W_2 kept parallel to each other and carrying currents I_1 and I_2 respectively in the same direction.

The separation between the wires is d.Consider a small . . . . ℓ of the wire W_2.

The magnetic field at $d\ell$ due to the wire W_1 is



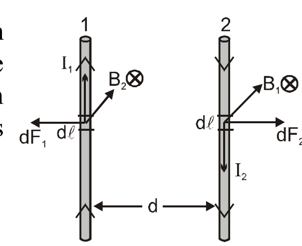
$$B_1 = \frac{\mu_0 I_1}{2\pi d} \qquad \text{.......(i)}$$

The field due to the portions of the wire W_2, above and below $d\ell$, is zero. Thus, eq^n (i) gives the net field at $d\ell$. The direction of this field is perpendicular to the plane of the diagram and going into it. The magnetic force at the element $d\ell$ due to wire W_1 is.

$$d\vec{F}_2 = I_2\,d\vec{\ell} \times \vec{B}_1 \quad \text{or,} \quad dF_2 = I_2\,d\ell\,\frac{\mu_0 I_1}{2\pi d}$$

The vector product $d\vec{\ell} \times \vec{B}$ has a direction towards the wire W_1. Thus, the length $d\ell$ of wire W_2 is attracted towards the wire W_1. The force per unit length of the wire W_2 due to the wire W_1 is $\frac{dF_2}{d\ell} = \frac{\mu_0 I_1 I_2}{2\pi d}$ ......(ii)

If we take an element $d\ell$ in the wire W_1 and calculate the magnetic force per unit length on wire W_1 due to W_2, it is again given by eq^n (ii)



$$\frac{dF_1}{dt} = \frac{\mu_0 I_2 I_1}{2\pi d}$$

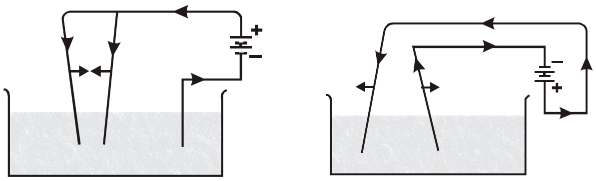
If the parallel wires currents in opposite directions, the wires repel each other.

The wires attract each other if current in the wires are flowing in the same direction.

And they repel each other if the currents are in opposite directions.

Experimental Demonstration

(a) Like currents attract **(b) Unlike currents repel**



Definition of Ampere : $F = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{r}$ N/m

When $I_1 = I_2 = 1$ ampere and r = 1m, then

$$F = \frac{\mu_0}{2\pi} = \frac{4\pi \times 10^{-7}}{2\pi}\ \text{N/m} = 2 \times 10^{-7}\ \text{N/m}$$

This leads to the following definition of ampere.

One ampere is that current which, if passed in each of two parallel conductors of infinite length and one metre apart in vacuum causes each conductor to experience a force of 2×10^{-7} newton per metre of length of conductor.

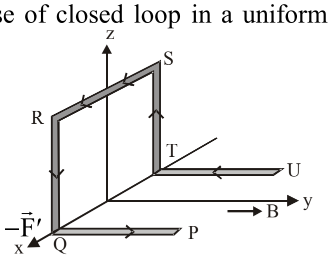
Dimensional of formula of μ_0

$$F = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{r} \quad \text{so } [\mu_0] = \frac{[F][r]}{[I_1 I_2]} = \frac{[ML^0T^{-2}][L]}{[I^2]} = [MLT^{-2}I^{-2}]$$

Example 4 :

A wire PQRSTU (with each side of length L) bent as shown in figure and carrying a current I is placed in a uniform magnetic induction B parallel to positive y direction. What is the force experienced by the wire?

Sol. If we join P to U be a straight conductor it will become a closed loop and as in case of closed loop in a uniform magnetic field,



if $\vec{F}_W$ is the force on the given network of wires and $\vec{F}'$ on the wire PU,

$\vec{F}_W + \vec{F}' = 0$ i.e., $\vec{F}_W = -\vec{F}'$

But as $\vec{F}' = B\,I\,L \sin 90°$ along negative z-axis, so

$\vec{F}_W = B\,I\,L$ along z-axis

TORQUE EXPERIENCED BY A CURRENT LOOP IN A UNIFORM MAGNETIC FIELD

Let us consider a rectangular current loop PQRS of sides a and b suspended vertically in a uniform magnetic field $\vec{B}$.

Let θ be the angle between the direction of $\vec{B}$ and the vector perpendicular to the plane of the loop.

Let us first consider the two straight parts PQ and RS.

The forces acting on these parts are clearly equal in magnitude and opposite in direction. These forces are collinear, so, the net force or net torque due to this pair of forces is zero.

The forces on the straight current segments SP and QR are

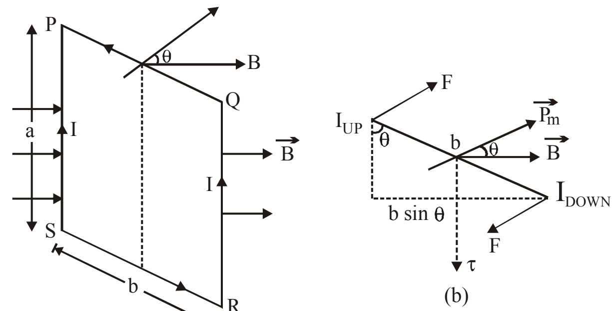
(i) equal in magnitude

(ii) opposite in direction

(iii) not collinear.

These forces shown in figure (b). This pair of forces produces a torque whose lever arm is b sinθ.

Magnitude of each force = B I a.



(a) (b)

The magnitude of the torque $\vec{\tau}$ is given by

$\tau = B\,I\,a\,(b \sin\theta)$

or $\tau = B\,I\,A \sin\theta$ ....(i)

where A is the area of the coil.

But IA = M (magnitude of magnetic dipole moment)

$\therefore$ $\tau = M\,B \sin\theta$. In vector form, $\vec{\tau} = \vec{M} \times \vec{B}$

The direction of the torque is vertically downwards along the axis of suspension [dotted line in fig (b)]

It will rotate the loop clockwise about its axis.

Note 1. If the rectangular loop has N turns, then the torque increases N times and becomes N B I A sin θ.

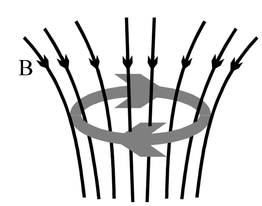
2. eq^n (i) could also be written as

$$\vec{\tau} = I(\vec{A} \times \vec{B}) \quad \text{or} \quad \vec{\tau} = I\,A\,\hat{n} \times \vec{B}$$

where $\hat{n}$ is a unit vector normal to the plane of the loop.

TRY IT YOURSELF-2

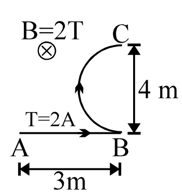
Q.1 The coil below has current flowing clockwise as seen from above. It sits in an external magnetic field shown by the field lines below. The coil will feel a magnetic force that is



(A) upwards (B) downwards

(C) zero (D) can't be predicted

Q.2 In the figure the force on the wire ABC in the given uniform magnetic field will be (in newtons):



(A) $(3 + 2\pi)4$ (B) 20

(C) 28 (D) 17

Q.3 Which of the following statement(s) is/are **false**?

(A) The magnetic force does zero work on a charged particle moving in a magnetic field.

(B) Dry charged pieces of paper are attracted to stationary magnet.

(C) Dry charged pieces of paper experience force in the presence of a moving magnet.

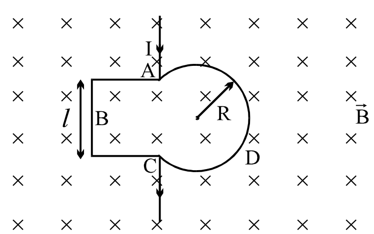
(D) The magnetic torque on a current-carrying coil of wire has its maximum magnitude when the magnetic field is perpendicular to the plane of the coil.

Q.4 A circular coil of 100 turns and effective diameter 20 cm carries a current of 0.5 A. It is to be turned in a magnetic field B = 2T from a position in which θ equals zero to θ equals 180°. The work required in this process is

(A) πJ (B) 2πJ

(C) 4πJ (D) 8πJ

Q.5 The figure shows a conducting loop ABCDA placed in a uniform magnetic field perpendicular to its plane. The part ABC is the $(3/4)^{th}$ portion of the square of side length *l*. The part ADC is a circular arc of radius R. The points A and C are connected to a battery which supply a current I to the circuit. The magnetic force on the loop due to the field B is



(A) zero (B) BI*l*

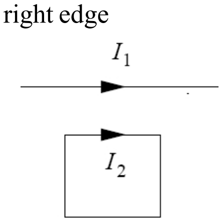
(C) 2BIR (D) $\dfrac{BIl}{l+R}$

Q.6 Imagine that a current is flowing around this test paper in the anticlockwise direction. If an external magnetic field is in +ve x direction, which edge of the paper would be lifted under the influence of the torque of the magnetic field?

(A) Top edge (B) bottom edge

(C) left edge (D) right edge

Q.7 A long straight wire carries a steady current I_1. Nearby is a rectangular loop that carries a steady current I_2. The directions of the two currents are shown in the figure.



Which statement is/are false ?

(A) The loop is attracted to the wire.

(B) There is no net force on the loop from the wire.

(C) The loop is attracted to the wire if $I_1 > I_2$; otherwise it is repelled.

(D) The loop is repelled from the wire if $I_1 > I_2$; otherwise it is attracted

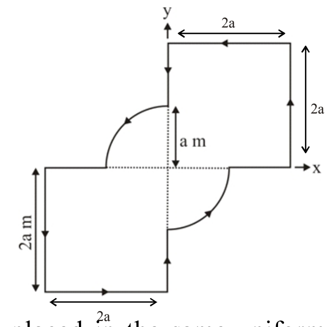
Q.8 A current I flows through a thin wire as shown in the figure. If there exists an external magnetic field B in the same plane of the wire. The torque acting on the coil is

(A) $I\left(\dfrac{\pi a^2}{2}+8a^2\right)B$

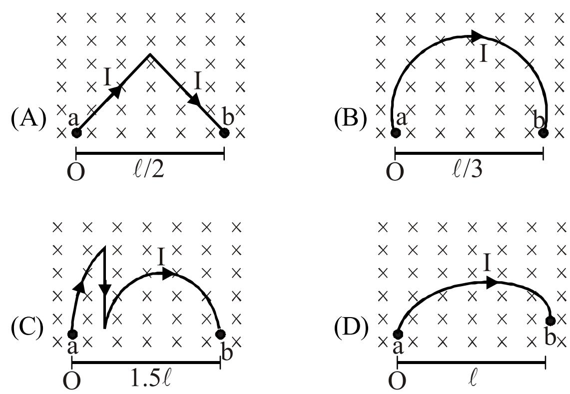
(B) $I\left(\dfrac{\pi a^2}{2}+4a^2\right)B$

(C) $I(\pi a^2+8a^2)B$

(D) zero



Q.9 Figure shows four wires placed in the same uniform magnetic field B and carrying the same current in which case force acting on the wire is minimum



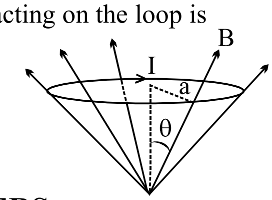
Q.10 A circular current loop of radius *a* is placed in a radial field B as shown. The net force acting on the loop is

(A) zero

(B) $2\pi Ba I\cos\theta$

(C) $2\pi a IB\sin\theta$

(D) None



ANSWERS

(1) (B)	**(2)** (B)	**(3)** (BD)
(4) (B)	**(5)** (B)	**(6)** (C)
(7) (BCD)	**(8)** (A)	**(9)** (B)
(10) (C)		

FORCE ON A CHARGED PARTICLE IN A MAGNETIC FIELD

Force experienced by a current element $I\,d\vec{\ell}$ in magnetic field $\vec{B}$ is given by $d\vec{F} = I\,d\vec{\ell}\times\vec{B}$ ....(i)

Now if the current element $I\,d\vec{\ell}$ is due to the motion of charge particles, each particle having a charge q moving with velocity $\vec{v}$ through a cross-section S,

$$I\,d\vec{\ell} = nSq\vec{v}.d\ell = n\,d\tau\,q\vec{v} \quad [\text{with volume } d\tau = S\,d\ell]$$

From eq^n (i) we can write $d\vec{F} = n\,d\tau\,q\,(\vec{v}\times\vec{B})$

$n\,d\tau$ = the total number of charged particles in volume $d\tau$ (n = number of charged particles per unit volume), force on a charged particle $\vec{F} = \frac{1}{n}\frac{d\vec{F}}{d\tau} = q(\vec{v} \times \vec{B})$

From this it is clear that :

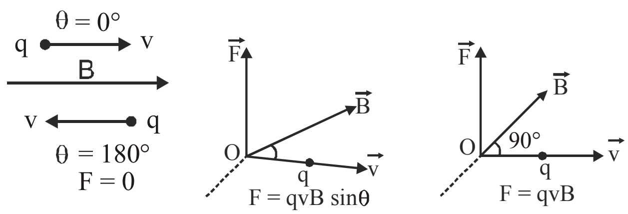
(a) The force $\vec{F}$ is always perpendicular to both the velocity $\vec{v}$ and the field $\vec{B}$.

(b) A charged particle at rest in a steady magnetic field does not experience any force.

If the charged particle is at rest then $\vec{v} = 0$, so $\vec{v} \times \vec{B} = 0$

(c) A moving charged particle does not experience any force in a magnetic field if its motion is parallel or antiparallel to the field. i.e., if $\theta = 0°$ or $180°$, then,

$|\vec{F}| = q\,v\,B\sin\theta = 0$ [$\because \sin 0° = 0$ and $\sin 180° = 0$]



(d) If the particle is moving perpendicular to the field.

In this situation all the three vectors $\vec{F}, \vec{v}$ and $\vec{B}$ are mutually perpendicular to each other.

Then $\sin\theta = \max = 1$, i.e., $\theta = 90°$,

The force will be maximum $F_{max} = q\,v\,B$

(e) Work done by force due to magnetic field in motion of a charged particle is always zero.

When a charged particle move in a magnetic field, then force acts on it is always perpendicular to displacement, so the work done,

$$W = \int \vec{F}.\vec{ds} = \int F ds \cos 90° = 0 \quad (\text{as } \theta = 90°),$$

And as by work-energy theorem $W = \Delta$ KE, the kinetic energy $(= \frac{1}{2}mv^2)$ remains unchanged and hence speed of charged particle v remains constant.

However, in this situation the force changes the direction of motion, so the direction of velocity $\vec{v}$ of the charged particle changes continuously.

(f) For motion of charged particle in a magnetic field

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

So magnetic induction $\vec{B}$ can be defined as a vector having the direction in which a moving charged particle does not experience any force in the field and magnitude equal to the ratio of the magnitude of maximum force to the product of magnitude of charge with velocity $B = \frac{F_{max}}{q\,v}$

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) ($\because F=0$)

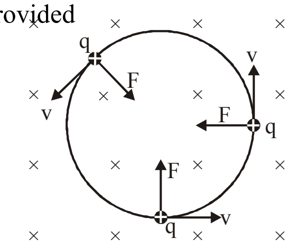
Only the following two cases are possible :

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

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

In case of circular motion of a charged particle in a steady magnetic field :

Momentum of the particle $p = mv = \sqrt{2mK}$,

[K = kinetic energy of the particle]

$$r = \frac{mv}{qB} = \frac{p}{qB} = \frac{\sqrt{2mK}}{qB} \quad \text{or } r \propto v \propto p \propto \sqrt{K}$$

i.e., with increase in speed or kinetic energy, the radius of the orbit increases.

For uniform circular motion $v = \omega r$

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

and the time period, $T = \frac{2\pi}{\omega} = 2\pi\frac{m}{qB}$

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.

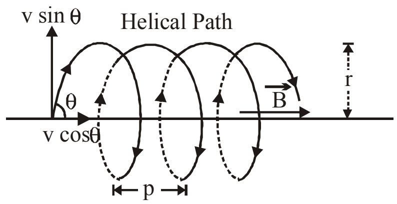
Case II : The charged particle is moving at an angle θ to the field : ($\theta \neq 0°, 90°$ or $180°$)

Resolving the velocity of the particle along and perpendicular to the field. The particle moves with constant velocity v cos θ 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 θ perpendicular to the field due to which it will describe a circle (in a plane perpendicular to the field)

Radius of the circular path $r = \frac{m(v\sin\theta)}{qB}$

and Time period $T = \frac{2\pi r}{v\sin\theta} = \frac{2\pi m}{qB}$

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 $p = T\,(v\cos\theta) = \dfrac{2\pi m}{qB}(v\cos\theta)$

MOTION OF CHARGED PARTICLE IN COMBINED ELECTRIC AND MAGNETIC FIELDS

Let a moving charged particle is subjected simultaneously to both electric field $\vec{E}$ and magnetic field $\vec{B}$.
The moving charged particle will experience electric force

$$\vec{F}_e = q\vec{E}$$

And magnetic force $\vec{F}_m = q\,(\vec{v}\times\vec{B})$.
Net force on the charge particle

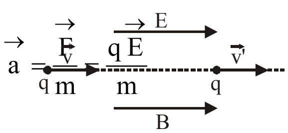
$$\vec{F} = q\,(\vec{E} + \vec{v}\times\vec{B}) \quad \text{[Lorentz-force]}$$

Depending on the direction of $\vec{v}, \vec{E}$ and $\vec{B}$ various situation are possible and the motion in general is quite complex.

Case I : $\vec{v}, \vec{E}$ and $\vec{B}$ **all the three are collinear :**

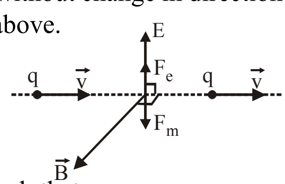
As the particle is moving parallel or antiparallel to the field.
The magnetic force on it will be zero
And only electric force will act
So, acceleration of the particle

$$\vec{a} = \frac{\vec{F}}{m} = \frac{q\vec{E}}{m}$$



Hence, the particle will pass through the field following a straight line path (parallel to the field) with change in its speed. In this situation speed, velocity, momentum and kinetic energy all will change without change in direction of motion as shown in figure above.

Case II : $\vec{v}, \vec{E}$ and $\vec{B}$ are mutually perpendicular :
If in this situation direction and qmagnitude of $\vec{E}$ and $\vec{B}$ are such that



Resultant force $\vec{F} = \vec{F}_e + \vec{F}_m = 0$ i.e., $\vec{a} = \dfrac{\vec{F}}{m} = 0$

Then as shown in fig., the particle will pass through the field with same velocity

$\because$ $F_e = F_m$ i.e., $qE = qvB$

or $v = \dfrac{E}{B}$ This principle is used in 'Velocity-selector' to get a charged beam having a specific velocity.

Example 5 :
An electron is projected with a velocity of 10^5 m/s at right angles to a magnetic field of 0.019G. Calculate the radius of the circular path described by the electron, if $e = 1.6\times10^{-19}$ C, $m = 9.1\times10^{-31}$ kg.

Sol. $\because$ $v = 10^5$ m/s ; $e = 1.6\times10^{-19}$ C;
$m = 9.1\times10^{-31}$ kg; $B = 0.019\text{ G} = 0.019\times10^{-4}$ T

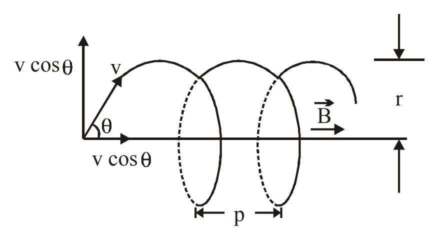
$$r = \frac{mv}{Be} = \frac{9.1\times10^{-31}\times10^5}{0.019\times10^{-4}\times1.6\times10^{-19}} = 0.299\text{ m}$$

Example 6 :
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 $= 1.67\times10^{-27}$ kg.

Sol. $r = \dfrac{mv\sin\theta}{qB}$ ($\because$ component of velocity $\perp$ to field is $v\sin\theta$)

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

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

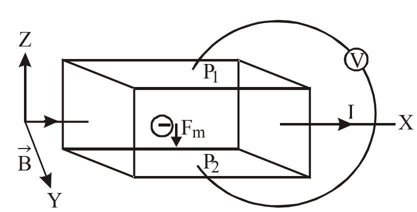


$$\therefore\; p = \frac{v\cos\theta\times2\pi r}{v\sin\theta} = \frac{\cos60^\circ\times2\pi\times(1.2\times10^{-2})}{\sin60^\circ}$$

$= 4.35\times10^{-2}$ m $= 4.35$ cm

HALL EFFECT

When a current passes through a slab of material in the presence of a transverse magnetic field, a small potential difference is established in a direction perpendicular to both, the current flow and the magnetic field.



This effect is called Hall effect The voltage thus developed is called Hall voltage. Hall effect enables us to
(i) Determine the sign of charge carriers inside the conductor.
(ii) Calculate the number of charge carriers per unit volume.

Explanation : Let us consider a conductor carrying current in +X direction. The magnetic field is applied along +Y direction. Consider two points P_1 and P_2 on the conductor and connect a voltmeter between these points. If no magnetic field is applied across the conductor, then the points P_1 and P_2 will be at same potential and there will be no deflection in the galvanometer. However, if a magnetic field is applied as shown in the figure, then the Lorentz force acts on electrons as shown in the figure. The Lorentz force on electrons

$F_m = -e\,(\vec{v}_d \times \vec{B})$ acts in the downwards direction.

Now there may be two cases:
(i) If the charge particles are negatively charged, then these negative charges will accumulate at the point P_2 and therefore P_2 will be at lower potential than P_1.
(ii) If the charged particle are positively charged, then the point P_2 will be at higher potential than P_1.

Magnitude of Hall Voltage : Let w be width and A be the cross-sectional area of the conductor. If e is magnitude of charge or the current carrier (electron or hole).
the force on the current carrier due to magnetic field

$$F_m = Bev_d$$

Here, v_d is drift velocity of the current carries.
Due to the force F_m, the opposite charges build up at the points P_1 and P_2 of the conductor. If V_H is Hall voltage developed across the two faces, then the strength of electric field due to Hall voltage is given by $E_H = \frac{V_H}{w}$.

Here $w = P_1P_2$.
This electric field exerts an electric force on the current carries in a direction opposite to that of magnetic force.

The magnitude of this force is $F_e = E_H e = \frac{V_H}{w} e$

In equilibrium condition, $F_e = F_m$, or $\frac{V_H}{w} e = B\,e\,v_d$,

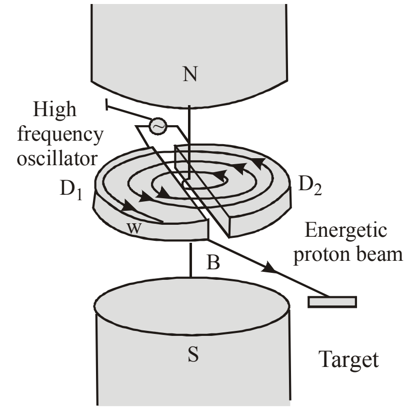
or $V_H = B\,v_d\,w$. Now, drift velocity of current carrier is given by, $v_d = \frac{j}{n\,e}$, where n is the number of current carries per unit volume of the strip.

$$\therefore \quad V_H = \frac{B\,w\,j}{n\,e}$$

$\frac{V_H}{I}$ is called the Hall resistance.

CYCLOTRON

A cyclotron is used for accelerating positive ions, so that they acquire energy large enough to carry out nuclear reactions.



In a cyclotron, the positive ions cross again and again the same alternating (radio frequency) electric field.
And gain the energy each time = q V.
q = charge and V = pot^n. difference in bet^n dees.
It is achieved by making them to move along spiral path under the action of a strong magnetic field.
Principle : A positive ion can acquire sufficiently large energy with a comparatively smaller alternating potential difference by making them to cross the same electric field again and again by making use of a strong magnetic field.
Construction : It consists of two D-shaped hollow semicircular metal chambers D_1 and D_2, called dees. The two dees are placed horizontally with a small gap separating them. The dees are connected to the source of high frequency electric field. The dees are enclosed in a metal box containing a gas at a low pressure of the order of 10^{-3} mm mercury.
The whole apparatus is placed between the two poles of a strong electromagnet NS as shown in fig. The magnetic field acts perpendicular to the plane of the dees.
The positive ions are produced in the gap between the two dees by the ionisation of the gas. To produce proton, hydrogen gas is used; while for producing α-particles, helium gas is used.
Theory : Consider that a positive ion is produced at the centre of the gap at the time, when the dee D_1 is at positive potential and the dee D_2 is at a negative potential.
The positive ion will move from dee D_1 to dee D_2.
The force on the positive ion due to magnetic field provides the centripetal force to the positive ion and it is deflected along a circular path because magnetic field is normal to the motion.
Let strength of the magnetic field = B,
mass of ion = m, velocity of ion = v and charge of the positive ion = q
and the radius of the semi-circular path = r

then $B\,q\,v = \frac{m\,v^2}{r}$ [inside the dee D_2]. Thus, $r = \frac{m\,v}{B\,q}$

After moving along the semi-circular path inside the dee D_2, the positive ion reaches the gap between the dees. At this stage, the polarity of the dees just reverses due to alternating "electric field" i.e. dee D_1 becomes negative and dee D_2 becomes positive. The positive ion again gains the energy, as it is attracted by the dee D_1. After moving along the semi-circular path inside the dee D_1, the positive ion again reaches the gap and it gains the energy.(=q V)
This process repeats itself because, the positive ion spends the same time inside a dee irrespective of its velocity or the radius of the circular path.
The time spent inside a dee to cover semi-circular path, is

$$t = \frac{\text{length of the semi circular path}}{\text{velocity}} = \frac{\pi r}{v}$$

or $$t = \frac{\pi m}{Bq} \qquad \left[\frac{r}{v} = \frac{m}{Bq}\right]$$

As positive ion gains kinetic energy its velocity increases, due to increasing velocity, decrease in time spent inside a dee of positive ions is exactly compensated by the increase in length of the semi circular path ($r \propto v$).
Due to this condition, the positive ion always crosses the alternating electric field across the gap in correct phase.

Cyclotron frequency

Under the action of the given magnetic field (B fixed), the given positive ion (e/m fixed) will cover the semi-circular path in a fixed time only, if t in equation is equal to T/2
Where T is the time period of the electric field.

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

The cyclotron angular frequency, $\omega = \frac{Bq}{m}$

Also, cyclotron frequency, $\nu = \frac{Bq}{2\pi m}$

Maximum energy of the positive ions : Maximum energy acquired by positive ions depends on the radius R of the dees. After acquire this energy positive ion emerge out the dees and use for hitting the target.
Let v_{max} be the velocity acquired by the positive ions, when it moves along the largest circular path i.e. path of radius equal to the radius R of the dees.

Then $$B q v_{max} = \frac{m v_{max}^2}{R} \quad \text{or} \quad v_{max} = \frac{BqR}{m}$$

Therefore maximum kinetic energy gained by the positive ion, $E_{max} = \frac{1}{2} m v_{max}^2 = \frac{1}{2} m \left(\frac{BqR}{m}\right)^2$ or $E_{max} = \frac{1}{2}\frac{B^2q^2R^2}{m}$

The maximum energy acquired by the positive ion can be expressed in another form as given below :
If V is the potential difference applied between the dees and N is the number of times, the positive ion cross the gap between the dees before leaving the dees, then

$$E_{max} = N q V$$

N = 2n, n = the number of rotations completed.

Example 7 :

A cyclotron in which the magnetic flux density is 1.4 tesla is used to accelerate protons. With what frequency the electric field between the "dees" should be reversed ?
Given : mass of proton = 1.67×10^{-27} kg.

Sol. $$\nu = \frac{Bq}{2\pi m} = \frac{1.4 \times 1.6 \times 10^{-19} \times 7}{2 \times 22 \times 1.67 \times 10^{-27}} \text{ Hz} = 2.1 \times 10^7 \text{ Hz}$$

Example 8 :

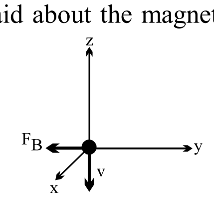
The frequency of oscillating potential applied to the dees of a cyclotron is 8×10^6 Hz. Determine the magnetic field required to accelerated an α-particle.
Given : mass of α-particle = 6.645×10^{-27} kg.

Sol. $$B = \frac{2\pi m \nu}{q}$$

$$= 2 \times \frac{22}{7} \times 6.645 \times 10^{-27} \times 8 \times 10^6 \times \frac{1}{3.2 \times 10^{-19}} \quad T = 1.04T$$

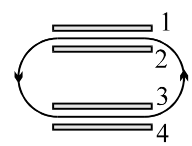
TRY IT YOURSELF-3

Q.1 A positively charged particle has a velocity in the negative z direction, as shown in the figure. The Lorentz force on the particle is in the negative y direction. From this observation alone, what can be said about the magnetic field at this point?



(A) Bx is positive
(B) Bx is negative
(C) By is positive
(D) By is negative

Q.2 Figure shows the path of an electron in a region of uniform magnetic field. The path consists of two straight sections, each between a pair of uniformly charged plates, and two half-circles.The plates are named 1, 2, 3 & 4. Then



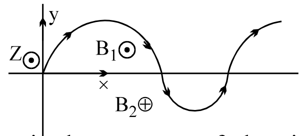
(A) 1 and 3 at higher (positive) potential and 2 and 4 at lower (negative) potential
(B) 1 and 3 at lower potential and 2 and 4 at higher potential
(C) 1 and 4 at higher potential and 2 and 3 at lower potential
(D) 1 and 4 at lower potentail and 2 and 3 at higher potential

Q.3 A charged particle is fired at an angle θ to a uniform magnetic field directed along the x-axis. During its motion along a helical path, if the pitch of the helical path is equal to the maximum distance of the particle from the x-axis

(A) $\cos \theta = 1/\pi$ (B) $\sin \theta = 1/\pi$
(C) $\tan \theta = 1/\pi$ (D) $\tan \theta = \pi$

Q.4 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 $|B_1| > |B_2|$



Q.5 A charged particle is moving in the presence of electric ($\vec{E}$) and magnetic ($\vec{B}$) fields. The directions of $\vec{E}$ and $\vec{B}$ are such that the charged particle moves in a straight line and its speed increases. The relations amongst $\vec{E}$, $\vec{B}$ and velocity $\vec{V}$ must be such that

(A) $\vec{E}\cdot\vec{B} = 0$, $\vec{V}$ is arbitrary
(B) $\vec{E}$, $\vec{B}$ and $\vec{V}$ are all parallel to each other
(C) $\vec{E}\cdot\vec{V} = 0$, $\vec{B}\cdot\vec{V} = 0$ but $\vec{E}\cdot\vec{B} \neq 0$
(D) $\vec{V}$ is parallel to $\vec{E}$ and perpendicular to $\vec{B}$

Q.6 A particle of specific charge σ (q / m) moving with a certain velocity v enters a uniform magnetic field of strength B directed along the negative Z-axis entending from $x = r_1$ to $x = r_2$. The minimum value of v required in order that the particle can just enter the region $x > r_2$ is :

(A) $\sigma r_2 B$ (B) $\sigma r_1 B$
(C) $\sigma (r_2 - r_1) B$ (D) $\sigma\sqrt{r_2^2 - r_1^2}\,B$

Q.7 In order to measure the speed v of blood flowing through an artery, a uniform magnetic field B is applied in a direction perpendicular to the flow and a voltmeter measures the voltage across the diameter D of the artery, at right angles to B. If positive and negative ions in the blood are longitudinally at rest with respect to the flow, the speed of the flow is closet to

(A) v = V/BD (B) v = BD/V
(C) v = VD/B (D) v = B/VD

Q.8 A proton and an alpha particle enter a uniform magnetic field with the same velocity. The period of rotation of the alpha particle will be

(A) four times that of proton
(B) two times that of proton
(C) three times that of proton
(D) the same as that of proton

Q.9 Two particles having the same specific charge (q/m) enter a uniform magnetic field with the same speed but at angles of 30° and 60° with the field. Let a, b and c be the ratios of their pitches, radii and periods of their helical paths respectively,

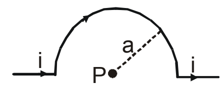
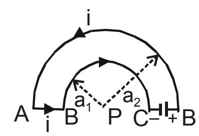
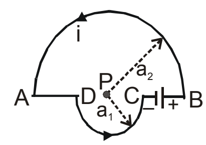
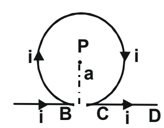
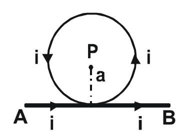
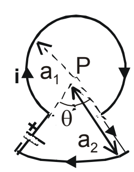
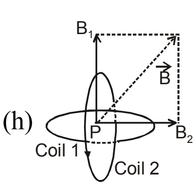
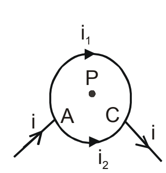
(A) abc = 1 (B) $a + b = 2\sqrt{c}$
(C) $a^2 = c$ (D) ab = c

ANSWERS

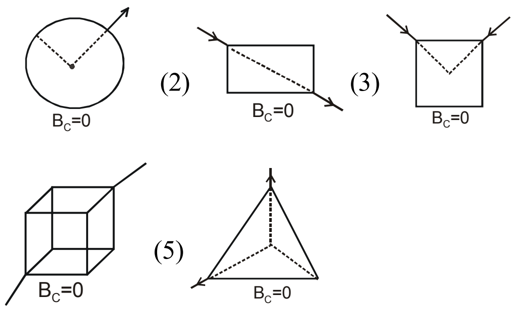
(1) (A)	**(2)** (C)	**(3)** (D)
(4) (A)	**(5)** (B)	**(6)** (C)
(7) (A)	**(8)** (B)	**(9)** (AD)

USEFUL TIPS

* **Magnetic field due to various geometries**

	Geometry	**Magnetic field**
(a)		$B = 0$
(b)		$B = \frac{\mu_0}{4\pi}\frac{i.\pi}{a} = \frac{\mu_0 i}{4a}\otimes$
(c)		$B = \frac{\mu_0}{4\pi}(\pi i)\left\{\frac{1}{a_1} - \frac{1}{a_2}\right\}\otimes$
(d)		$B = \frac{\mu_0 \pi i}{4\pi}\left(\frac{1}{a_1} + \frac{1}{a_2}\right)\odot$
(e)		$B = \frac{\mu_0 i}{2a}\left(1 - \frac{1}{\pi}\right)$
(f)		$B = \frac{\mu_0 i}{2a}\left(1 + \frac{1}{\pi}\right)\odot$
(g)		$B = \frac{\mu_0 i}{4\pi}\left\{\frac{2\pi - \theta}{a_1} + \frac{\theta}{a_2}\right\}\otimes$
(h)		$B_1 = \frac{\mu_0}{4\pi}\frac{2\pi i_1}{a_1}\hat{k}$ $B_2 = \frac{\mu_0}{4\pi}\frac{2\pi i_2}{a_2}\hat{j}$ $B = \sqrt{B_1^2 + B_2^2} = \frac{\mu_0}{2}\sqrt{\frac{i_1^2}{a_1^2} + \frac{i_2^2}{a_2^2}}$
(i)		$B = 0$

* If in a symmetrical geometry, current enters from one end and exit from the other, then magnetic field at the center is zero.



Note : In all the above cases, $B_C = 0$

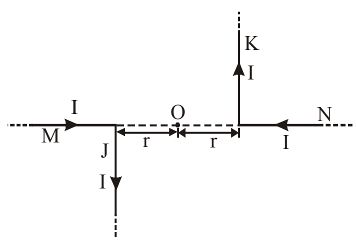
* For current carrying coil $\vec{M} = NI\vec{A}$;

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

ADDITIONAL EXAMPLES

Example 1 :

Two infinite wires bent in the form of L carries current I as shown in figure. What is the magnetic field at point O.



Sol. As point O is along the length of segments M and N so the field O due to these segments will be zero.

Again as point O is near one end of a long wire,

$$\vec{B} = \vec{B}_J + \vec{B}_K = \frac{\mu_0 I}{4\pi r} \odot + \frac{\mu_0 I}{4\pi r} \odot \text{ or } B = \left[\frac{\mu_0 I}{4\pi r} \times 2\right] \odot$$

Example 2 :

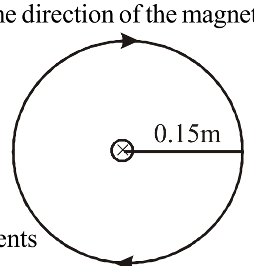
A straight wire carries a current of 3A. Calculate the magnitude of the magnetic field at a point 15 cm away from the wire. Draw a diagram to show the direction of the magnetic field.

Sol. $I = 3\,A, r = 0.15\,m$

$$B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7}}{2\pi \times 0.15}\,T$$

$= 4.0 \times 10^{-6}\,T$

The 'cross' ⊗ in the fig. represents current into the plane of the paper.

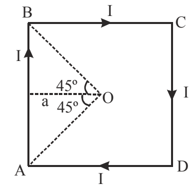


Example 3 :

Calculate the magnetic field at the centre of a coil in the form of a square of side 2a carrying a current I.

Sol. The current carrying coil ABCD may be assumed to be made of four current-carrying conductors AB, BC, CD and DA.

Magnetic field at O due to current-carrying conductor AB is:



$$B = \frac{\mu_0 I}{4\pi a}[\sin 45° + \sin 45°]$$

$$= \frac{\mu_0 I}{4\pi a} 2\sin 45°$$

or $B = \frac{\mu_0 I}{4\pi a} \times 2 \times \frac{1}{\sqrt{2}}$ or $B = \frac{\sqrt{2}\mu_0 I}{4\pi a}$

Total magnetic field at O,

$$B' = 4B = 4 \times \frac{\sqrt{2}\,\mu_0 I}{4\pi a} = \frac{\sqrt{2}\,\mu_0 I}{\pi a}$$

Example 4 :

Two straight infinitely long and thin parallel wires are spaced 0.1 m apart and carry a current of 10 ampere each. Find the magnetic field at a point distance 0.1 m from both wires in the two cases when the currents are in the

(a) same and (b) opposite directions.

Sol. As the point P is equidistant from both the wires W_1 and W_2 and the distance between the wires is equal to the distance of point P from a wire, so W_1, W_2 and P will lie on vertices of equilateral triangle of side 0.1 m.

$$B_1 = B_2 = B = \frac{\mu_0}{4\pi} \times \frac{2I}{d} = 10^{-7} \times \frac{2 \times 10}{0.1} = 2 \times 10^{-5}\,T$$

Now as lines of force in case of a current-carrying wire are circles encircling the wire

so B_1 is perpendicular to W_1 P and $B_2 \perp W_2$ P

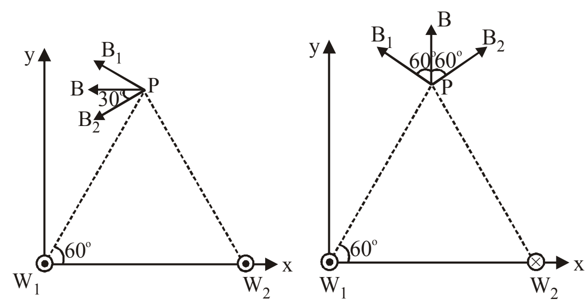


fig. (a) **fig. (b)**

(a) If wires carry current in the same direction (say out to the page), B_1 and B_2 will have directions as shown in fig. (a) and angle is 60° between them. So

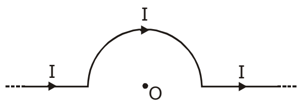
$B_R = 2B\cos 30 = 2\sqrt{3} \times 10^{-5}$ T along negative x-axis.

(b) If the wires carry current in opposite direction (say in W_1 out of the page while in W_2 into the page), then B_1 and B_2 will have directions as shown in fig. (b) with ∠ 120° between them. So,

$B_R = 2B\cos 60° = 2 \times 10^{-5}$ T along positive y-axis.

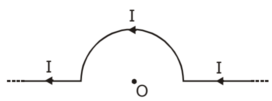
Example 5 :

A straight wire carrying a current of I is bent into a semicircular arc of radius r as shown in fig. What is the direction and magnitude of magnetic field at the centre of the arc ?



Sol. $B = \frac{\mu_0 I}{4r}$ $\quad \alpha = \pi$

If the wire were bent into a semicircular arc of the same radius but in the opposite way as shown in figure.
The field will be of the same magnitude



but its direction will be normal to the plane of paper and in outward direction.

Example 6 :

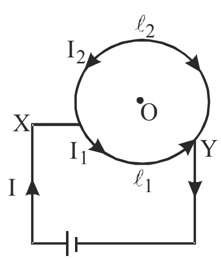
The radius of the first electron orbit of a hydrogen atom is 0.5 Å. The electron moves in this orbit with a uniform speed of 2.2×10^6 m/s. What is the magnetic field produced at the centre of the nucleus due to the motion of this electron ?

Sol. $B = \frac{\mu_0 I}{2r} = \frac{\mu_0 e}{2rT}$. But $T = \frac{2\pi r}{v}$; $B = \frac{\mu_0 ev}{2r \times 2\pi r} = \frac{\mu_0 ev}{4\pi r^2}$

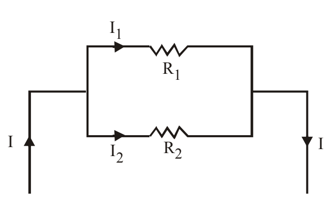
or $B = \frac{4\pi \times 10^{-7} \times 1.6 \times 10^{-19} \times 2.2 \times 10^6}{4\pi(0.5 \times 10^{-10})^2} T = 14.08\ T$

Example 7 :

As shown in figure, a cell is connected across X & Y of a uniform circular conductor. Prove that the magnetic field at the centre will be zero.



Sol. Let ℓ_1 and ℓ_2 be the lengths of the shorter and longer segments respectively and their respective resistances are R_1 and R_2. Resistance per unit length of wire $= \rho$
$R_1 = \rho\, \ell_1$ and $R_2 = \rho\, \ell_2$



Let I_1 and I_2 be the respective current.
The shorter and the longer segments are in parallel.

$\therefore\ I_1R_1 = I_2R_2$ or $I_1\rho \frac{\ell_1}{a} = I_2\rho \frac{\ell_2}{a}$ or $I_1\ell_1 = I_2\ell_2$

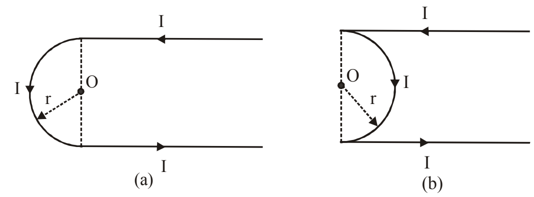
Let B_1 and B_2 be the magnetic fields at the centre O of the coil due to shorter and longer segments respectively.

Now, $B_1 = \frac{\mu_0}{4\pi}\frac{I_1\ell_1}{r^2}$, $\qquad B_2 = \frac{\mu_0}{4\pi}\frac{I_2\ell_2}{r^2}$

Clearly, $B_1 = B_2$. Also the direction of the fields are opposite. So, the net field at O is zero.

Example 8 :

Calculate the field at the centre of a semicircular wire of radius r in situations shown in figure (a) and (b), if the straight wire is of infinite length.



Sol. If the conductor is of infinite length but one end is infront of point P then magnetic field at distance r from it is $\left(\frac{\mu_0 I}{4\pi r}\right)$

And at the centre of a semicircular coil is $\left(\frac{\mu_0 \pi I}{4\pi r}\right)$

hence net magnetic field at point O is $\vec{B}_R = \vec{B}_a + \vec{B}_b + \vec{B}_c$

(a) $\vec{B}_R = \frac{\mu_0}{4\pi}\frac{I}{r} \odot + \frac{\mu_0}{4\pi}\frac{\pi I}{r} \odot + \frac{\mu_0}{4\pi}\frac{I}{r} \odot$

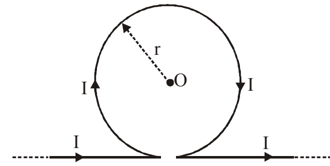
$= \frac{\mu_0}{4\pi}\frac{I}{r}[\pi + 2]$ out of the page

(b) $\vec{B}_R = \frac{\mu_0}{4\pi}\frac{I}{r} \odot + \frac{\mu_0}{4\pi}\frac{\pi I}{r} \otimes + \frac{\mu_0}{4\pi}\frac{I}{r} \odot$

$= \frac{\mu_0}{4\pi}\frac{I}{r}[\pi - 2]$ into the page

Example 9 :

Figure shows a current-carrying system of straight wire and loop. Determine the magnetic field at the centre O of the loop. Given : r is radius of loop and I is current flowing in the system.



Sol. Magnetic field at O due to straight wire, $B_1 = \frac{\mu_0 I}{2\pi r}$

normal to the plane of paper and directed outwards.
Magnetic field at O due to current-carrying loop,

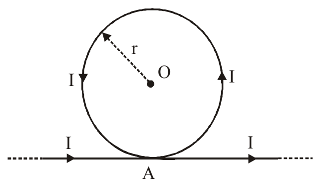
$B_2 = \frac{\mu_0 I}{2r}$ normal to the plane of paper and directed inwards.

Net magnetic field at O, $B = B_2 - B_1$

$$\text{or } B = \frac{\mu_0 I}{2r} - \frac{\mu_0 I}{2\pi r} \qquad \text{or } B = \frac{\mu_0 I}{2\pi r}\left[1 - \frac{1}{\pi}\right] \otimes$$

It is normal to the plane and directed inwards.

Straight wire and loop there is no contact at point A



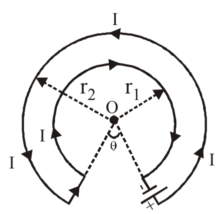
At the centre O of the loop and at distance r from straight wire $B = B_2 + B_1$

$$\text{or } B = \frac{\mu_0 I}{2r} + \frac{\mu_0 I}{2\pi r} \text{ or } B = \frac{\mu_0 I}{2\pi r}\left[1 + \frac{1}{\pi}\right] \odot \text{ out of the page}$$

Example 10 :

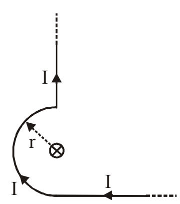
A wire loop is formed by joining two circular wires of radii r_1 and r_2 as shown in fig. If the loop carries a current I, find the magnetic field at the centre O.

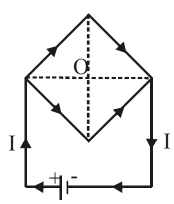
$$B = \left[\frac{\mu_0 I(2\pi - \theta)}{4\pi r} - \frac{\mu_0 I(2\pi - \theta)}{4\pi r}\right] \otimes$$



Semicircular arc and straight conductor

$$B = \frac{\mu_0 I}{4r}\left[1 + \frac{1}{\pi}\right]$$ ⊗ Normal to plane of paper downward





At the centre of the square B = 0

Example 11 :

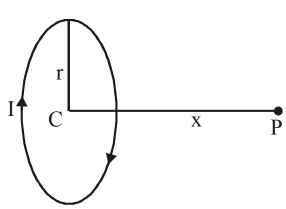
An electric current is flowing in a circular coil of radius r. At what distance from the centre on the axis of the coil will the magnetic field be 1/8th of its value at the centre ?

Sol. If B_1 and B_2 be the magnetic fields at P and C respectively,

then $B_1 = \frac{1}{8} B_2$

$$\frac{\mu_0 I r^2}{2(r^2 + x^2)^{3/2}} = \frac{1}{8}\frac{\mu_0 I}{2r}$$

or $x = r\sqrt{3}$



Example 12 :

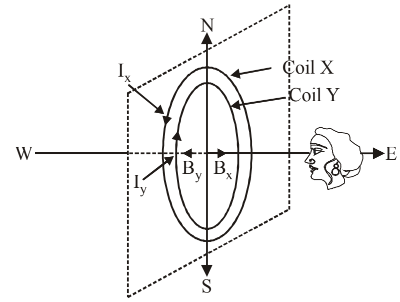
Two concentric circular coils X and Y of radii 16 cm and 10cm respectively lie in the same vertical plane containing the north-south direction. Coil X has 20 turns and carries a current of 16 A; coil Y has 25 turns and carries a current of 18 A. The sense of the current in X is anticlockwise, and in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

(i) Due to coil X alone ? (ii) Due to coil Y alone ?

(iii) Due to both the coils ?

Sol. According to the figure the magnitude of the magnetic field at the centre of coil X is

$$B_x = \frac{\mu_0}{2}\frac{I_x N_x}{r_x} = \frac{2\pi \times 10^{-7}}{2} \times \frac{16 \times 20}{0.16} = 4\pi \times 10^{-4}\,T$$



Since the current in coil X is anticlockwise, the direction of B_x is towards the east as shown in figure.

The magnitude of magnetic field at the centre of the coil Y is given by

$$B_Y = \frac{\mu_0}{2}\frac{I_Y N_Y}{a_Y} = \frac{4\pi \times 10^{-7}}{2} \times \frac{18 \times 25}{2} = 9\pi \times 10^{-4}\,T$$

∵ since the current in coil Y is clockwise, the direction of field B_Y is towards the west (see fig.).

Since the two fields are collinear and oppositely directed, The magnitude of the resultant field = difference between the two fields.

And its direction is that of the bigger field. Hence the net magnetic field at the common centre is $5\pi \times 10^{-4}$ T and is directed towards the west.

Example 13 :

Two circular coils are made of two identical wires of same length. If the number of turns of the two coils are 4 and 2. Find out the ratio of magnetic induction at centres of them.

Sol. $L = n_1 2\pi r_1 = n_2 2\pi r_2$

$$\Rightarrow n_1 r_1 = n_2 r_2 \Rightarrow \frac{r_1}{r_2} = \frac{n_2}{n_1}\ ;\ B = \frac{\mu_0 n i}{2r}$$

$$\Rightarrow \frac{B_1}{B_2} = \frac{\mu_0 n_1 i / 2r_1}{\mu_0 n_2 i / 2r_2} = \frac{n_1}{n_2} \cdot \frac{r_2}{r_1} = \left(\frac{n_1}{n_2}\right)^2 = \frac{4}{1}$$

Example 14 :

Two coaxial coils of equal radii placed at a distance equal to the radius of either of the coils and current 0.1 amp. is flowing through them, number of turns in each coil is 25 and radius is 10 cm. Find out magnetic field intensity at the middle point.

Sol. $B = 0.76\dfrac{\mu_0 \, n\, I}{a} = 0.76 \times \dfrac{4\times 3.14\times 10^{-7}\times 25\times 0.1}{0.1}$

$= 2.38 \times 10^{-5}$ Wb./m^2

Example 15 :

A solenoid is 2m long and 3cm in diameter. It has 5 layers of winding of 1000 turns each and carries a current of 5 A. What is the magnetic field at its centre ? Use the standard value of μ_0.

Sol. Length of solenoid, $\ell = 2$m

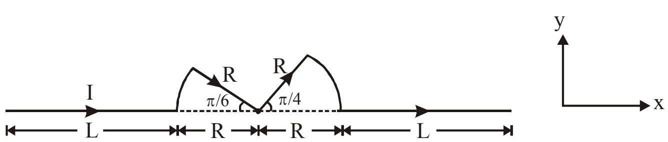
Total number of turns, $N = 5 \times 1000 = 5000$

Number of turns per unit length, $n = \dfrac{N}{\ell} = \dfrac{5000}{2} = 2500\ m^{-1}$

Now, $B = \mu_0\, n\, I = 4\pi \times 10^{-7} \times 2500 \times 5\ T = 1.57 \times 10^{-2}\ T$

Example 16 :

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



(A) If $\vec{B}$ is along $\hat{z}$, $F \propto (L + R)$

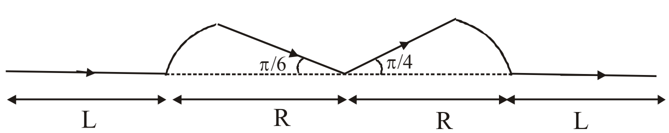
(B) If $\vec{B}$ is along $\hat{x}$, $F = 0$

(C) If $\vec{B}$ is along $\hat{y}$, $F \propto (L + R)$

(D) If $\vec{B}$ is along $\hat{z}$, $F = 0$

Sol. **(ABC).**

$\vec{F} = i\,(\vec{\ell} \times \vec{B}) = i\,\{2\,(L + R)\,\hat{i} \times \vec{B}\}$



If $\vec{B}$ is along $\hat{z}$, $\vec{F} = [i\,2\,(L + R)\,B]\,(-\hat{j})$

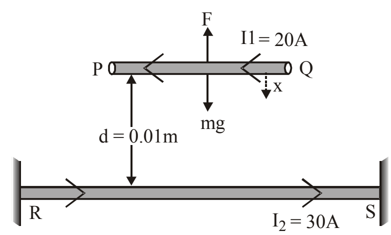
If $\vec{B}$ is along $\hat{x}$, $\vec{F} = 0$

If $\vec{B}$ is along $\hat{y}$, $\vec{F} = i\,\{2\,(L + R)\,B]\,\hat{k}\}$

Example 17 :

A long horizontal wire PQ which is free to move in a vertical plane and carries a steady current of 20 A, is in equilibrium at a height of 0.01 m over another parallel long wire RS, which is fixed in a horizontal plane and caries a steady current of 30 A as shown in figure. Show that when PQ is slightly depressed and released it executes simple harmonic motion. Find the period of oscillations.

Sol. Force per unit length between two parallel current carrying wires, $\dfrac{dF}{dL} = \dfrac{\mu_0}{4\pi}\dfrac{2I_1I_2}{d}$



and is repulsive if current through them are in opposite directions, so for the equilibrium of wire PQ,

$$\frac{mg}{L} = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{d} \qquad \text{....... (1)}$$

Now if the upper wire is displaced by x towards the lower one, the magnetic repulsive force will increase and so the restoring force will be

$$F_2 - F_1 = \frac{\mu_0}{4\pi} 2I_1I_2L\left[\frac{1}{(d-x)} - \frac{1}{d}\right] \text{ vertically up}$$

or $f = -\dfrac{\mu_0}{4\pi}\dfrac{2\,I_1\,I_2\,L}{4\,\pi\,d\,(d-x)}x$ [as f is opposite to x]

or $\dfrac{\mu_0}{4\pi}\dfrac{2I_1I_2L}{d^2}x$ [as x << d]

As the restoring force is linear, motion will be simple harmonic with force constant $k = \dfrac{\mu_0}{4\pi}\dfrac{2I_1I_2L}{d^2}$

so that $T = 2\pi\sqrt{\dfrac{m}{k}} = 2\pi\sqrt{\dfrac{4\,\pi\,m\,d^2}{\mu_0 2\,I_1I_2L}}$

Using Eqn. (1), $T = 2\pi\sqrt{\dfrac{m\,d^2}{m\,g\,d}} = 2\pi\sqrt{\dfrac{d}{g}}$

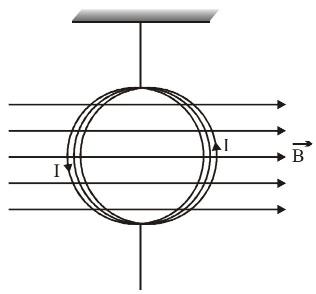
So here $T = 2\pi\sqrt{\dfrac{0.01}{9.8}} = \dfrac{2\times 3.14}{31.3} = 0.2$ sec

Example 18 :

A circular coil of 25 turns and radius 6.0 cm, carrying a current of 10 A, is suspended vertically in a uniform magnetic field of magnitude 1.2 T. The field lines run horizontally in the plane of the coil. Calculate the force and torque on coil due to the magnetic field. In which direction should a balancing torque be applied to prevent the coil from turning ?

Sol. Let us consider any element $\vec{d\ell}$ of the coil.

The force on this element is $I\,(\vec{d\ell} \times \vec{B})$.



For each element $d\vec{\ell}$, there is another element $-d\vec{\ell}$ diametrically opposite on the closed loop

Since $\vec{B}$ is uniform therefore the forces cancel for each pair of such elements.

So, the net force on the coil is zero.

The torque $\vec{\tau}$ on a plane loop of any shape carrying a current I in a magnetic field B is given by

$$\vec{\tau} = I A\, \hat{n} \times \vec{B}$$

[$\hat{n}$ = unit vector normal to the plane of the loop]

For a circular coil of radius r and N turns area $A = N \times \pi r^2$

The angle between $\hat{n}$ and $\vec{B}$ is 90°.

So, the magnitude of torque $\tau = B\, I\, A \sin\alpha$

or $\tau = 1.2 \times 10 \times 25 \times \pi(0.06)^2 \sin 90° = 3.39$ N m

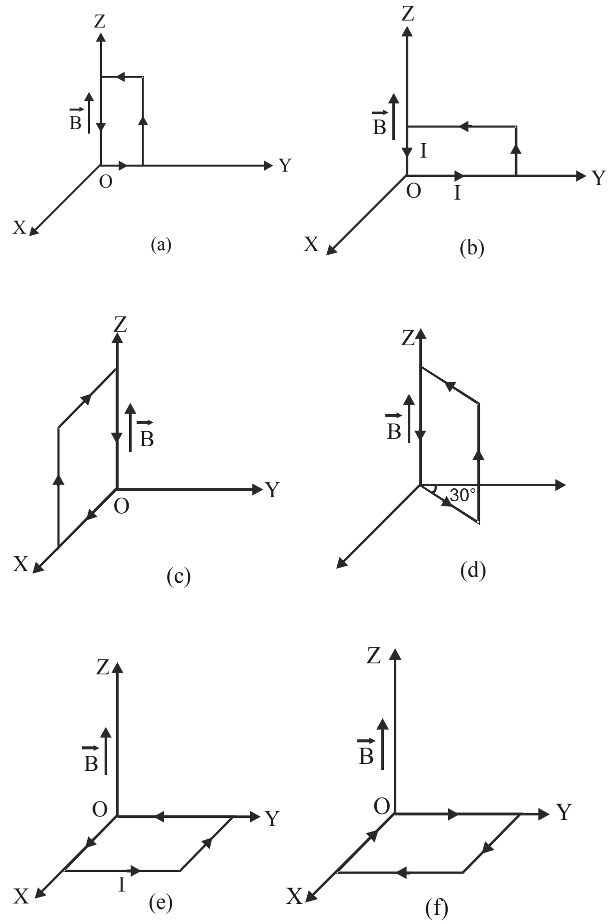
The direction of $\vec{\tau}$ is vertically upwards. To prevent the coil from turning, an equal and opposite torque must be applied.

Example 19 :

A uniform magnetic field of 5000 gauss is established along the positive z-direction. A rectangular loop of side 20 cm and 5 cm carries a current of 10 A is suspended in this magnetic field. What is the torque on the loop in the different cases shown in the following figures ? What is the force in each case ? Which case corresponds to stable equilibrium ?

Sol. (a) Torque on loop, $\tau = BIA \cos\theta$

where θ is the angle between the plane of loop and direction of magnetic field.



Here, θ = 0°; B = 5000 gauss = 5000×10^{-4} tesla = 0.5 tesla

I = 10 ampere, $A = 20 \times 5\ cm^2 = 100 \times 10^{-4} = 10^{-2}\ m^2$

Now, $\tau = 0.5 \times 10 \times 10^{-2} = 5 \times 10^{-2}$ N m

It is directed along –y-axis

(b) Same as (a). (c) $\tau = 5 \times 10^{-2}$ N m along –x-direction

(d) $\tau = 5 \times 10^{-2}$ N m at an angle of 240° with +x direction.

(e) τ is zero. ∵ Angle between plane of loop and direction of magnetic field is 90°]

(f) τ is zero.

resultant force is zero in each case.

Case (e) corresponds to stable equilibrium.

Example 20 :

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 is (a) transverse to its initial velocity (b) makes an angle of 30° with the initial velocity. Take mass of electron = 9×10^{-31} kg.

Sol. V = 2 kilo volt = 2000 volt; B = 0.15 T

$$v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 2 \times 10^{3}}{9 \times 10^{-31}}} \text{ m/s}$$

$$= \frac{8}{3} \times 10^{7} \text{ m/s} \qquad [\because \frac{1}{2} mv^2 = eV]$$

(a) When the magnetic field is perpendicular to the initial velocity : For the circular motion of the electron the necessary centripetal force is provided by magnetic force. $\therefore$ Bev = $\frac{mv^2}{r}$

or $r = \frac{mv}{Be} = \frac{9\times10^{-31}\times8\times10^{7}}{3\times0.15\times1.6\times10^{-19}}$ m $= 10^{-3}$ m $= 1$ mm

(b) When initial direction of the particle makes an angle of 30° with the magnetic field

Due to component of velocity perpendicular to the field, the electron move along a circular path and no change in component of velocity in the direction of the field. Due to combined effect of these two the electron will move along helical path.

Radius of helical path,

$$r = \frac{m\,v\sin\theta}{e\,B} = \frac{9\times10^{-31}\times8\times10^{7}\sin30°}{3\times0.15\times1.6\times10^{-19}} = 0.5\text{ mm}$$

Example 21 :

In a chamber, a uniform magnetic field of 8×10^{-4} T is maintained. An electron with a speed of 4.0×10^{6} m/s enters the chamber in a direction normal to the field.

(a) Describe the path of the electron.

(b) What is the frequency of revolution of the electron ?

(c) What happens to the path of the electron if it progressively loses its energy due to collisions with the atoms or molecules of the environment ?

Sol. (a) The path of the electron is a circle of radius

$$r = \frac{m\,v}{e\,B} = \frac{9.1\times10^{-31}\times4\times10^{6}}{1.6\times10^{-19}\times8\times10^{-4}} = 2.8\times10^{-2}\text{ m}$$

The sense of rotation of the electron in its orbit can be determined from the direction of the centripetal force. $\vec{F} = -e(\vec{v}\times\vec{B})$. So, if we look along the direction of $\vec{B}$, the electron revolves clockwise.

(b) The frequency of revolution of the electron in its circular orbit $\nu = \frac{v}{2\pi r} = \frac{1.6\times10^{-19}\times8.0\times10^{-4}}{2\pi\times9.1\times10^{-31}}$ Hz $= 22.4$ MHz

(c) Due to collision with the atomic consistent of the environment, the electron progressively loses its speed. If the velocity vector of the electron remains in the same plane of the initial circular orbit after collisions, the radius of the circular orbit will decrease in proportion to the decreasing speed. However, in general, the velocity of the electron will not remain in the plane of the initial orbit after collision. In that case, the component of velocity normal to $\vec{B}$ will determine the radius of the orbit, while the component of velocity parallel to $\vec{B}$ remains constant. Thus, the path of the electron, between two collisions is, in general, helical. But an important fact must be noted: the frequency of orbital revolution remains the same, whatever be the speed of the electron.

Example 22 :

Electron moving at right angles to the uniform magnetic field completes a circular orbit in 10^{-6}s. Calculate the value of magnetic field.

Sol. Period of revolution $T = \frac{2\pi m}{B e}$ $[\because T = 10^{-6}\text{ s}]$

or $B = \frac{2\pi m}{e T} = \frac{2\pi\times9\times10^{-31}}{1.6\times10^{-19}\times10^{-6}} = 3.534\times10^{-5}$ Tesla

Example 23 :

An electron in passing through a field but no forces acting on it. Under what condition it is possible, that the motion of the electron will be in the (i) electric field (ii) magnetic field?

Sol. (i) In electric field, there is always a force on the moving electron opposite to the direction of field. Thus the force will be zero only if field is zero.

(ii) In magnetic field, the force acting on a moving electron is $F = q\,v\,B\sin\theta$, it is zero if $\theta = 0°$ or $180°$

i.e., the electron is moving parallel to the direction of magnetic field.

Example 24 :

The energy of a charged particle moving in a uniform magnetic field does not change. Explain

Sol. When a charged particle is moving in a uniform magnetic field it experiences a force in a direction, perpendicular to its direction of motion. Due to which the speed of the charged particle remains unchanged and work done on it is zero, hence its kinetic energy remains same.

Example 25 :

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

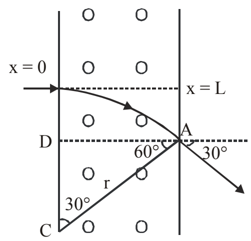
Sol. (a) The particle is moving with velocity $v_0\hat{i}$, perpendicular to magnetic field $B_0\hat{k}$. Hence the particle will move along a circular arc OA of radius $r = \frac{m\,v_0}{q\,B_0}$

Let the particle leave the magnetic field at A.

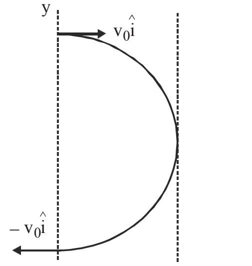
From ΔCDA, $\cos 60° = \dfrac{AD}{CA} = \dfrac{L}{r}$

or $L = r\cos 60° = \dfrac{r}{2}$

$\therefore\ L = \dfrac{m\,v_0}{2q\,B_0}$



(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 $= \dfrac{\pi r}{v_0} = \dfrac{\pi m}{q\,B_0}$

Example 26 :

A test charge of 1.6×10^{-19} C is moving with velocity $\vec{v} = (2\hat{i} + 3\hat{j})$ m/s in a magnetic field $\vec{B} = (2\hat{i} + 3\hat{j})$ Wb m^2. Find the force acting on the test charge.

Sol. $e = 1.6 \times 10^{-19}$ C; $\vec{v} = (2\hat{i} + 3\hat{j})$ m/s;

$\vec{B} = (2\hat{i} + 3\hat{j})$ Wb m^{-2}

$$\vec{F} = e(\vec{v} \times \vec{B}) = 1.6 \times 10^{-19}\,[(2\hat{i} + 3\hat{j}) \times (2\hat{i} + 3\hat{j})] = 0$$

Example 27 :

A beam of protons is deflected sideways. Could this deflection be caused be (i) a magnetic field (ii) an electric field? If either possible, what would be the difference?

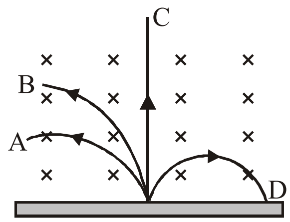
Sol. Yes, the moving charged particle (e.g., proton, α-particles etc.) may be deflected sideway either by an electric or by a magnetic field.

(i) The force exerted by a magnetic field on the moving charged particle is always perpendicular to direction of motion, so that no work is done on the particle by this magnetic force. That is the magnetic field simply deflects the particle and does not increase its kinetic energy.

(ii) The force exerted by electric field on the charged particle at rest or in motion is always along the direction of field and the kinetic energy of the particle changes.

Example 28 :

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.

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

With the help of RHSR, it will experience a force to the right; so track D corresponds to electron.

If the charge on particle is positive.

With RHSR, 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 $\left(\dfrac{m}{q}\right)_p = \dfrac{m}{e}$

i.e., $\left(\dfrac{m}{q}\right)_\alpha > \left(\dfrac{m}{q}\right)_p$, so $r_\alpha > r_p$

i.e., track B to α-particle and A corresponds to proton.

Example 29 :

If a charged particle is deflected either by an electric or a magnetic field, how can be ascertain the nature of the field?

Sol. By observing the trajectory and measuring the kinetic energy of the charged particle as in a magnetic field the trajectory is a circle in a plane perpendicular to the field and the KE (and hence the speed) remains constant while in an electric field the trajectory is a parabola in a plane parallel to the field and the KE (and hence the speed) of the particle changes.

If the velocity of a particle remains unchanged in passing through a certain region,

apart from $\vec{E} = 0$ and $\vec{B} = 0$ only possible situations are:

(a) $\vec{E} = 0$ and $\vec{B} \neq 0$ $\rightarrow$ When $\vec{v} \parallel \vec{B}$

(b) $\vec{E} \neq 0$ and $\vec{B} \neq 0$ are possible. $\rightarrow$ When $\vec{F}_E = -\vec{F}_M$

Example 30 :

A cyclotron is operating with a flux density of 3 Wb/m^2. The ion which enters the field is a proton having mass 1.67×10^{-27} kg. If the maximum radius of the orbit of the particle is 0.5 m, find (a) the maximum velocity of the proton, (b) the kinetic energy of the particle, and (c) the period for a half cycle.

Sol. (a) For motion of a charged particle in a magnetic field,

$$r = \frac{mv}{qB} \quad \text{or} \quad v = \frac{qBr}{m} \quad \text{So,} \quad v_{max} = \frac{qBr_{max}}{m}$$

$$\text{So, } v_{max} = \frac{1.6\times10^{-19}\times3\times0.5}{1.67\times10^{-27}} = 1.43\times10^{8}\text{ m/s}$$

(b) $$KE = \frac{1}{2}mv^2 = \frac{1}{2}\times1.67\times10^{-27}\times(1.43\times10^{8})^2$$

$$\text{i.e., } KE = 1.71\times10^{-11}\text{ J} = \frac{1.71\times10^{-11}}{1.6\times10^{8}} = 108\text{ MeV}$$

(c) In case of circular motion, as

$$T = \frac{2\pi r}{v} = \frac{2\pi\times0.5}{1.43\times10^{8}} = 2.18\times10^{-8}\text{ s},$$

So time for half cycle,

$$t = \frac{1}{2}(T) = \frac{1}{2}(2.18\times10^{-8}) = 1.09\times10^{-8}\text{ s}$$

Example 31 :

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 ? Given $e = 1.60\times10^{-19}$ C, $m = 1.67\times10^{-27}$ kg. Express your answer in units of MeV. (Given, 1 MeV $= 1.6\times10^{-13}$ J)

Sol. $$B = \frac{2\pi m\nu}{e} = \frac{2\pi\times1.67\times10^{-27}\times10^{7}}{1.60\times10^{-19}} = 0.656\text{ Tesla}$$

$m = 1.67\times10^{-27}$ kg; $e = 1.60\times10^{-19}$ C;
$\nu = 10$ MHz $= 10^{7}$ Hz; $R = 60$ cm $= 0.6$ m

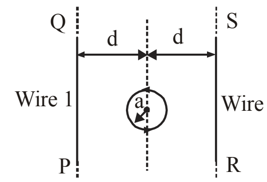
$$E_{max} = \frac{B^2e^2R^2}{2m}$$

$$= \frac{(0.656)^2\times(1.60\times10^{-19})^2(0.6)^2}{2\times1.67\times10^{-27}}$$

$$= 11.874\times10^{-13}\text{ J} = \frac{11.874\times10^{-13}}{1.6\times10^{-13}}$$
$$= 7.421\text{ MeV}$$

Paragraph For Ex. 32 and 33

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.



Ex.32 When $d \approx a$ but wires are not touching the loop, it is found that the net magnetic field on the axis of the loop is zero at a height h above the loop. In that case

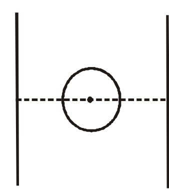
(A) Current in wire 1 and wire 2 is the direction PQ and RS, respectively and $h \approx a$.
(B) Current in wire 1 and wire 2 is the direction PQ and SR, respectively and $h \approx a$
(C) Current in wire 1 and wire 2 is the direction PQ and SR, respectively and $h \approx 1.2a$
(D) Current in wire 1 and wire 2 is the direction PQ and RS, respectively and $h \approx 1.2a$.

Sol. **(C).** $$\frac{\mu_0 ia^2}{2(a^2+h^2)^{3/2}} = \frac{2\times\mu_0 ia}{2\pi(a^2+h^2)}$$

$$\frac{a^2}{\sqrt{a^2+h^2}} = \frac{2a}{\pi}\ ;\ \frac{a^4}{a^2+h^2} = \frac{4a^2}{\pi^2}$$

$$10a^2 = 4a^2 + 4h^2$$
$$6a^2 = 4h^2$$

$$\frac{3a^2}{2} = h^2 \Rightarrow h = 1.2\,a$$



Ex.33 Consider $d >> a$, and the loop is rotated about its diameter parallel to the w ires 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)

(A) $\dfrac{\mu_0 I^2a^2}{d}$ (B) $\dfrac{\mu_0 I^2a^2}{2d}$

(C) $\dfrac{\sqrt{3}\mu_0 I^2a^2}{d}$ (D) $\dfrac{\sqrt{3}\mu_0 I^2a^2}{2d}$

Sol. **(B).** $$B = \frac{\mu_0 I}{2\pi d}\times2$$

$$\tau = \frac{\mu_0 I\times2}{2\pi d}\times I\times\pi a^2\times\frac{1}{2} = \frac{\mu_0 I^2a^2}{2d}$$

3B

MAGNETISM

MAGNETISM

The phenomenon of attracting magnetic substances like iron, cobalt nickel etc. is called magnetism. A body possessing the property of magnetism is called magnet.

HISTORICAL FACTS

(1) The word magnet is derived from the name of an island in Greece called magnesia where magnetic ore deposits were found.

(2) Thallus of Miletus knew that pieces of lodestone or magnetite (black iron oxide Fe_2O_3) could attract small pieces of iron.

(3) The Chinese discovered that a linear piece of lodestone when suspended freely pointed in north and south direction. That is why name lodestone which is given to magnetite means leading stone.

(4) The Chinese are credited with making technological use of this directional property for navigation of ships.

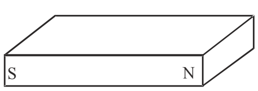
(5) In 1600 BC William Gilbert published a book De Magnete which gave an account of then known facts of magnetism.

(6) Due to their irregular shapes and weak attracting power natural magnets are rarely used.

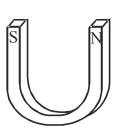
(7) Lodestone or magnetite is natural magnet. Earth is also a natural magnet.

ARTIFICAL MAGNETS

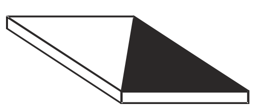
(1) The permanent artificial magnets are made of some metals and alloys like carbon-steel, Alnico, Platinum-cobalt, Alcomax, Ticonal. The permanent magnets are made of ferromagnetic substances with large coercivity and retentivity and can have desired shape like bar-magnet, U shaped magnet or magnetic needle etc. These magnet retain its attracting power for a long time.



Bar-magnet



U-shape magnet

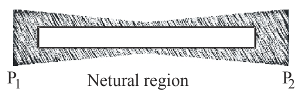


Magnetic-needle

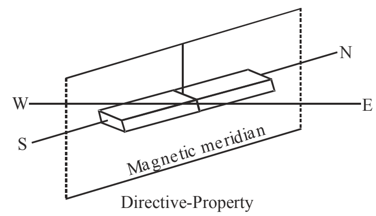
(2) The temporary artificial magnet like electromagnets are prepared by passing current through coil wound on soft iron core. These cannot retain its attracting power for a long time. These are made from soft iron, non-metal and alloy.

PROPERTIES OF BAR MAGNET

(1) Attractive Property and Poles : When a magnet is dipped into iron fillings it is found that the concentration of iron filings, i.e., attracting power of the magnet is maximum at two points near the ends and minimum at the centre. The places in a magnet where its attracting power is maximum are called poles while the place of minimum attracting power is called the neutral region.



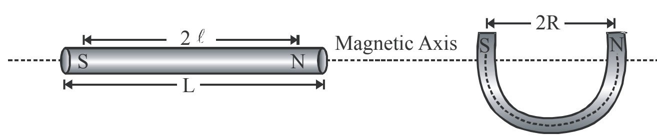
Attractive Property



Directive-Property

(2) Directive Property and N-S Poles : When magnet is suspended its length becomes parallel to N-S direction. The pole pointing north is called the north pole while the other pointing south is called the south pole.

(3) Magnetic Axis and Magnetic Meridian : The line joining the two poles of a magnet is called magnetic axis and the vertical plane passing through the axis of a freely suspended or pivoted magnet is called magnetic meridian.



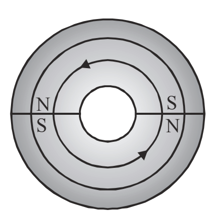
Effective length = 2 ℓ
Actual length = L

Effective length = 2R
Actual length = πR

(4) Magnetic Length (2ℓ) : The distance between two poles along the axis of a magnet is called its effective or magnetic length. As poles are not exactly at the ends, the effective length is lesser then the actual length of the magnet.

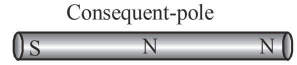
(5) Poles Exist in Pairs : In a magnet the two poles are found to be equal in strength and opposite in nature. If a magnet is broken into number of pieces, each piece becomes a magnet with two equal and opposite poles. This shows that monopoles do not exist.

(6) Consequent-poles and No-pole : Monopoles do not exist in a magnet but there are two poles of equal strength and opposite nature :



Magnet with no poles

Consequent-pole



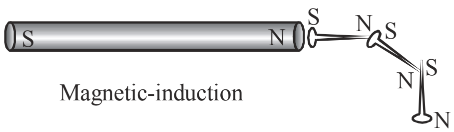
Magnet with similar poles
(or with three poles)

(a) There can be magnets with no poles, e.g., a magnetised ring called toroid or solenoid of infinite length has properties of a magnet but no poles.

(b) There can be magnets with two similar poles (or with three poles), e.g., due to faulty magnetisation of a bar, temporarily identical poles at the two ends with an opposite pole of double strength at the centre of bar (called consequent pole) are developed.

(7) Repulsion is a Sure Test of Polarity : A pole of a magnet attracts the opposite pole while repels similar pole. A sure test of polarity is repulsion and not attraction, as attraction can take place between opposite poles or a pole and a piece of unmagnetised magnetic material due to 'induction effect'.

(8) Magnetic Induction : A magnet attracts certain other substances through the phenomenon of magnetic induction i.e., by inducing opposite pole in a magnetic material on the side facing it as shown in fig.



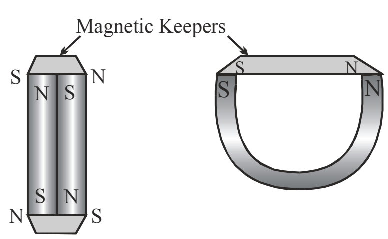
Magnetic-induction

(9) Magnetic and Non-magnetic Materials : The substances such as steel, iron, cobalt and nickel, etc., which are attracted by a magnet are called magnetic while substances such as copper, aluminium stainless steel, wood, glass and plastic, etc. which are not attracted by the magnet are usually called non-magnetic.

(10) Permanent and Temporary Magnets : If a magnet retains its attracting power for a long time it is said to be permanent, otherwise temporary. Permanent magnets are made of steel, Alnico, Alcomax or Ticonal while temporary of soft iron, non-metal or alloy.

(11) Demagnetisation : A magnet gets demagnetised, i.e., loses its power of attraction if it is heated, hammered or ac is passed through a wire wound over it.

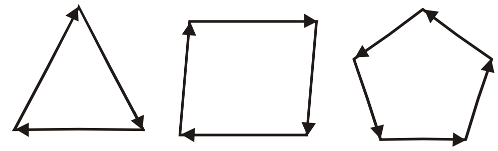
(12) Magnetic Keepers : A magnet tends to become weaker with age owing to self-demagnetisation due to poles at the ends which tends to neutralise each other. However, by using pieces of soft iron called keepers, the poles at the ends are neutralised and consequently the demagnetising effect disappears and the magnet can retain its magnetism for a longer period.



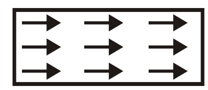
ATOMIC THEORY OF MAGNETISM

(1) Each atom behaves like a complete magnet having a north and south pole of equal strength. The electrons revolving around the nucleus in an atom are equivalent to small current loops which behaves as magnetic dipole.

(2) In unmagnetised magnetic substance these atomic magnets (represented by arrows) are randomly oriented and form closed chains. The atomic magnets cancel the effect of each other and thus resultant magnetism is zero.



(3) In magnetised substance all the atomic magnets are aligned in same direction & thus resultant magnetism is non-zero.



The atomic theory explains the following facts in magnetism.

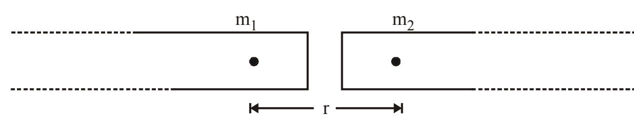
(i) Non existence of monopoles. The magnetic poles always exist in pairs and are of equal strength.

(ii) When a magnet breaks than each part behaves like a complete magnet.

(ii) Magnetisation of an electromagnet can be explained as alignment of atomic magnets in direction of magnetic field.

(iv) This explains the phenomenon of saturation magnetisation i.e. acquired magnetism remains constant even on increasing the external magnetising field.

COULOMB'S LAW IN MAGNETISM

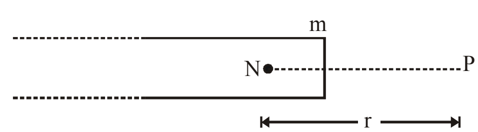


If two magnetic poles of strengths m_1 and m_2 are kept at a distance r apart then force of attraction or repulsion between the two poles is directly proportional to the product of their pole strengths and inversely proportional to the square of the distance between them

$$F \propto \frac{m_1 m_2}{r^2} \quad \text{or} \quad F = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{r^2}$$

where $F = \frac{\mu_0}{4\pi} = 10^{-7}\ \text{Wb A}^{-1}\ \text{m}^{-1} = 10^{-7}$ henry/m where μ_0 is permeability of free space.

MAGNETIC FLUX DENSITY



The force experienced by a unit north pole when placed in a magnetic field is called magnetic flux density or field intensity at that point $\vec{B} = \frac{\vec{F}}{m} = \frac{\mu_0}{4\pi}\frac{m}{r^2}\hat{r}$

This is the magnetic field produced by a pole of strength m at distance r.

POLE STRENGTH

In relation $F = \frac{\mu_0}{4\pi} \frac{m_1 m_2}{r^2}$

If $m_1 = m_2 = m$, $r = 1$m and $F = 10^{-7}$ N

then $10^{-7} = 10^{-7} \times \frac{m \times m}{1^2}$ or $m^2 = 1$

or m = ± 1 ampere metre (A-m)

The strength of a magnetic pole is said to be one ampere meter if it repels an equal and similar pole with a force of 10^{-7} N when placed in vacuum (or air) at a distance of one meter from it. The pole strength of north pole is defined as the force experienced by the pole when kept in unit magnetic field. $m = \frac{\vec{F}}{\vec{B}}$

(i) Pole strength is a scalar quantity with dimension $M^0L^1T^0A^1$.

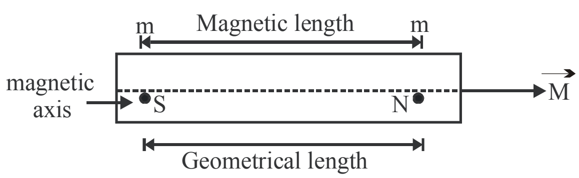
(ii) The unit is newton/Tesla or ampere meter.

(iii) The pole strength depends on nature of material of magnet, state of magnetisation (with an upper limit called saturation) and area of cross-section.

(iv) The north pole experiences a force in the direction of magnetic field while south pole experiences force opposite to field.

MAGNETIC DIPOLE AND MAGNETIC DIPOLE MOMENT :

Magnetic Dipole : An arrangement of two magnetic poles of equal and opposite strengths separated by a finite distance is called a magnetic dipole.



Two poles of a magnetic dipole or a magnet are of equal strength and opposite nature. The line joining the poles of the magnet is called magnetic axis. The distance between the two poles of a bar magnet is called the magnetic length of magnet. It is denoted by 2ℓ. The distance between the ends of the magnet is called geometrical length of the magnet. The ratio of magnetic length and geometrical length is 5/6 or 0.83.

A small bar magnet is treated like a magnetic dipole.

MAGNETIC DIPOLE MOMENT

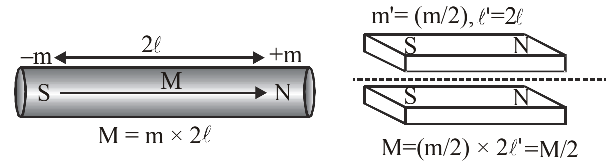
The product of strength of either pole and the magnetic length of the magnet is called magnetic dipole moment.

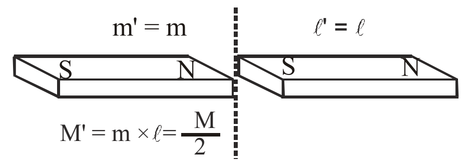
$$\vec{M} = m\,(2\vec{\ell})$$

It is a vector quantity whose direction is from south pole to north pole of magnet. The unit of magnetic dipole moment is ampere metre^2 (Am^2) and Joule/Tesla (J/T). The dimensions are $M^0L^2T^0A^1$. If a magnet is cut into two equal parts along the length then pole strength is reduced to half and length remains unchanged.

New magnetic dipole moment $M' = m'(2\ell) = \frac{m}{2} \times 2\ell = \frac{M}{2}$.

The new magnetic dipole moment of each part becomes half of original value.

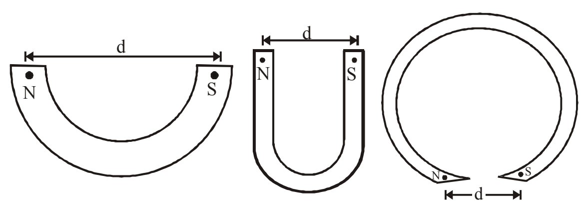




If a magnet is cut into two equal parts transverse to the length then pole strength remains unchanged and length is reduced to half. New magnetic dipole moment

$$M' = m\left(\frac{2\ell}{2}\right) = \frac{M}{2}.$$

The new magnetic dipole moment of each part becomes half of original value. In magnetism existence of magnetic monopole is not possible. The magnetic dipole moment of a magnet is equal to product of pole strength and distance between poles. $M = m\,d$



As magnetic moment is a vector, in case of two magnets having magnetic moments M_1 and M_2 with angle θ between them, the resulting magnetic moment.

$$M = \left[M_1^2 + M_2^2 + 2M_1M_2\cos\theta\right]^{1/2}$$

with $\tan\phi = \left[\frac{M_2 \sin\theta}{M_1 + M_2\cos\theta}\right]$

Example 1 :

The force between two magnetic poles in air is 9.604 mN. If one pole is 10 times stronger than the other, calculate the pole strength of each if distance between two poles is 0.1m?

Sol. Force between poles $F = \frac{\mu_0}{4\pi} \frac{m_1 m_2}{r^2}$

or $9.604 \times 10^{-3} = \frac{10^{-7} \times m \times 10m}{0.1 \times 0.1}$

or $m^2 = 96.04\ N^2\ T^{-2}$ or $m = 9.8$ N/T

So strength of other pole is 9.8 × 10 = 98 N/T

Example 2 :

A steel wire of length L has a magnetic moment M. It is then bent into a semicircular arc. What is the new magnetic moment?

Sol. If m is the pole strength then $M = m \cdot L$ or $m = \frac{M}{L}$

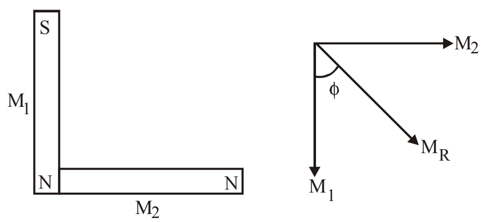
If it is bent into a semicircular arc then $L = \pi r$ or $r = L/\pi$

So new magnetic moment

$$M' = m \times 2r = \frac{M}{L} \times 2 \times \frac{L}{\pi} = \frac{2M}{\pi}$$

Example 3 :

Two identical bar magnets each of length L and pole strength m are placed at right angles to each other with the north pole of one touching the south pole of other. Evaluate the magnetic moment of the system.



Sol. $M_1 = M_2 = mL$

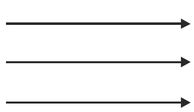
$$\therefore \quad M_R = \sqrt{M_1^2 + M_2^2 + 2M_1M_2\cos\frac{\pi}{2}} = \sqrt{2}\ mL$$

and $\tan\phi = \frac{M\sin 90}{M + M\cos 90} = 1$ i.e. $\phi = \tan^{-1} 1 = 45°$

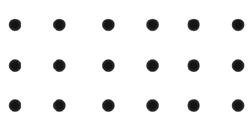
MAGNETIC FIELD

The space around a magnet (or a current carrying conductor) in which its magnetic effect can be experienced is called the magnetic field.

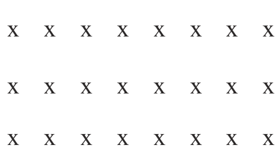
The magnetic field in a region is said to be uniform if the magnitude of its strength and direction is same at all points in that region.



Uniform field in plane of paper



Uniform field perpendicular to plane of paper upwards



Uniform field perpendicular to plane of paper inwards

A magnetic field in a region is said to be uniform if the magnitude of its strength and direction is same at all the points in that region. The strength of magnetic field is also known as magnetic induction or magnetic flux density. The SI unit of strength of magnetic field is Tesla (T)

1 Tesla = 1 newton ampere^{-1} metre^{-1} ($NA^{-1}m^{-1}$)

= 1 Weber metre^{-2} ($Wb\ m^{-2}$)

The cgs unit is gauss (G)

1 gauss (G) = 10^{-4} Tesla (T)

MAGNETIC LINES OF FORCE AND THEIR PROPERTIES

The magnetic field lines is the graphical method of representation of magnetic field. This was introduced by Michael Faraday.

Properties :

(1) A line of force is an imaginary curve the tangent to which at a point gives the direction of magnetic field at that point.

(2) The magnetic field line is the imaginary path along which an isolated north pole will tend to move if it is free to do so.

(3) The magnetic lines of force are closed curves. They appear to converge or diverge at poles outside the magnet they run from north to south pole and inside from south to north.

(4) The number of lines originating or terminating on a pole is proportional to its pole strength.
Magnetic flux = number of magnetic lines of force = $\mu_0 \times m$
where μ_0 is number of lines associated with unit pole.

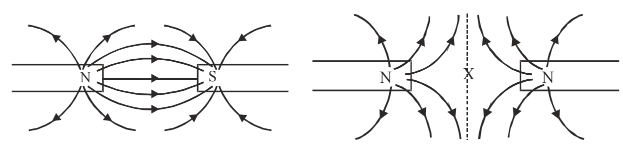
(5) Magnetic lines of force do not intersect each other because if they do there will be two directions of magnetic field which is not possible.

(6) The magnetic lines of force may enter or come out of surface at any angle.

(7) The number of lines of force per unit area at a point gives magnitude of field at that point. The crowded lines show a strong field while distant lines represent a weak field.

(8) The magnetic lines of force have a tendency to contract longitudinally like a stretched elastic string producing attraction between opposite pole.

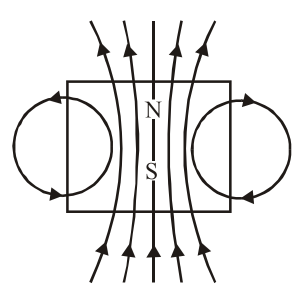
(9) The magnetic lines of force have a tendency to repel each other laterally resulting in repulsion between similar poles.



Longitudnal contraction (attraction) Lateral expansion (repulsion)

(10) The region of space with no magnetic field has no lines of force. At neutral point where resultant field is zero there cannot be any line of force.

(11) Magnetic lines of force exist inside every magnetised material.



IMPORTANT POINTS

(i) Magnetic lines of force always form closed and continuous curves whereas the electric lines of force are discontinuous.

(ii) Each electric line of force starts from a positive charge and ends at a negative charge. Electric lines of force are discontinuous because no such lines exist inside a charged body.

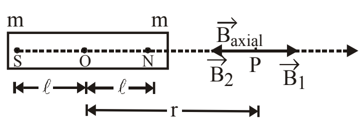
(iii) In magnetism, as there are no monopoles, therefore, the magnetic field lines will be along closed loops with no starting or ending. The magnetic lines of force would pass through the body of the magnet.

(iv) At very far off points, the lines due to an electric dipole and a magnetic dipole appear identical.

MAGNETIC FIELD DUE TO A SHORT BAR MAGNET (MAGNETIC DIPOLE)

(1) **On axial point or end on position :** The magnetic field $\vec{B}_{axial}$ at a point P due to bar magnet will be the resultant of the magnetic fields $\vec{B}_1$ due to N-pole of magnet and $\vec{B}_2$ due to S-pole of magnet.

$$\vec{B}_{axial} = \vec{B}_1 + \vec{B}_2$$



$$\vec{B}_1 = \frac{\mu_0}{4\pi}\frac{m}{(r-\ell)^2}(\hat{r}) \text{ and } \vec{B}_2 = \frac{\mu_0}{4\pi}\frac{m}{(r+\ell)^2}(-\hat{r})$$

$$\therefore \quad \vec{B}_{axial} = \left[\frac{\mu_0}{4\pi}\frac{m}{(r-\ell)^2} - \frac{\mu_0}{4\pi}\frac{m}{(r+\ell)^2}\right]\hat{r}$$

$$= \frac{\mu_0 m}{4\pi}\left[\frac{4r\ell}{(r-\ell)^2\ (r+\ell)^2}\right]\hat{r}$$

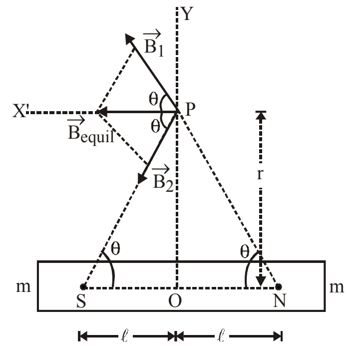
$$\vec{B}_{axial} = \frac{\mu_0}{4\pi}\frac{2\vec{M}r}{(r^2-\ell^2)^2}$$

Magnetic field due to a bar magnet at an axial point has same direction as that of its magnetic dipole moment vector. For a bar magnet of very small length $\ell << r$

$$\vec{B}_{axial} = \frac{\mu_0}{4\pi}\frac{2\vec{M}}{r^3}$$

(2) **On equatorial point or broadside position :** The magnetic field $\vec{B}_{equi}$ at a point P due to bar magnet will be the resultant of the magnetic fields $\vec{B}_1$ due to N-pole of magnet and $\vec{B}_2$ due to S-pole of magnet $\vec{B}_{equi} = \vec{B}_1 + \vec{B}_2$

$$|\vec{B}_1| = \frac{\mu_0}{4\pi}\frac{m}{NP^2} = \frac{\mu_0}{4\pi}\frac{m}{r^2+\ell^2} \text{ along NP}$$



$$|\vec{B}_2| = \frac{\mu_0}{4\pi}\frac{m}{SP^2} = \frac{\mu_0}{4\pi}\frac{m}{(r^2+\ell^2)} \text{ along PS}$$

So $|\vec{B}_1| = |\vec{B}_2|$ On resolving $\vec{B}_1$ and $\vec{B}_2$ along PX' and PY we find $|\vec{B}_1|\sin\theta$ and $|\vec{B}_2|\sin\theta$ are equal and opposite so they cancel each other. So resultant field

$$\vec{B}_{equi} = \vec{B}_1\cos\theta\,(-\hat{r}) + \vec{B}_2\cos\theta\,(-\hat{r})$$

$$= \left[\frac{\mu_0}{4\pi}\frac{m}{(r^2+\ell^2)}\cos\theta + \frac{\mu_0}{4\pi}\frac{m}{(r^2+\ell^2)}\cos\theta\right](-\hat{r})$$

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

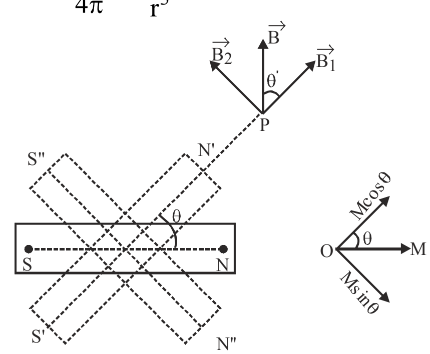
$$\vec{B}_{equi} = -\frac{\mu_0}{4\pi}\frac{\vec{M}}{(r^2+\ell^2)^{\frac{3}{2}}}$$

The direction of magnetic field at a point on equatorial line is opposite to magnetic dipole moment vector.
For a bar magnet of very small length $\ell << r$

$$\vec{B}_{equi} = -\frac{\mu_0}{4\pi}\frac{\vec{M}}{r^3}$$

(3) **At an arbitrary point :** The point P is on axial line of magnet S'N' with magnetic moment Mcosθ. Magnetic flux density

$$B_1 = \frac{\mu_0}{4\pi}\frac{2M\cos\theta}{r^3}.$$



The point P is simultaneously on the equatorial line of other magnet N"S" with magnetic moment Msinθ. Magnetic flux density $B_2 = \frac{\mu_0}{4\pi}\frac{M\sin\theta}{r^3}$

Total magnetic flux density at P

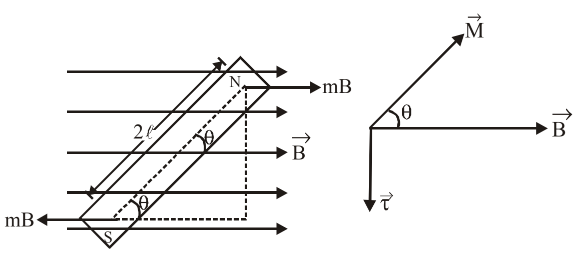
$$B = \sqrt{B_1^2 + B_2^2} = \frac{\mu_0}{4\pi}\frac{M}{r^3}\sqrt{4\cos^2\theta + \sin^2\theta}$$

or $$B = \frac{\mu_0}{4\pi}\frac{M}{r^3}\sqrt{1 + 3\cos^2\theta}$$

$$\tan\theta' = \frac{B_2}{B_1} = \frac{\frac{\mu_0}{4\pi}\frac{M\sin\theta}{r^3}}{\frac{\mu_0}{4\pi}\frac{2M\cos\theta}{r^3}} = \frac{1}{2}\tan\theta \quad \text{or} \quad \theta' = \tan^{-1}\left(\frac{1}{2}\tan\theta\right)$$

TORQUE ON A BAR MAGNET IN A MAGNETIC FIELD

When a bar magnet is placed in a uniform magnetic field the two poles experience a force. The forces are equal in magnitude and opposite in direction and do not have same line of action. They constitute a couple of forces which produces a torque. The torque tries to rotate the magnet so as to align it parallel to direction of field.



Net force on bar magnet = $mB\,\hat{i} + mB\,(-\hat{i}) = 0$

Torque, τ = force × perpendicular distance between forces

$\tau = MB\,(2\ell\sin\theta) = MB\sin\theta$

In vector notation $\vec{\tau} = \vec{M} \times \vec{B}$

IMPORTANT POINTS

(1) When a bar magnet is kept in a uniform magnetic field it experiences no force.

(2) The bar magnet experiences a torque $\vec{\tau} = \vec{M} \times \vec{B}$. The direction of torque is perpendicular to plane containing $\vec{M}$ and $\vec{B}$. This torque produces rotational motion of magnet.

(3) $\tau = \tau_{max} = mB$ when $\theta = \frac{\pi}{2}$. The magnet experiences maximum torque when dipole moment vector is perpendicular to magnetic field.

(4) $\tau = \tau_{min} = 0$ when θ = 0 or π. The magnet experiences minimum torque when dipole moment vector is parallel or antiparalled to magnetic field.

WORK DONE IN ROTATING THE MAGNETIC DIPOLE (BAR MAGNET) AND POTENTIAL ENERGY

When a bar magnet of dipole moment M is kept in a uniform magnetic field B it experiences a torque τ = MBsinθ which tries to align it parallel to direction of field. If magnet is to be rotated against this torque work has to be done. The workdone in rotating dipole by small angle dθ is dW = τdθ

Total work done in rotating it from angle θ_1 to θ_2 is

$$W = \int dW = \int_{\theta_1}^{\theta_2} \tau\, d\theta$$

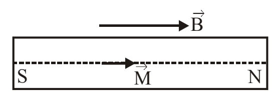
$$= MB\int_{\theta_1}^{\theta_2} \sin\theta\, d\theta = MB\,(\cos\theta_1 - \cos\theta_2)$$

This work done in rotating the magnet is stored inside the magnet as its potential energy.

So $U = MB\,(\cos\theta_1 - \cos\theta_2)$

The potential energy of a bar magnet in a magnetic field is defined as work done in rotating it from a direction perpendicular to field to any given direction.

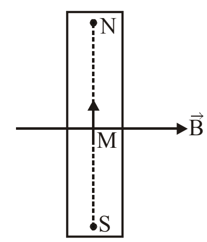
$$U = W_\theta - W_{\frac{\pi}{2}} = -MB\cos\theta = -\vec{M}\cdot\vec{B}$$



$\theta = 0$ $\tau = \tau_{min} = 0$

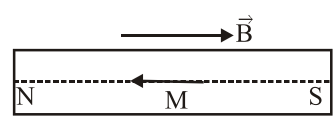
$U = U_{min} = -MB$

Stable equilibrium



$\theta = \frac{\pi}{2}$, $\tau = \tau_{max} = MB$

U = 0



$\theta = \pi$ $\tau = \tau_{min} = 0$

$U = U_{max} = MB$

Unstable equilibrium

GAUSS LAW IN MAGNETISM

The surface integral of magnetic field $\vec{B}$ over a closed surface S is always zero.

Mathematically $\oint_S \vec{B}\cdot\vec{da} = 0$

Isolated magnetic poles do not exist is a direct consequence of gauss law in magnetism. The total magnetic flux linked with a closed surface is always zero. If a number of magnetic field lines are leaving a closed surface, an equal number of field lines must also be entering the surface.

Example 4 :

A bar magnet of length 0.1 m has a pole strength of 50 Am. Calculate the magnetic field at a distance of 0.2 m from its centre on its equatorial line.

Sol. $B_{equi} = \frac{\mu_0}{4\pi} \frac{M}{(r^2+\ell^2)^{\frac{3}{2}}} = \frac{10^{-7} \times 50 \times 0.1}{(0.2^2+0.05^2)^{\frac{3}{2}}} = \frac{5 \times 10^{-7}}{(0.04+0.0025)^{\frac{3}{2}}}$

or $B_{equi} = 5.7 \times 10^{-5}$ Tesla

Example 5 :

What is the magnitude of the equatorial and axial fields due to a bar magnet of length 5 cm at a distance of 50 cm from its mid-point. The magnetic moment of the bar magnet is 0.40 Am^2?

Sol. Here r >> ℓ. So equatorial field

$$B_{equi} = \frac{\mu_0}{4\pi} \frac{M}{r^3} = \frac{10^{-7} \times 0.4}{(0.5)^3} = 3.2 \times 10^{-7}\,T$$

Axial field, $B_{axial} = \frac{\mu_0}{4\pi} \frac{2M}{r^3} = 2 \times 3.2 \times 10^{-7} = 6.4 \times 10^{-7}\,T$

Example 6 :

Find the magnetic field due to a dipole of magnetic moment 1.2 Am^2 at a point 1 m away from it in a direction making an angle of 60° with the dipole axis?

Sol. $B = \frac{\mu_0}{4\pi} \frac{M}{r^3} \sqrt{1+3\cos^2\theta} = \frac{10^{-7} \times 1.2\sqrt{1+3\cos^2 60}}{1}$

$$= \frac{10^{-7} \times 1.2 \times \sqrt{7}}{2} = 1.59 \times 10^{-7}\,T$$

$$\tan\theta' = \frac{1}{2}\tan\theta = \frac{1}{2}\tan 60° = \frac{\sqrt{3}}{2} = 0.866$$

So $\theta' = \tan^{-1} 0.866 = 40.89°$

Example 7 :

A circular coil of 100 turns and having a radius of 0.05 m carries a current of 0.1 A. Calculate the work required to turn the coil in an external field of 1.5 T through 180° about an axis perpendicular to the magnetic field. The plane of coil is initially at right angles to magnetic field?

Sol. Work done $W = MB(\cos\theta_1 - \cos\theta_2) = NIAB(\cos\theta_1 - \cos\theta_2)$

or $W = NI\pi r^2 B(\cos\theta_1 - \cos\theta_2)$

$= 100 \times 0.1 \times 3.14 \times (0.05)^2 \times 1.5(\cos 0° - \cos\pi) = 0.2355$ J

Example 8 :

A bar magnet of magnetic moment 1.5 H T^{-1} lies aligned with the direction of a uniform magnetic field of 0.22 T. (a) What is the amount of work required to turn the magnet so as to align its magnetic moment. (i) Normal to the field direction? (ii) Opposite to the field direction? (b) What is the torque on the magnet in case (i) and (ii)?

Sol. Here, $M = 1.5\,JT^{-1}$, $B = 0.22$ T.

(a) P.E. with magnetic moment aligned to field = – MB
P.E. with magnetic moment normal to field = 0
P.E. with magnetic moment antiparallel to field = + MB

(i) Work done = increase in P.E. = 0 – (–MB)
$= MB = 1.5 \times 0.22 = 0.33$ J.

(ii) Work done = increase in P.E. = MB – (–MB) = 2MB
$= 2 \times 1.5 \times 0.22 = 0.66$ J.

(b) We have $\tau = MB\sin\theta$
(i) $\theta = 90°$, $\sin\theta = 1$, $\tau = MB\sin\theta = 1.5 \times 0.22 \times 1 = 0.33$ J.
This torque will tend to align M with B.
(ii) $\theta = 180°$, $\sin\theta = 0$, $\tau = MB\sin\theta = 1.5 \times 0.22 \times 0 = 0$

Example 9 :

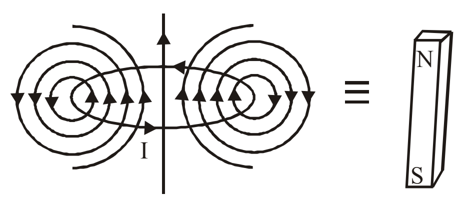
A short bar magnet of magnetic moment 0.32 J/T is placed in uniform field of 0.15 T. If the bar is free to rotate in plane of field then which orientation would correspond to its (i) stable and (ii) unstable equilibrium? What is potential energy of magnet in each case?

Sol. (i) If M is parallel to B then $\theta = 0°$.
So potential energy $U = U_{min} = -MB$
$U_{min} = -MB = -0.32 \times 0.15\,J = -4.8 \times 10^{-2}$ J
This is case of stable equilibrium

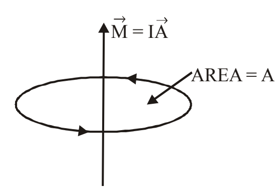
(ii) If M is antiparallel to B then $\theta = \pi°$ so potential energy
$U = U_{max} = +MB = +0.32 \times 0.15 = 4.8 \times 10^{-2}$ J
This is case of unstable equilibrium.

CURRENT LOOP AS A MAGNETIC DIPOLE

We consider a circular coil carrying current I. When seen from above current flows in anti clockwise direction.



(1) The magnetic field lines due to each elementary portion of the circular coil are circular near the element and almost straight near centre of circular coil.



(2) The magnetic lines of force seem to enter at lower face of coil and leave at upper face.

(3) The lower face through which lines of force enter behaves as south pole and upper face through which field lines leave behaves as north pole.

(4) A planar loop of any shape behaves as a magnetic dipole.

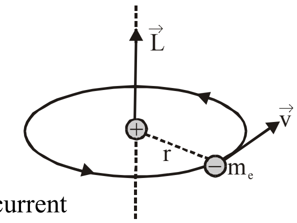
(5) The dipole moment of current loop (M)
= ampere turns (nI) × area of coil (A) or M = nIA.

(6) The unit of dipole moment is ampere meter^2 (A-m^2)

(7) Magnetic dipole moment is a vector with direction from S pole to N pole or along direction of normal to planar area.

ATOM AS A MAGNETIC DIPOLE

In an atom electrons revolve around the nucleus. These moving electrons behave as small current loops. So atom possesses magnetic dipole moment and hence behaves as a magnetic dipole. The angular momentum of electron due to orbital motion $L = m_e vr$.



The equivalent current due to orbital motion

$$I = -\frac{e}{T} = -\frac{ev}{2\pi r}$$

–ve sign shows direction of current is opposite to direction of motion of electron.

Magnetic dipole moment

$$M = IA = -\frac{ev}{2\pi r} \cdot \pi r^2 = -\frac{evr}{2}$$

Using $L = m_e vr$ we have, $M = -\frac{e}{2m_e} L$

In vector form, $\vec{M} = -\frac{e}{2m_e}\vec{L}$

The direction of magnetic dipole moment vector is opposite to angular momentum vector.

According to Bohr's theory $L = \frac{nh}{2\pi}$ $\quad n = 0, 1, 2.........$

$$M = \left(\frac{e}{2m_e}\right)\frac{nh}{2\pi} = n\left(\frac{eh}{4\pi m_e}\right) = n\mu_B \quad \text{where } \mu_B = \frac{eh}{4\pi m_e}$$

$$= \frac{(1.6\times10^{-19}\,C)\ (6.62\times10^{-34}\,Js)}{4\times3.14\times(9.1\times10^{-31}\,kg)} = 9.27\times10^{-24}\ Am^2$$

is called Bohr Magneton. This is natural unit of magnetic moment.

Bohr Magneton : It is defined as the magnetic dipole moment associated with an atom due to orbital motion of an electron in the first orbit of hydrogen atom. This is the smallest value of magnetic moment.

The electron possesses magnetic moment due to its spin motion also $\vec{M}_S = \frac{e}{m_e}\vec{S}$ where $\vec{S}$ is spin angular momentum of electron and $S = \pm\frac{1}{2}\left(\frac{h}{2\pi}\right)$

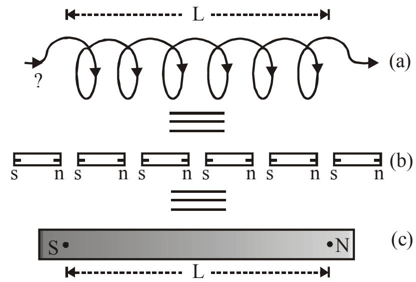
The total magnetic moment of electron is the vector sum of its magnetic moments due to orbital and spin motion. The resultant angular momentum of the atom is given by vector sum of orbital and spin angular momentum due to all electrons.

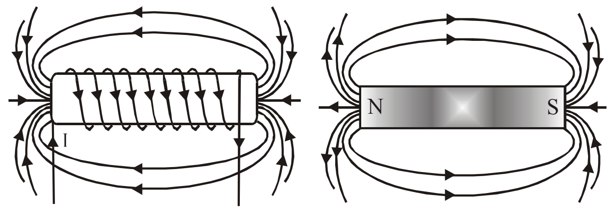
Total angular momentum, $\vec{J} = \vec{L} + \vec{S}$

The resultant magnetic moment $\vec{M}_J = -g\left(\frac{e}{2m}\right)\vec{J}$

where g is Lande's splitting factor which depends on state of an atom. For pure orbital motion g = 1 and pure spin motion g = 2.

BAR MAGNET AS AN EQUIVALENT SOLENOID





In solenoid each turn behaves as a small magnetic dipole having dipole moment IA. A solenoid is treated as arrangement of small magnetic dipoles placed in line with each other. The number of dipoles is equal to number of turns in a solenoid. The south and north poles of each turn cancel each other except the ends. So solenoid can be replaced by single south and north pole separated by distance equal to length of solenoid. The magnetic field produced by a bar magnet is identical to that produced by a current carrying solenoid.

TERRESTRIAL MAGNETISM

The branch of Physics which deals with the study of earth's magnetic field is called terrestrial magnetism.

William Gilbert suggested that earth itself behaves like a huge magnet. This magnet is so oriented that its S pole is towards geographic north and N pole is towards the geographic south.

The earth behaves as a magnetic dipole inclined at small angle 11.5° to the earth's axis of rotation with its south pole pointing geographic north. The idea of earth having magnetism is supported by following facts.

(a) A freely suspended magnet always comes to rest in N-S direction. (b) A piece of soft iron buried in N-S direction inside the earth acquires magnetism. (c) Existence of neutral points. When we draw field lines of bar magnet we get neutral points where magnetic field due to magnet is neutralized by earth's magnetic field. The magnetic field at the surface of earth ranges from nearly 30 μT near equator to about 60 μT near the poles. The magnetic field on the axis is nearly twice the magnetic field on the equatorial line.

CAUSE OF EARTH'S MAGNETISM

(1) Sir William Gilbert first suggested the existence of a powerful magnet inside the earth. This is not possible because.

(a) Temperature inside earth is so high that it will not be possible for magnet to retain magnetism.

(b) If there was a magnet inside the earth then position of earth's magnetic poles would have not changed.

(c) The process of magnetisation of this magnet is not understood.

(2) Grover suggested that earth's magnetism is due to flow of current near outer surface of earth. These currents are produced due to sun. The hot air rising from regions near equator while going towards north and south hemispheres gets electrified. These then magnetise ferromagnetic materials near surface of earth.

(3) According to another view earth's core has many conducting materials like iron and nickel in molten state. Conventional currents are produced in this semi fluid core due to rotation of earth about its axis which generates magnetism. (4) Another view says magnetism is due to presence of ionised gases in atmosphere. The high energy sun rays ionize gas atoms in upper layer of atmosphere. The radioactivity of atmosphere and cosmic rays also ionize the gases. Strong electric currents flow due to rotation of earth producing magnetism. Thus most likely cause of earth's magnetism is the motion and distribution of charged materials in and outside the earth.

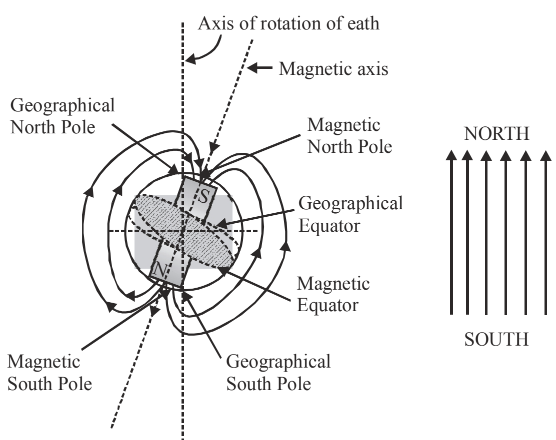
SOME DEFINITIONS

(1) Geographic Axis : It is straight line passing through the geographic poles of the earth. It is the axis of rotation of the earth. It is known as polar axis.

(2) Geographic Meridian : It is a vertical plane passing through geographic north and south poles of the earth.

(3) Geographic Equator : A great circle on the surface of the earth in a plane perpendicular to geographical axis is called geographic equator. All places on geographic equator are at equal distances from geographical poles.

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



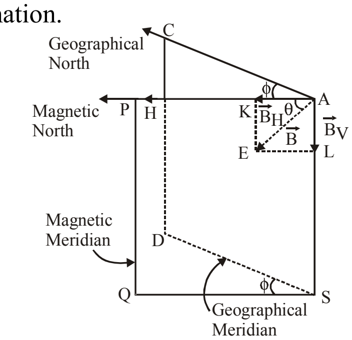
(5) Magnetic Meridian : It is a vertical plane passing through the magnetic north and south poles of the earth.

(6) Magnetic Equator : A great circle on the surface of the earth in a plane perpendicular to magnetic axis is called magnetic equator. All places on magnetic euqator are at equal distance from magnetic poles.

MAGNETIC ELEMENTS

The physical quantities which determine the intensity of earth's total magnetic field completely both in magnitude and direction are called magnetic elements.

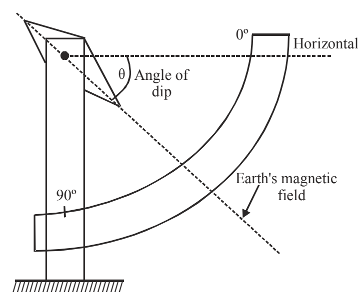
(1) Angle of Declination (ϕ) : The angle between the magnetic meridian and geographic meridian at a place is called angle of declination.



(a) Isogonic Lines : Lines drawn on a map through places that have same declination are called isogonic lines.

(b) Agonic Line : The line drawn on a map through places that have zero declination is known as an agonic line.

(2) Angle of dip or inclination : The angle through which the N pole dips down with reference to horizontal is called the angle of dip. At magnetic north and south pole angle of dip is 90°. At magnetic equator the angle of dip is zero.



OR The angle which the direction of resultant field of earth makes with the horizontal line of magnetic meridian is called angle of dip.

(a) Isoclinic Lines : Lines drawn up on a map through the places that have same dip are called isoclinic lines.

(b) Aclinic Line : The line drawn through places that have zero dip is known as aclinic line. This is the magnetic equator.

(3) Horizontal component of earth's magnetic field : The total intensity of the earth's magnetic field makes an angle θ with horizontal. It has

(i) Component in horizontal plane called horizontal component B_H

(ii) Component in vertical plane called vertical component B_V.

$$B_V = B\sin\theta \qquad B_H = B\cos\theta$$

So $\frac{B_V}{B_H} = \tan\theta$ and $B = \sqrt{B_H^2 + B_V^2}$

Note :

(a) If θ and ϕ are known we can find direction of B.

(b) If θ and B_H are known we can find magnitude of B.

(c) So if θ, ϕ and B_H are known we can find total field at a place. So these are called as Elements of earth's magnetic field.

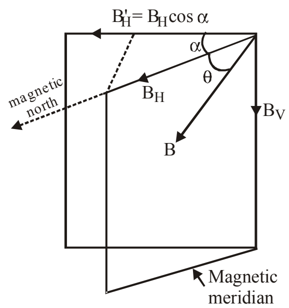
(d) The declination gives the plane, dip gives the direction and horizontal component gives magnitude of earth's magnetic field.

(e) If declination is ignored, then the horizontal component of earth's magnetic field is from geographic south to geographic north.

(f) Angle of dip is measured by instrument called dip circle.

APPARENT DIP

The dip at a place is determined by a dip circle. It consists of magnetised needle capable of rotation in vertical plane about a horizontal axis. The needle moves over a vertical scale graduated in degrees.



(a) When the plane of scale of dip circle is in the magnetic meridian the needle comes to rest in direction of earth's magnetic field. The angle made by the needle with the horizontal is called true dip.

(b) If the plane of the scale of the dip circle is not in the magnetic meridian then the needle will not indicate correct direction of earth's magnetic field. The angle made by the needle with the horizontal is called apparent dip.

Suppose dip circle is set at angle α to magnetic meridian.

Horizontal component $B_H' = B_H \cos\alpha$

Vertical component $B_V' = B_V$ (remains unchanged)

Apparent dip is θ'

$$\tan\theta' = \frac{B_V'}{B_H'} = \frac{B_V}{B_H\cos\alpha} = \frac{\tan\theta}{\cos\alpha}\left(\tan\theta = \frac{B_V}{B_H} = \text{true dip}\right)$$

Note :

(1) For a vertical plane other than magnetic meridian α > 0 or cos α < 1 so θ' > θ. In a vertical plane other than magnetic meridian angle of dip is more than in magnetic meridian.

(2) For a plane perpendicular to magnetic meridian $\alpha = \frac{\pi}{2}$

$$\therefore \tan\theta' = \infty \quad \text{so} \quad \theta' = \frac{\pi}{2}$$

So in a plane perpendicular to magnetic meridian dip needle will become vertical.

At magnetic equator :

Angle of dip is zero. Vertical component of earths magnetic field becomes zero $B_V = B\sin\theta = B\sin 0 = 0$

A freely suspended magnet will become horizontal at magnetic equator. At equator earth's magnetic field is parallel to earth's surface i.e., horizontal.

At magnetic poles :

Angle of dip is 90°. Horizontal component of earth's magnetic field becomes zero. $B_H = B\cos\theta = B\cos 90 = 0$

A freely suspended magnet will become vertical at magnetic poles. At poles earth's magnetic field is perpendicular to the surface of earth i.e. vertical.

Example 10 :

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 – α with magnetic meridian. If θ_1 and θ_2 are apparent dips than

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

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

$$\cot^2\theta_1 + \cot^2\theta_2 = \frac{1}{(\tan\theta_1)^2} + \frac{1}{(\tan\theta_2)^2}$$

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

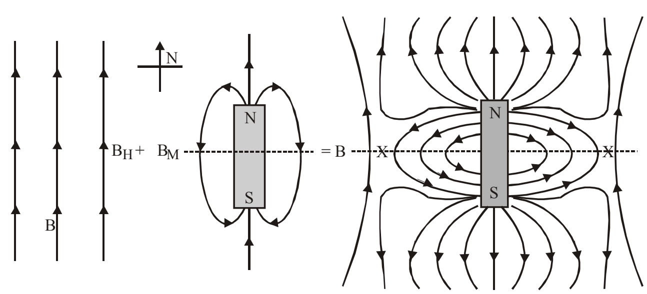
So $\cot^2\theta_1 + \cot^2\theta_2 = \cot^2\theta$

NEUTRAL POINT

When we plot magnetic field of a bar magnet the curves obtained represent the superposition of magnetic fields due to bar magnet and earth.

Neutral Point : A neutral point in the magnetic field of a bar magnet is that point where the field due to the magnet is completely neutralized by the horizontal component of earth's magnetic field. At neutral point field due to bar magnet (B) is equal and opposite to horizontal component of earth's magnetic field (B_H) or $B = B_H$.

Neutral point when north pole of magnet is towards geographical north of earth.



The neutral points N_1 and N_2 lie on the equatorial line. The magnetic field due to magnet at neutral point is

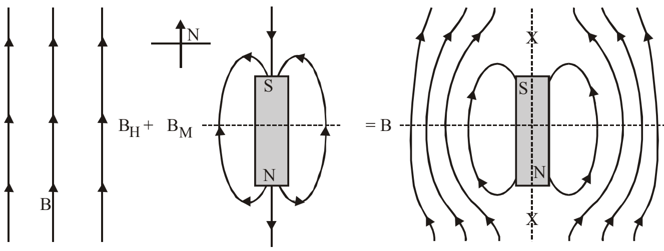
$$B = \frac{\mu_0}{4\pi}\frac{M}{(r^2+\ell^2)^{\frac{3}{2}}}$$. Where M is magnetic dipole moment of magnet, 2ℓ is its length and r is distance of neutral point.

At neutral point $B = B_H$.

so $\frac{\mu_0}{4\pi}\frac{M}{(r^2+\ell^2)^{\frac{3}{2}}} = B_H$

For a small bar magnet ($\ell^2 << r^2$) then $\frac{\mu_0}{4\pi}\frac{M}{r^3} = B_H$

Neutral point when south pole of magnet is towards geographical north of earth.



The neutral points N_1 and N_2 lie on the axial line of magnet. The magnetic field due to magnet at neutral point is

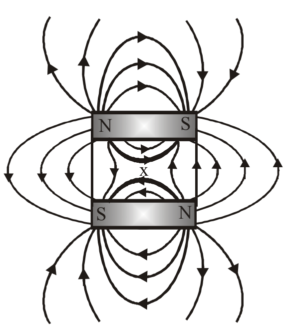
$$B = \frac{\mu_0}{4\pi}\frac{2Mr}{(r^2-\ell^2)^2}$$

At neutral point $B = B_H$ so $\frac{\mu_0}{4\pi}\frac{2Mr}{(r^2-\ell^2)^2} = B_H$

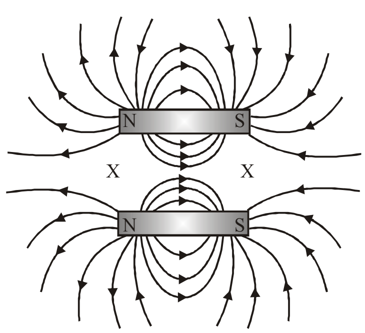
For a small bar magnet ($\ell^2 << r^2$) then $\frac{\mu_0}{4\pi}\frac{2M}{r^3} = B_H$

Special Point : When a magnet is placed with its S pole towards north of earth neutral points lie on its axial line. If magnet is placed with its N pole towards north of earth neutral points lie on its equatorial line. So neutral points are displaced by 90° on rotating magnet through 180°. In general if magnet is rotated by angle θ neutral point turn through an angle θ/2

NEUTRAL POINTS IN SPECIAL CASES



(a)



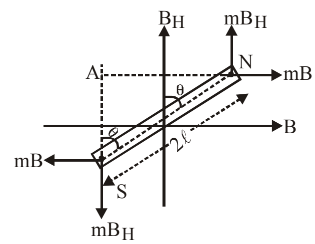
(b)

(a) If two bar magnets are placed with their axis parallel to each other and their opposite poles face each other then there is only one neutral point (x) on the perpendicular bisector of the axis equidistant from the two magnets.

(b) If two bar magnets are placed with their axis parallel to each other and their like poles face each other then there are two neutral points on a line equidistant from the axis of the magnets.

TANGENT LAW

If a small bar magnet is suspended in two mutually perpendicular uniform magnetic fields B and B_H such that it comes to rest making angle θ with direction of field B_H then $B = B_H \tan\theta$.



When a bar magnet is kept in two mutually perpendicular magnetic fields then each field will exert a couple on the magnet tending to set it parallel to itself. The torque due to B_H tries to rotate the magnet in anticlockwise direction while torque due to B in clockwise direction.

In equilibrium, torque due to B_H = torque due to B

$$mB_H \times AN = mB \times AS. \text{ So, } B = B_H\frac{AN}{AS} = B_H \tan\theta$$

TANGENT GALVANOMETER

It is an instrument used to measure very small currents. It is a galvanometer with a fixed coil and moving magnet. It is based on tangents law.

Construction and working : It consists of a circular coil of a large number of turns of insulated copper wire wound on vertical circular frame of non magnetic material. This frame can be rotated about its vertical diameter as axis. A small magnetic compass needle pivoted at centre is free to rotate in horizontal plane over a horizontal circular scale graduated in degrees. The position of needle is read by a long aluminium pointer attached at right angles to magnetic needle.

Initially coil is made vertical by levelling screws and coil is brought in magnetic meridian. Now B_H is in plane of coil. As current is passed through coil magnetic field B is produced which is perpendicular to plane of coil.

According to Tangent law

$$B = B_H \tan\theta \quad \text{or} \quad \frac{\mu_0 nI}{2a} = B_H \tan\theta$$

$$\text{or } I = \frac{2a}{n\mu_0}B_H\tan\theta = \frac{B_H}{G_1}\tan\theta = K\tan\theta$$

where $G_1 = \frac{n\mu_0}{2a}$ is galvanometer constant and $K = \frac{B_H}{G_1}$ is reduction factor of galvanometer.

If θ = 45° then I = K, so reduction factor of a tangent galvanometer is numerically equal to the current in ampere through the galvanometer which produces a deflection of 45° when the plane of its coil lies in the magnetic meridian. K depends on geometry of coil and value of B_H.

Sensitivity : A tangent galvanometer is both sensitive and accurate if the change in its deflection is large for a given fractional change in current.

$I = K\tan\theta$ or $dI = K\sec^2\theta\, d\theta$

or $\frac{dI}{I} = \frac{d\theta}{\sin\theta\cos\theta} = \frac{2d\theta}{\sin 2\theta}$ or $d\theta = \frac{\sin 2\theta}{2}\frac{dI}{I}$

$d\theta = (d\theta)_{max}$

if $\sin 2\theta = 1 = \sin\frac{\pi}{2}$ so $\theta = \frac{\pi}{4}$

The tangent galvanometer has maximum sensitivity when $\theta = 45°$.

Example 11 :

Two tangent galvanometers differ only in the matter of number of turns in the coil. On passing current through the two joined in series, the first shows a deflection of 35° and the other shows a 45° deflection. Calculate the ratio of their number of turns. Use tan 35° = 0.7.

Sol. In tangent galvanometer $\frac{\mu_0 NI}{2r} = B_H\tan\theta$

Here, $N \propto \tan\theta$ so

$\frac{N_1}{N_2} = \frac{\tan\theta_1}{\tan\theta_2} = \frac{\tan 35}{\tan 45} = \tan 35 = \frac{7}{10}$

Required ratio is 7 : 10

Example 12 :

Two tangent galvanometers A and B have their number of turns in the ratio 1 : 3 and diameters in the ratio 1 : 2

(a) which galvanometer has greater reduction factor

(b) which galvanometer shows greater deflection when both are connected in series to a dc source?

Sol. (a) $K = \frac{2a}{n\mu_0}B_H$ so $\frac{K_1}{K_2} = \frac{a_1}{a_2} \cdot \frac{n_2}{n_1} = 3\times\frac{1}{2} = \frac{3}{2}$

or $K_1 = \frac{3}{2}K_2$ so $K_1 > K_2$.

Galvanometer A has greater reduction factor

(b) $\frac{\mu_0 nI}{2a} = B_H\tan\theta$ so $\tan\theta \propto \frac{n}{a}$

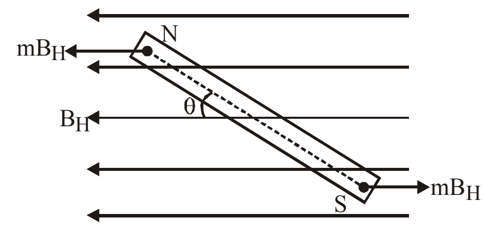
$\frac{\tan\theta_1}{\tan\theta_2} = \frac{n_1}{a_1}\times\frac{a_2}{n_2} = \frac{1}{3}\times\frac{2}{1} = \frac{2}{3}$

so $\tan\theta_1 > \tan\theta_2$ or $\theta_2 > \theta_1$

so B shows greater deflection.

VIBRATION MAGNETOMETER

It is an instrument used to compare magnetic moments of two bar magnets, comparison of horizontal components of earth's magnetic field at two places and for measuring the horizontal component of earth's magnet field.



Principle : When a bar magnet suspended freely in a uniform magnetic field is displaced from its equilibrium position it starts executing simple harmonic motion about the equilibrium position.

The torque acting on magnet is

$\tau = -mB_H(2\ell\sin\theta) = -MB_H\sin\theta$

–ive sign shows that torque acts in the direction of decreasing θ. If θ is small $\tau = -MB_H\theta$.

If α is angular acceleration of magnet and I is moment of inertia of magnet about axis of suspension then

$I\alpha = -MB_H\theta$

Time period

$$T = 2\pi\sqrt{\frac{\text{Angular displacement}}{\text{Angular acceleration}}} = 2\pi\sqrt{\frac{I}{MB_H}}$$

(1) Comparison of Magnetic Moments of Magnets of same size: Let two magnets be of same mass and size. Let M_1 and M_2 be the magnetic moments of the magnets then time period of oscillation of each magnet is given by

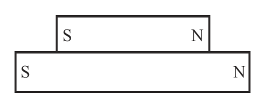
$$T_1 = 2\pi\sqrt{\frac{I}{M_1B_H}} \quad \text{and} \quad T_2 = 2\pi\sqrt{\frac{I}{M_2B_H}}$$

So $\frac{T_1}{T_2} = \sqrt{\frac{M_2}{M_1}}$ or $\frac{T_1^2}{T_2^2} = \frac{M_2}{M_1} = \frac{m_2}{m_1}$

(2) Comparison of Magnetic Moments of Magnets of different sizes : Let two magnets have moments of inertia I_1 and I_2 and magnetic moments M_1 and M_2 respectively.

In case (a)

$$T_1 = 2\pi\sqrt{\frac{I_1 + I_2}{(M_1 + M_2)B_H}}$$

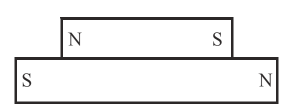


$M = M_1 + M_2$

(a) Sum Combination

In case (b)

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



$M = M_1 - M_2$

(b) Difference Combination

so $\frac{T_1}{T_2} = \sqrt{\frac{M_1 - M_2}{M_1 + M_2}}$ or $\frac{T_1^2}{T_2^2} = \frac{M_1 - M_2}{M_1 + M_2}$ or $\frac{M_1}{M_2} = \frac{T_1^2 + T_2^2}{T_2^2 - T_1^2}$

Knowing T_1 and T_2 we can find $\frac{M_1}{M_2}$

(3) Comparison of horizontal component of earth's magnetic field at different places : Let a magnet of moment of inertia I and magnetic moment M be vibrated in places with horizontal component B_H and B_H'. Then

$$T = 2\pi\sqrt{\frac{I}{MB_H}} \quad \text{and} \quad T' = 2\pi\sqrt{\frac{I}{MB'_H}}$$

$$\text{so} \quad \frac{T'}{T} = \sqrt{\frac{B_H}{B'_H}} \quad \text{or} \quad \frac{B_H}{B'_H} = \frac{T'^2}{T^2}$$

Example 13 :

A thin rectangular magnet suspended freely has a period of oscillation of 4 sec. What will be the period of oscillation if the magnet is broken into two halves (each having half the original length) and one of the piece is made to oscillate in the same field ?

Sol. In case of torsional vibrations of magnet ;

$$T = 2\pi\sqrt{\frac{I}{MB}} \qquad \text{........(1)}$$

When the magnet is broken into equal halves perpendicular to its length,

$$M' = m \times \ell = \left(\frac{M}{2}\right) \qquad [\text{as } M = m \times 2\ell]$$

$$\text{and, } I; = \frac{1}{12}(\rho S\ell)\times(\ell)^2 = \left(\frac{I}{8}\right) \quad \left[\text{as } I = \frac{1}{12}(2\rho S\ell)\times(2\ell)^2\right]$$

$$\text{So, } T' = 2\pi\sqrt{\frac{I'}{M'B}} = 2\pi\sqrt{\frac{(I/8)}{(M/2)B}} = \pi\sqrt{\frac{I}{MB}} \qquad \text{........(2)}$$

And then dividing eq^n. (2) by (1)

$$\frac{T'}{T} = \frac{1}{2} \quad \text{i.e., } T' = \frac{T}{2} = \frac{4}{2} = 2 \text{ sec.}$$

Note : If the magnet is broken into two equal pieces parallel to its length, then as

$$M' = \left(\frac{m}{2}\right)(2\ell) = \frac{M}{2} \quad \text{and} \quad I' = \left(\frac{\text{mass}}{2}\right)(2\ell)^2 = \left(\frac{I}{2}\right)$$

So the new time period

$$T'' = 2\pi\sqrt{\frac{(I/2)}{(M/2)B}} = 2\pi\sqrt{\frac{I}{MB}} = T = 4 \text{ sec.}$$

Example 14 :

Two bar magnets of same length and breadth but having magnetic moments M and 2M are joined together pole for pole and suspended by a string. The time of oscillation of this assembly in a magnetic field of strength B is 3 sec. What will be the period of oscillation if the polarity of one of the magnets is changed and the combination is again made to oscillate in the same field?

Sol. As magnetic moment is a vector, so when magnets are joined together pole for pole $M \to M + 2M = 3M$; so

$$T = 2\pi\sqrt{\frac{(I_1 + I_2)}{2MB}} \qquad \text{.......(1)}$$

When polarity of one magnet is reversed, $M' = 2M - M = M$;

$$\text{so } T' = 2\pi\sqrt{\frac{(I_1 + I_2)}{MB}} \qquad \text{.......(2)}$$

Dividing eq^n. (2) by (1),

$$\frac{T'}{T} = \sqrt{3} \quad \text{i.e., } T' = (\sqrt{3})\,T = 3\sqrt{3} \text{ sec}$$

Example 15 :

A circular coil of 16 turns and radius 10 cm, carrying a current of 0.75 A rests with its plane normal to an external field of magnitude 5.0×10^{-2} T. The coil is free to turn about an axis in its plane perpendicular to the field direction. When the coil is turned slightly and released, it oscillated about its stable equilibrium with a frequency of 2.0 s^{-1}. What is the moment of inertia of the coil about its axis of rotation?

Sol. Here, N = 16, r = 10 cm = 0.1 m i.e., $A = \pi(0.1)^2$
$I = 0.75$ A, $B = 5.0 \times 10^{-2}$ T, $\nu = 2\ s^{-1}$ i.e., T = 0.5 sec.
magnetic moment of coil

$$M = NAI = 16 \times \pi(0.1)^2 \times 0.75 = 0.3768 \text{ A m}^2$$

$$T = 2\pi\sqrt{\frac{I}{MB}} \quad (I = \text{Moment of inertia of the coil})$$

$$I = \frac{T^2 MB}{4\pi^2} = \frac{0.5 \times 0.5 \times 0.3768 \times 5.0 \times 10^{-2}}{4 \times 3.14 \times 3.14}$$

$$= \frac{5 \times 5 \times 3768 \times 5}{4 \times 314 \times 314} \times 10^{-4} = 1.1943 \times 10^{-4} \text{ kg-m}^2.$$

MAGNETIC PROPERTIES OF MATTER

MAGNETIZING FIELD (MAGNETIC INTENSITY)

The degree to which a magnetic field can magnetise a substance or the capability of external magnetic field to magnetise the substance is called magnetic intensity.

The magnetic field produced by the external source of current is called magnetising field. The magnetising field depends on external free currents and geometry of current carrying conductor. Magnetic intensity at a point in a magnetic field is defined as the number of magnetic lines of force passing normally per unit area about that point taken in free space in the absence of any substance. In vacuum the ratio of magnetic induction (B_0) and magnetic permeability (μ_0) is called magnetising field H i.e. $H = \frac{B_0}{\mu_0}$

In a toroidal solenoid the magnetic induction of field produced in material of toroid is

$$B = \mu nI \quad \text{so magnetising field } H = \frac{B}{\mu} = nI$$

The magnetic intensity may be defined as the number of ampere turns flowing round a unit length of toroidal solenoid to produce that magnetic field in the solenoid.

Unit of H

In SI system

$$H = \frac{B}{\mu} = \frac{\text{tesla}}{\text{tesla meter} - \text{amp}^{-1}} = \text{ampere-meter}^{-1} \,(\text{Am}^{-1})$$

$$H = \frac{B_0}{\mu_0} = \frac{\frac{F}{q_0 v}}{\mu_0} = \frac{F}{q_0 v \mu_0} = \frac{N}{C\,(\text{ms}^{-1})\,\text{TmA}^{-1}} = \text{Nm}^{-2}\text{T}^{-1}$$

$$H = \frac{N}{m^2 T} = \frac{N}{Wb} = NWb^{-1} = Jm^{-1}\,Wb^{-1}$$

In cgs system unit of H is oerested

1 oerested

$$= \frac{1\,\text{gauss}}{\mu_0} = \frac{10^{-4}\,T}{4\pi \times 10^{-7}\,\text{TmA}^{-1}} = \frac{1000}{4\pi}\text{Am}^{-1} = 80\text{Am}^{-1}$$

It is a vector quantity with dimensions $M^0 L^{-1} T^0 A^1$. Its direction is from north pole outwards.

B and H for different situations

(a) Solenoid $B = \mu_0 nI$ $H = nI$ with $n = \frac{N}{L}$ = no. of turns per unit length.

(b) Toroid $B = \mu_0 nI$ $H = nI$ with $n = \frac{N}{2\pi R}$

(c) Plane coil $B = \frac{\mu_0 nI}{2R}$; $H = \frac{nI}{2R}$

(d) Current carrying element

$$dB = \frac{\mu_0 I\, d\vec{\ell} \times \vec{r}}{4\pi r^3} \quad ; \quad dH = \frac{I\,(d\vec{\ell} \times \vec{r})}{4\pi r^3}$$

The magnetic intensity is independent of nature of medium.

INTENSITY OF MAGNETISATION

It is defined as the magnetic dipole moment developed per unit volume when a magnetic material is subjected to magnetising field.

Intensity of magnetisation

$$I = \frac{\text{magnetic dipole moment}}{\text{volume}} = \frac{M}{V}$$

It is a vector quantity whose direction is along the direction of magnetising field.

Its SI unit is ampere/m (A/m) and dimensions is $M^0 L^{-1} T^0 A^1$.

The intensity of magnetisation shows the extent to which the substance is magnetised.

$I = \frac{M}{V} = \frac{m \times 2\ell}{A \times 2\ell} = \frac{m}{A}$. Intensity of magnetisation is also defined as pole strength developed per unit area of cross-section of specimen.

I depends on nature of material.

I depends on temperature.

Different relations for intensity of magnetisation

(a) Volume intensity of magnetisation $I = \frac{M}{V}$

(b) Mass intensity of magnetisation

$$I_{mass} = \frac{1}{\rho}\left(\frac{M}{V}\right) = \frac{I}{\rho} \text{ where } \rho \text{ is density of material}$$

(c) Molar intensity of magnetisation

$$I_{molar} = \frac{W}{\rho}\left(\frac{M}{V}\right) = \left(\frac{W}{\rho}\right) I$$

where W is atomic weight of substance

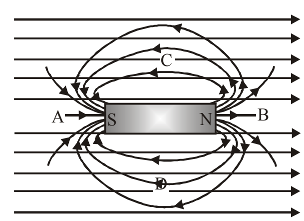
(d) Molecular intensity of magnetisation

$$I_{molecular} = \frac{W}{\rho N}\left(\frac{M}{V}\right) = \frac{W}{N} I_{mass} = \frac{I_{molar}}{N}$$

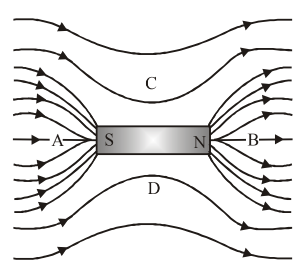
where N is Avogadro's number.

MAGNETIC INDUCTION OR MAGNETIC FLUX DENSITY

Let a uniform magnetising field B_0 represented by the parallel lines exist in vacuum. When a soft iron bar (ferromagnetic material) is placed inside the field it gets magnetised. The left end becomes S pole and right end becomes N pole. It produces its own magnetic field. At A and B field is increased while at C and D it is reduced.



The magnetic induction is defined as the number of magnetic lines of induction (magnetic lines inside the material) crossing per unit area normally through the magnetic substance.



The magnetic induction B is sum of magnetic field B_0 and field $\mu_0 I$ produced due to magnetisation of substance

$B = B_0 + \mu_0 I = \mu_0 (H + I)$

Unit is tesla (T) or weber m^{-2} (Wbm^{-2}). These are equivalent to $Nm^{-1}A^{-1}$ or $JA^{-1}m^{-1}$.

The CGS unit is gauss (G). 1 tesla = 10^4 gauss.

MAGNETIC SUSCEPTIBILITY

The magnetic susceptibility of a magnetic substance is defined as the ratio of the intensity of magnetisation to magnetic intensity $\chi_m = \frac{I}{H}$

It is ratio of two quantities with same units (Am^{-1}) so has no units. It gives the measure of ease with which a material can be magnetised by magnetising field. The value of χ_m depends on nature of material and temperature.

If H = 1 then χ_m = I. So magnetic susceptibility is the intensity of magnetisation developed in the substance when placed in a magnetising field of unit strength.

Different relations for magnetic susceptibility are

(a) Volume magnetic susceptibility $\chi_m = \frac{I}{H}$

(b) Mass magnetic susceptibility

$\chi_{mass} = \frac{\chi_m}{\rho}$ $\quad\rho$ = density of material

(c) Molar magnetic susceptibility $\chi_{molar} = \frac{W\chi_m}{\rho}$

W = atomic weight

(d) Molecular magnetic susceptibility

$$\chi_{molecular} = \frac{W}{N}\left(\frac{\chi_m}{\rho}\right) = \frac{\chi_{molar}}{N}$$

MAGNETIC PERMEABILITY

The magnetic permeability of a magnetic substance is defined as the ratio of the magnetic induction to the magnetic intensity so $\mu = \frac{B}{H}$

It is a scalar with unit weber/ampere-meter or henry/meter or newton/ampere^2 and dimension $M^1 L^1 T^{-2} A^{-2}$.

It is a measure of ability of a medium to allow passage of magnetic lines of force through it or measure of degree to which magnetic field can penetrate through a material.

Relative permeability

$$\mu_r = \frac{\mu}{\mu_0} = \frac{B}{B_0} = \frac{\text{number of lines of magnetic induction per unit area in a material}}{\text{number of lines per unit area in vacuum}}$$

μ_r is a dimensionless quantity. μ is always positive and depends of nature of material and temperature.

Relation between relative magnetic permeability and susceptibility :

When a magnetic material is kept in a magnetising field (H). Then total number of magnetic lines of force inside the material = magnetic lines of force due to magnetising field + magnetic lines of force due to magnetisation of specimen

i.e. Magnetic induction (B) = B_0 (no. of lines of force due to H) + $\mu_0 I$ (no. of lines due to magnetisation of specimen)

or $B = B_0 + \mu_0 I = \mu_0 H + \mu_0 I = \mu_0 (H + I)$

$B = \mu_0 (H + I) = \mu_0 H (1 + \chi_m)$

as $\chi_m = \frac{I}{H}$; $B = \mu H = \mu_0 H (1 + \chi_m)$

or $\mu = \mu_0 (1 + \chi_m)$ or $\mu_r = 1 + \chi_m$.

Example 16 :

A tungsten rod of length 10 cm and area of cross-section 0.25 cm^2 is placed in a magnetising field of 314 oersted, with its length parallel to the field. The magnetic susceptibility of tungsten is 6.8×10^{-5}. Calculate the (i) intensity of magnetisation (ii) magnetic moment and (iii) absolute permeability.

Sol. Given H = 314 oersted $= \frac{314 \times 10^3}{4\pi}$ amp./m. $= \frac{10^5}{4}$ amp./m.

(i) Intensity of magnetisation

$$I = \frac{\chi_m}{H} = \frac{6.8 \times 10^{-5} \times 10^5}{4} = 1.7 \text{ amp./m.}$$

(ii) Magnetic moment M = IV

$= 1.7 \times 0.1 \times 0.25 \times 10^{-4} = 4.25 \times 10^{-6}$ amp./m.

(iii) Absolute permeability $\mu = \mu_r \mu_0 = \mu_0 (1 + \chi_m)$

$= 4\pi \times 10^{-7} [1 + 6.8 \times 10^{-5}] = 12.56 \times 10^{-7}$ Wb/A-m

Example 17 :

A solenoid of 500 turns/m is carrying a current of 3A. Its core is made of iron which has a relative permeability of 5000. Determine the magnitude of magnetic intensity, magnetisation and magnetic field inside the core.

Sol. Magnetic intensity $H = ni = 500 \times 3 = 1500$ A/m

$\mu_r = 1 + \chi_m$ so $\chi_m = \mu_r - 1 = 4999 \approx 5000$

Intensity of magnetisation

$I = \chi H = 5000 \times 1500 = 7.5 \times 10^6$ A/m

Magnetic field

$B = \mu_r \mu_0 H = 5000 \times 4\pi \times 10^{-7} \times 1500 = 9.4$ tesla.

Example 18 :

An electron in an atom revolves around the nucleus in an orbit of radius 0.53 A. Calculate the equivalent magnetic moment if the frequency of revolution is 6.8×10^9 MHz.

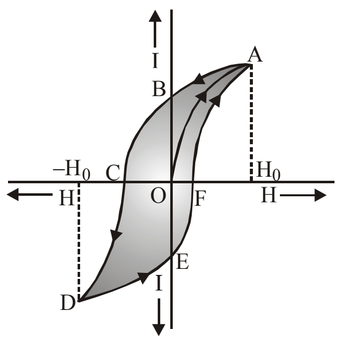
Sol. Magnetic moment $M = IA = \frac{e}{T} \times \pi r^2 = ev\pi r^2$

So $M = 1.6 \times 10^{-19} \times 6.8 \times 10^9 \times 3.14 \times (0.53 \times 10^{-10})^2$

$= 9.6 \times 10^{-24}$ Am^2.

HYSTERESIS

The lagging of intensity of magnetisation (I) or magnetic induction (B) behind the magnetising field (H) during the process of magnetisation and demagnetisation of a ferromagnetic material is called hysteresis.



Important Points :

(1) At point O the magnetising field (H) is zero and intensity of magnetisation (I) or B is also zero.

(2) The part OA of curve shows that I (or B) increases with H. At point A ferromagnetic material acquires the state of magnetic saturation.

(3) When H decreases I (or B) also decreases along AB. At point B magnetising field H becomes zero but I (or B) is non zero.

Retentivity : The value of I (or B) of a material when the magnetising field is reduced to zero is called retentivity or residual magnetism of the material. Retentivity is measured by part OB of curve.

(4) Now H is increased in reverse direction to make I (or B) zero. I (or B) now decreases along BC and becomes zero at C.

Coercivity : The value of reverse magnetising field required to reduce residual magnetism to zero is called coercivity of the material. This is measured by part OC of curve.

(5) When H is further increased I (or B) increases along CD. At D material acquires state of magnetic saturation. (D is symmetrical to point A).

(6) Here magnetising field H becomes zero before I (or B). The intensity of magnetisation I (or B) always lags behind H. This is called hysteresis. The entire hysteresis loop is traced if H is repeatedly changed between H_0 and $-H_0$.

(7) The area of hysteresis loop is a measure of energy dissipated per cycle per unit volume of the specimen and depends on nature of material.
In SI system area of B-H loop = μ_0 (area of I-H loop)
In cgs system area of B H loop = 4π (area of I-H loop)

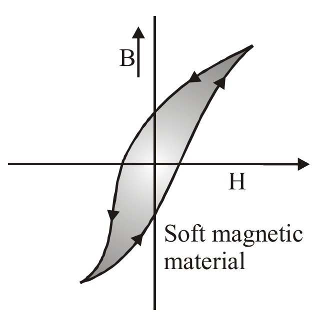
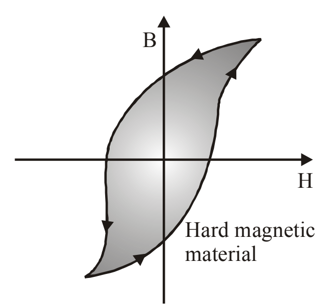
(8) The loss in energy appears as heat.

(9) The slope of B-H curve gives permeability of material while the slope of I-H curve gives susceptibility.

(10) If A is area of loop, V is volume of material, n is frequency then energy lost in magnetising and demagnetising specimen for time t is E = AVnt Joule and

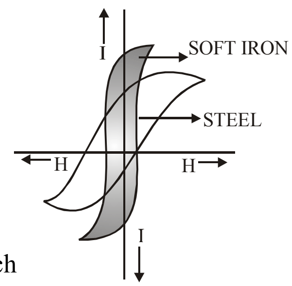
$$\text{Heat produced} = \frac{AVnt}{J}\,\text{calorie}$$

SOFT AND HARD MAGNETIC MATERIALS

Soft Magnetic Material	Hard Magnetic Material
(1) These materials have low retentivity, low coercivity, small hysteresis loss and high saturation magnetisation	These materials have high retentivity, high coercivity, large hysteresis loss and high saturation magnetisation
Soft magnetic material	Hard magnetic material
(2) These are suitable for temporary magnetism. e.g. Soft iron for making electromagnets, cores of transformers, motors, generators mu-metal for audio coils, magnetic shielding Stalloy for pulse transformers, magnetic amplifiers.	These are suitable for permanent magnetism. eg. Steel, Alnico, Alcomax and Ticonal are used in making different types of permanent magnets, electric meters and loudspeakers

Comparison of properties of Soft iron and Steel :

(1) The area of hysteresis loop for soft iron is much smaller than for steel so energy loss per unit volume per cycle or soft iron is smaller than steel.



(2) The retentivity of soft iron is greater than that of steel.

(3) The coercivity of steel is much larger than that of soft iron.

(4) The magnetisation and demagnetisation is easier in soft iron than steel.

(5) Soft iron acquires saturation magnetisation for quite low value of magnetising field than in case of steel or soft iron is much strongly magnetised than steel.

Example 19 :

An iron sample of mass 8.4 kg is repeatedly magnetised and demagnetised at a frequency of 50 cycles/sec. 3.2×10^4 Joule of energy is lost as heat in 30 minutes. If density of iron is 7200 kg/m^3 calculate the value of energy dissipated per unit volume per cycle in iron sample.

Sol. If H is energy lost per unit volume per second in iron sample then energy lost by sample in a given time t is E = HVnt where V is volume of sample.

So $$H = \frac{E}{Vnt} = \frac{3.2 \times 10^4 \times 7200}{8.4 \times 50 \times 30 \times 60} = 304.8 \text{ J m}^{-3} \text{ cycle}^{-1}$$

DIA, PARA AND FERROMAGNETIC SUBSTANCES

DIAMAGNETIC SUBSTANCES

The substances which when placed in a magnetic field are feebly magnetised in a direction opposite to that of the magnetising field are called diamagnetic substances.

(1) The property of diamagnetism is found to exist normally in substances whose atoms or molecules have even number of electrons. The orbital motion of electrons in a pair are in opposite direction. So each atom has net magnetic dipole moment equal to zero.

(2) When diamagnetic substance is kept in an external field it causes acceleration of one electron and deceleration of other in the pair. A net dipole moment is produced in a direction opposite to field.

(3) Diamagnetic effects are very weak. The diamagnetic property is not affected by temperature of substance.

(4) Some diamagnetic substances are Cu, Zn, Bi, Ag, Au, Pb, He, Ar, NaCℓ, H_2O, marble, glass etc.

PARAMAGNETIC SUBSTANCES

The substances which when placed in a magnetic field are feebly magnetised in the direction of magnetising field are called paramagnetic substances.

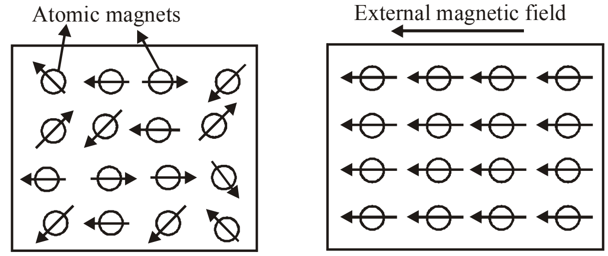
(1) The property of paramagnetism is found to exist in substances whose atoms or molecules have an excess of electron spinning in same direction.

(2) Atoms of paramagnetic substances possess a permanent magnetic dipole moment and thus behave like small bar magnets called atomic magnets.

(3) In absence of external magnetic field paramagnetic substances to not show any magnetism because atomic magnets are randomly oriented so net magnetic dipole moment is zero.

(4) In presence of external field each atomic magnet experiences a torque which tries to rotate and align them parallel to direction of magnetic field. The substance acquires net dipole moment and thus gets magnetised in direction of field.

(5) The property of paramagnetism is temperature dependent. The thermal agitation on increase of temperature spoils the alignment of atomic magnets which reduces net magnetic dipole moment.



(6) Some paramagnetic substances are Aℓ, Na, Sb, Pt, CuCℓ_2, Mn, Cr, liquid oxygen etc.

FERROMAGNETIC SUBSTANCES

The substances which when placed in a magnetic field are strongly magnetised in the direction of the magnetising field are called ferromagnetic substances.

(1) Each atom of ferromagnetic material possesses permanent magnetic dipole moment before application of external magnetic field.

(2) The unpaired electron of one atom interacts with electron of neighbouring atom through quantum mechanical exchange interaction and align in a common direction over a small volume of material. These small volume of uniform magnetisation are called domains which are small in size (10^{-18} m^3) but contain large number of atomic dipoles (~10^{11})

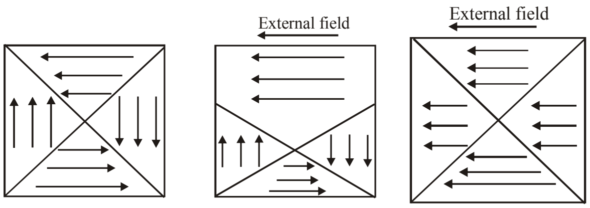
(3) In absence of external field the domains may be randomly oriented so that their resultant magnetic dipole moment in any direction is zero.

(4) If presence of external field the magnetic dipole moment increases due to :

(a) **Displacement of boundaries of domains**. Here size of domain with magnetic dipole moment parallel to applied field increases while for others it decreases.

(b) **Rotation of domains**. Here domains rotate until their magnetic dipole moments are aligned parallel to direction of external field.

(5) In presence of weaker fields displacement of boundaries takes place while in stronger fields rotation of domains takes place.



Random orientation of domains   Displacement of domains   Rotation of domains

(6) When external magnetic field is removed substance is not totally demagnetised and some magnetism is left in specimen.

(7) On heating it loses properly of ferromagnetism at certain temperature called Curie temperature and becomes paramagnetic. On cooling it becomes ferromagnetic again. The Curie temperature for iron is 770°C.

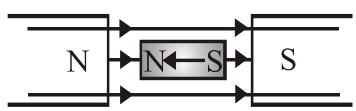
(8) Ferromagnetic substances are paramagnetic substances which acquire very high magnetism in external magnetic field. The two differ in the order of their intensity of magnetism.

(9) Example : Fe, Co, Ni, Cd, Fe_3O_4, etc.

PROPERTIES OF DIAMAGNETIC, PARAMAGNETIC & FERROMAGNETIC MATERIALS

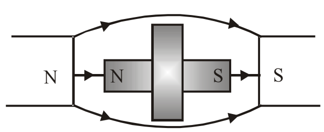
Diamagnetic materials

(1) The substances which when placed in a magnetising field get feebly magnetised in a direction opposite to magnetising field are called diamagnetic.

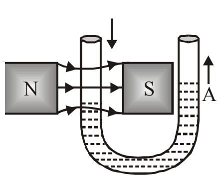


(2) The substances are weakly repelled by the field so in a non uniform field these have a tendency to move from strong to weak field.

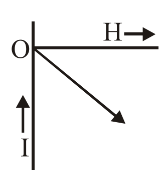
(3) A diamagnetic rod sets itself perpendicular to field because field is strongest at poles.



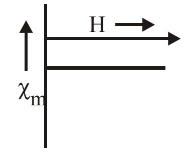
(4) A diamagnetic liquid in a U-tube depresses in the limb which is between the poles of magnet.



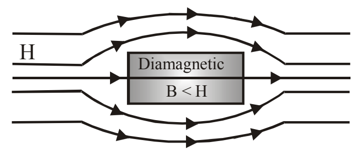
(5) Intensity of magnetisation I is very small, negative and proportional to magnetising field.



(6) Magnetic susceptibility $\chi_m = \frac{I}{H}$ is small and negative ($\approx 10^{-5}$)

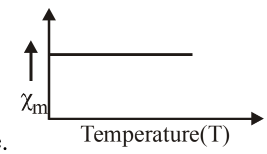


(7) The relative permeability $\mu_r = \frac{\mu}{\mu_0}$ is slightly less than unity. The field inside the material B is less than magnetising field H. They have a tendency to expel lines of force.



(8) Magnetic dipole moment (M) is small and opposite to magnetising field H.

(9) Diamagnetic substances do not obey Curie's law and show no transition at Curie temperature X_m is independent of temperature.



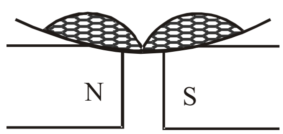
(10) The origin of diamagnetism is the induced dipole moment due to change in orbital motion of electrons in atoms by applied field.

Imp. : Diamagnetism is present in all materials and is independent of temperature. As it is weak it is often masked by para and ferromagnetic effects.

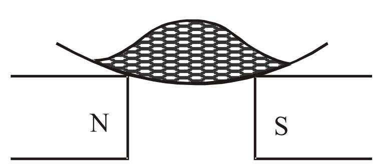
(11) The atoms do not have any permanent dipole moment i.e. paired spin.

(12) Diamagnetism is exhibited by solids, liquids and gases.

(13) If a diamagnetic liquid is placed in a watch glass placed on two pole pieces which are quite close to each other then liquid accumulates at sides and shows depression in the middle, where field is strongest.



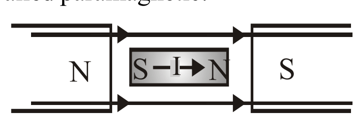
(14) If a diamagnetic liquid is placed in a watch glass placed on two pole pieces which are sufficiently apart then liquid accumulates in the middle where field is weakest.



(15) Diamagnetic substances are Cu, Zn, Bi, Ag, Au, Pb, He, Ar, NaCℓ, H_2O, marble, glass etc.

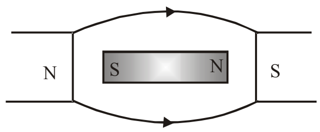
PARAMAGNETIC SUBSTANCES

(1) The substances which when placed in a magnetising field get feebly magnetised in a direction parallel to magnetising field are called paramagnetic.

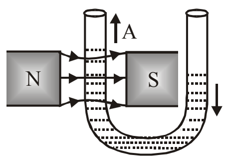


(2) The substances are weakly attracted by the field so in non uniform field they have a tendency to move from strong to weak fields.

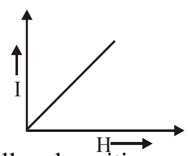
(3) A paramagnetic rod sets itself parallel to the field because field is strongest near poles.



(4) A paramagnetic liquid in a U-tube ascends in the limb which is between the poles of magnet.

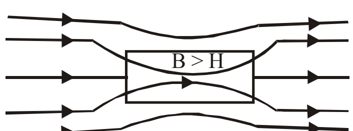


(5) Intensity of magnetisation I is very small, positive and directly proportional to magnetising field.



(6) Magnetic susceptibility $\chi_m = \frac{I}{H}$ is small and positive ($\sim 10^{-3}$ to 10^{-5}).

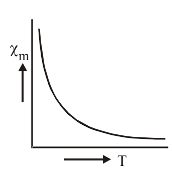
(7) The relative permeability $\mu_r = \frac{\mu}{\mu_0}$ is slightly greater than one. The field B inside the material B is greater than magnetising field H. They have a tendency to pull in the lines of force.



Paramagnetic

(8) Magnetic dipole moment (M) is small and parallel to magnetising field H.

(9) The paramagnetic substances obey Curies law according to which magnetic susceptibility is inversely proportional to its absolute temperature. $\chi_m = \frac{I}{H} = \frac{C}{T}$

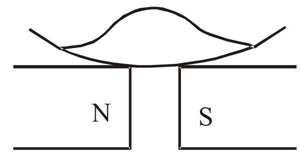


(10) Paramagnetism is due to partial alignment of randomly oriented atomic dipoles along the field.

(11) The atoms of paramagnetic substances have permanent dipole moment i.e. unpaired spin.

(12) Paramagnetism is exhibited by solids, liquids and gases.

(13) If a paramagnetic liquid is placed in a watch glass placed on two pole pieces which are quite close to each other then liquids accumulates in the middle where field is strongest.



(14) If a paramagnetic liquid is placed in a watch glass placed on two pole pieces which are sufficiently apart then liquid accumulates at sides and shows depression in the middle because field is strongest at poles.

(15) Paramagnetic substances are $A\ell$, Na, K, Sb, Pt, $CuC\ell_2$, Mn, Cr, Sn, liquid oxygen etc.

FERROMAGNETIC SUBSTANCES

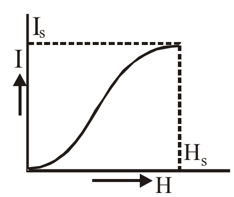
(1) The substances which when placed in a magnetising field get strongly magnetised in a direction parallel to magnetising field are called ferromagnetic.

(2) The substances are strongly attracted by the field so in non uniform field they have a tendency to stick at poles where field is strongest.

(3) The ferromagnetic rod sets itself parallel to the field immediately.

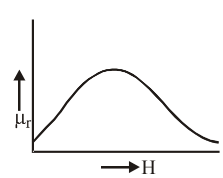
(4) When a ferromagnetic substance is liquefied it loses ferromagnetic properties due to larger temperature.

(5) Intensity of magnetisation I is very large, positive and varies non-linearly with magnetising field. I_s is saturation magnetisation with depends on nature of material.



(6) The magnetic susceptibility χ_m is very large ($\sim 10^3$ to 10^5) and positive.

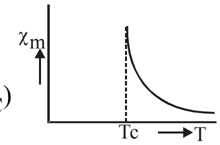
(7) The relative permeability $\mu_r = \frac{\mu}{\mu_0}$ is also very large ($\sim 10^3 - 10^5$) and varies non linearly with magnetising field. The field inside the material B is much stronger than magnetising field H. They have a tendency of pulling in a large number of lines of force by the material.



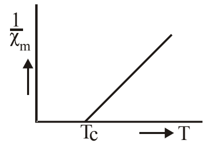
(8) Magnetic dipole moment (M) is large and in direction of magnetising field H.

(9) The ferromagnetic substances obey Curie-Weiss law

$$\chi_m = \frac{C}{T - T_C} \quad (\text{for } T > T_C)$$



T_C is Curie temperature which depends on nature of material (T_C of iron = 1043K = 770°C). Above Curie temperature a ferromagnetic material behaves as paramagnetic.

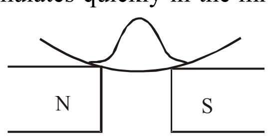


(10) Ferromagnetism arises due to spin orbit interaction. Due to interaction of spin of electrons of one atom with neighbouring atom, material gets divided into small regions called domains which are magnetised. The direction of magnetisation varies from one domain to other. In presence of weak external field the material is magnetised by domain growth through wall displacement and by domain rotation in presence of strong fields.

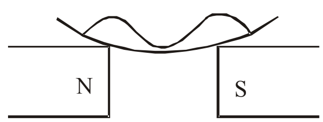
(11) The atoms of ferromagnetic substances have permanent dipole moment present in domains.

(12) Ferromagnetism is exhibited by crystalline solids.

(13) If a ferromagnetic powder is placed in a watch glass place on two pole pieces which are quite close to each other then powder accumulates quickly in the middle where field is strongest.



(14) If a ferromagnetic powder is placed in a watch glass placed on two pole pieces which are sufficiently apart then powder accumulates at sides and shows depression in the middle because field is strongest at poles.



(15) Fe, Co, Ni and their alloys are ferromagnetic.

TRY IT YOURSELF

Q.1 At $\cos^{-1}(1/3)$ to the magnetic meridian, the apparent dip is 60°. Find the true dip.

Q.2 At which place, earth's magnetic field becomes horizontal
(A) Magnetic pole (B) Geographical pole
(C) Magnetic meridian (D) Magnetic equator

Q.3 Which of the following demonstrated that earth has a magnetic field?
(A) Intensity of comic rays is more at the poles than at the equator.
(B) Earth is surrounded by an ionosphere.
(C) Earth is planet rotating about the north-south axis.
(D) Large quantity of iron ore is found on the earth.

Q.4 A magnetising field of 1600 Am^{-1} produces a magnetic flux 2.4×10^{-5} weber in an iron bar of cross-sectional area 0.2 cm^2. The susceptibility of the iron bar will be –
(A) 1788 (B) 1192
(C) 596 (D) 298

Q.5 A bar magnet has a coercivity 4×10^3 Am^{-1}. It is desired to demagnetize it by inserting it inside a solenoid 12cm long and having 60 turns. The current carried by the solenoid should be –
(A) 8A (B) 6A
(C) 4.5 A (D) 2A

Q.6 A specimen of iron of permeability 8×10^{-3} weber/Am is placed in a magnetic field of strength 160 A/m. Magnetic induction in this iron is –
(A) 0.8 Wb/m^2 (B) 5×10^{-5} Wb/m^2
(C) 1.28 Wb/m^2 (D) 20×10^3 Wb/m^2

Q.7 In a permanent magnet at room temperature
(A) magnetic moment of each molecule is zero.
(B) the individual molecules have non-zero magnetic moment which are all perfectly aligned.
(C) domains are partially aligned.
(D) domains are all perfectly aligned.

Q.8 A paramagnetic sample shows a net magnetisation of 8 Am^{-1} when placed in an external magnetic field of 0.6T at a temperature of 4K. When the same sample is placed in an external magnetic field of 0.2 T at a temperature of 16 K, the magnetisation will be
(A) (32/3) Am^{-1} (B) (2/3) Am^{-1}
(C) 6 Am^{-1} (D) 2.4 Am^{-1}

Q.9 The primary origin(s) of magnetism lies in
(A) atomic currents.
(B) Pauli exclusion principle.
(C) polar nature of molecules.
(D) intrinsic spin of electron.

Q.10 Essential difference between electrostatic shielding by a conducting shell and magnetostatic shielding is due to
(A) electrostatic field lines can end on charges and conductors have free charges.
(B) lines of B can also end but conductors cannot end them.
(C) lines of B cannot end on any material and perfect shielding is not possible.
(D) shells of high permeability materials can be used to divert lines of B from the interior region.

Q.11 Let the magnetic field on earth be modelled by that of a point magnetic dipole at the centre of earth. The angle of dip at a point on the geographical equator
(A) is always zero.
(B) can be zero at specific points.
(C) can be positive or negative.
(D) is bounded.

ANSWERS

(1) θ = 30°	**(2)** (D)	**(3)** (A)
(4) (C)	**(5)** (A)	**(6)** (C)
(7) (C)	**(8)** (B)	**(9)** (AD)
(10) (ACD)	**(11)** (BCD)	

USEFUL TIPS

* B on the axial line or end on position of a bar magnet

$$B = \frac{\mu_0}{4\pi}\frac{2Md}{(d^2-\ell^2)^2} \qquad \left(\text{for } d >> \ell,\ B = \frac{\mu_0}{4\pi}\frac{2\mu}{d^3}\right)$$

* B on the equatorial line or broad side on position of a bar magnet $B = \frac{\mu_0}{4\pi}\frac{M}{(d^2+\ell^2)^{3/2}}$ $\left(\text{for } d >> \ell,\ B = \frac{\mu_0}{4\pi}\frac{M}{d^3}\right)$

* Consider a material placed in an external magnetic field $\vec{B}_0$. The magnetic intensity is defined as, $\vec{H} = \frac{\vec{B}_0}{\mu_0}$.

The magnetisation $\vec{M}$ of the material is its dipole moment per unit volume. The magnetic field B in the material is,

$\vec{B} = \mu_0(\vec{H} + \vec{M})$

* For a linear material $\vec{M} = \chi\vec{H}$. So that $\vec{B} = \mu\vec{H}$ and χ is called the magnetic susceptibility of the material. The three quantities, χ, the relative magnetic permeability μ_r, and the magnetic permeability μ are related as follows:

$\mu = \mu_0\mu_r$; $\mu_r = 1 + \chi$.

* For paramagnetic materials, $\chi_m \propto 1/T$

For Ferromagnetic materials, $\chi_m \propto \frac{1}{T - T_C}$

where T_C = Curie temperature.

* **The electrostatic analog**

	Electrostatics	**Magnetism**
	$1/\varepsilon_0$	μ_0
Dipole moment	**p**	**M**
Equatorial Field for a short dipole	$-\mathbf{p}/4\pi\varepsilon_0 r^3$	$-\mu_0\mathbf{M}/4\pi r^3$
Axial Field for a short dipole	$2\mathbf{p}/4\pi\varepsilon_0 r^3$	$-\mu_0 2\mathbf{M}/4\pi r^3$
External Field: torque	$\mathbf{p} \times \mathbf{E}$	$\mathbf{M} \times \mathbf{B}$
External Field: Energy	$-\mathbf{p}.\mathbf{E}$	$-\mathbf{M}\,.\,\mathbf{B}$

ADDITIONAL EXAMPLES

Example 1 :

The main difference between electric lines of force and magnetic lines of force is

(1) Electric lines of force are closed curves whereas magnetic lines of force are open curves.

(2) Electric lines of force are open curves whereas magnetic lines of force are closed curves.

(3) Magnetic lines of force cut each other whereas electric lines of force do not cut.

(4) Electric lines of force cut each other whereas magnetic lines of force do not cut.

Sol. (2). The magnetic lines of force are in the form of closed curves whereas electric lines of force are open curves.

Example 2 :

A 30 cm long bar magnet is placed in the magnetic meridian with its north pole pointing south. The neutral point is obtained at a distance of 40cm from the center of the magnet. Find the magnetic dipole moment at pole strength of the magnet. The horizontal component of earth's magnetic field is 0.34 Gauss.

Sol. As the magnet is placed with its north pole pointing south, the neutral points are obtained on the axial line. At the neutral points the magnetic field B due to the magnet becomes equal and opposite to the horizontal component of earth's magnetic field i.e., B_H. Hence, if M be the magnetic dipole moment of the magnet of length 2ℓ and r the distance of neutral point from the center of the magnet, then we have $B = \frac{\mu_0}{4\pi}\frac{2Mr}{(r^2-\ell^2)^2} = B_H$

Given that $\mu_0 = 4\pi \times 10^{-7}\ TmA^{-1}$, r = 40 cm = 0.40m,
ℓ = 15 cm = 0.15 cm and
H_H = 0.34 Gauss = 034 × 10^{-4} T

$$\therefore\ M = \frac{4\pi}{\mu_0}\frac{B_H(r^2-\ell^2)^2}{2r}$$

$$= 10^{-7} \times \frac{(0.34\times10^{-4}) - [(0.40)^2 - (0.15)^2]^2}{2\times0.40} = 8.0\ Am^2$$

The pole strength of the magnet is ,

$$m = \frac{M}{2\ell} = \frac{8.0}{0.30} = 26.7\ Am$$

Example 3 :

The length, breadth and mass of two bar magnets are same but their magnetic moments are 3M and 2M respectively. These are joined pole to pole and are suspended by a string. When oscillated in a magnetic field of strength B, the time period obtained is 5s. If the poles of either of the magnets are reverse then the time period of the combination in the same magnetic field will be

(1) $3\sqrt{3}$ s (2) $2\sqrt{2}$ s

3) $5\sqrt{5}$ s (4) 1s

Sol. (3). $T = 2\pi\sqrt{\frac{I}{MB}}$ or $T \propto \frac{1}{\sqrt{M}}$; $\frac{T_1}{T_2} = \sqrt{\frac{3M-2M}{3M+2M}}$

or $T_2 = 5\sqrt{5}$ s

Example 4 :

A magnetising field of 2×10^3 amp/m produces a magnetic flux density of 8π Tesla in an iron rod. The relative permeability of the rod will be -

(1) 10^2 (2) 10^0

(3) 10^4 (4) 10^1

Sol. (3). $\because\ \mu_r = \frac{\mu}{\mu_0} = \frac{B}{H\mu_0}$ or $\mu_r = \frac{8\pi}{2\times10^3\times4\pi\times10^{-7}} = 10^4$

Example 5 :

A north of strength 50 Am and south pole of strength 100 Am are separated by a distance of 10 cm in air. Find the force between them. Also find the force when the distance between them is doubled.

Sol. Force between magnetic poles in air is given by

$$F = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{r^2}$$

Given that $m_1 = 50$ Am, $m_2 = 100$ Am, $r = 10$ cm $= 0.1$ m and $\mu_0 =$ permeability of air $= 4\pi \times 10^{-7}$ Hm^{-1}.

$$\therefore F = \frac{4\pi \times 10^{-7}}{4\pi}\frac{50 \times 100}{0.1 \times 0.1} = 50 \times 10^{-3}\text{ N}$$

Now, let $F_1 = 50 \times 10^{-3}$ N, $r_1 = r$

Given that $r_2 = 2r$, $F_2 = ?$

$$\frac{F_1}{F_2} = \frac{r_2^2}{r_2^2} \quad \text{or,} \quad \frac{50 \times 10^{-3}}{F_2} = \frac{4r^2}{r^2} = 4$$

$$\therefore F_2 = \frac{50 \times 10^{-3}}{4} = 12.5 \times 10^{-3}\text{N}$$

Example 6 :

A bar magnet of length 0.2 m and pole strength 5 Am is kept in a uniform magnetic induction field of strength $15 Wbm^{-2}$ making an angle of 30º with the field. Find the couple acting on it.

Sol. Couple acting on a bar magnet of dipole moment M when placed in a magnetic field, is given by $\tau = MB \sin\theta$ where θ is the angle made by the axis of magnet with the direction of field.

Given the $m = 5$Am, $2\ell = 0.2$m, $\theta = 30º$ and $B = 15$ Wbm^{-2}

$\therefore \tau = MB \sin\theta = (m \times 2\ell) B \sin\theta$

$$= 5 \times 0.2 \times 15 \times \frac{1}{2} = 7.5 \text{ Nm.}$$

Example 7 :

A bar magnet of magnetic 1.5 JT^{-1} lies aligned with the direction of a uniform magnetic field of 0.22 T.

(a) What is the amount of work required to turn the magnet so as to align is magnetic moment

(i) normal to the field direction,

(ii) opposite to the field direction ?

(b) What is the torque on the magnet in cases (i) and (ii) ?

Sol. Given that : M 1.5 JT^{-1} and B = 0.22 T

(a) The potential energy of the magnet when its magnetic moment vector $\vec{M}$ makes an angle θ with the magnetic field is given by, $U = -MB\cos\theta$

When the magnetic moment is normal to the field i.e., θ - 0, the potential energy is

$U_0 = -MB\cos 0º = -MB$

When the magnetic moment is normal to the field direction , i.e., $\theta = 90º$, then potential energy is

$U_0 = -MB \cos 90º = 0$.

When the magnetic moment is opposite to the field direction i.e., $\theta = 180º$, the potential energy is

$U_{180} = -MB\cos 180º = +MB$

(i) Hence, work done to turn the magnet to align its magnetic dipole moment normal to the field

$W_{0-90} = U_{90} - U_0 = 0 - (-MB)$

$= MB = 1.5 \times 0.22\text{J} = 0.33$ J

(ii) Similarly, work done to turn the magnet to align its magnetic dipole moment opposite to the field direction.

$W_{0-180} = U_{180} - U_0 = MB - (-MB)$

$= 2MB = 2 \times 0.33 = 0.66$ J

(b) Torque on the magnet in case (i) ;

$\tau_1 = MB \sin 90º = MB = 0.33$ N - m

Similarly, torque on the magnet in case (ii) :

$\tau_2 = MB \sin 180º = 0$ N -m

Example 8 :

A circular coil of 16 turns and radius 10cm carries a current of 0.75 A and rest with its plane normal to an external magnetic field of 5.0×10^{-2} T. The coil is free to rotate about its stable equilibrium position with a frequency of 2.0 s^{-1} Compute the moment of inertia of the coil about its axis of rotation.

Sol. The magnetic moment of the coil is

$M = NIA = 16 \times 0.75 \times \pi \times (0.1)^2 = 0.377\text{ Am}^2$

if K be the moment of inertia of the coil about its axis of rotation, then its period of oscillation in a magnetic field B

is given by $T = 2\pi\sqrt{\frac{K}{MB}}$

or its frequency ν is $= \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{MB}{K}}$

This gives $K = \frac{MB}{4\pi^2\nu^2}$

Given that $B = 5.0 \times 10^{-2}$ T, $M = 0.377$ and $\nu = 2s^{-1}$

$$\therefore K = \frac{0.377 \times 5.0 \times 10^{-2}}{4 \times (3.14)^2 \times (2)^2} = 1.2 \times 10^{-4}\text{ kgm}^2$$

QUESTION BANK

CHAPTER 3 : MAGNETIC EFFECTS OF CURRENT AND MAGNETISM

EXERCISE - 1 [LEVEL-1]

Choose one correct response for each question.

PART - 1 : MAGNETIC FORCE

Q.1 An electron is travelling horizontally towards east. A magnetic field in vertically downward direction exerts a force on the electron along
(A) East (B) West
(C) North (D) South

Q.2 An electron is moving in the north direction. It experiences a force in vertically upward direction. The magnetic field at the position of the electron is in the direction of
(A) East (B) West
(C) North (D) South

Q.3 An electron (charge q coulomb) enters a magnetic field of H weber/m^2 with a velocity of vm/s in the same direction as that of the field the force on the electron is
(A) Hqv Newton's in the direction of the magnetic field
(B) Hqv dynes in the direction of the magnetic field
(C) Hqv Newton's at right angles to the direction of the magnetic field
(D) Zero

Q.4 A 1m long conducting wire is lying at right angles to the magnetic field. A force of 1 kg. wt is acting on it in a magnetic field of 0.98 Tesla. The current flowing in it will be-
(A) 100 A (B) 10 A
(C) 1 A (D) 0

Q.5 A charged particle is moving with velocity v in a magnetic field of induction B. The force on the particle will be maximum when –
(A) v and B are in the same direction
(B) v and B are in opposite directions
(C) v and B are perpendicular
(D) v and B are at an angle of 45°

Q.6 A current of 10 ampere is flowing in a wire of length 1.5 m. A force of 15 N acts on it when it is placed in a uniform magnetic field of 2 tesla. The angle between the magnetic field and the direction of the current is
(A) 30° (B) 45°
(C) 60° (D) 90°

Q.7 Motion of a moving electron is not affected by
(A) An electric field applied in the direction of motion.
(B) Magnetic field applied in the direction of motion.
(C) Electric field applied perpendicular to the direction of motion.
(D) Magnetic field applied perpendicular to the direction of motion.

PART - 2 : MOTION IN A MAGNETIC FIELD

Q.8 The radius of curvature of the path of the charged particle in a uniform magnetic field is directly proportional to
(A) The charge on the particle
(B) The momentum of the particle
(C) The energy of the particle
(D) The intensity of the field

Q.9 A charged particle moves in a uniform magnetic field. The velocity of the particle at some instant makes an acute angle with the magnetic field. The path of the particle will be
(A) A straight line
(B) A circle
(C) A helix with uniform pitch
(D) A helix with non-uniform pitch

Q.10 A positively charged particle moving due east enters a region of uniform magnetic field directed vertically upwards. The particle will –
(A) Get deflected vertically upwards.
(B) Move in a circular orbit with its speed increased.
(C) Move in a circular orbit with its speed unchanged.
(D) Continue to move due east.

Q.11 A homogeneous electric field E and a uniform magnetic field $\vec{B}$ are pointing in the same direction. A proton is projected with its velocity parallel to $\vec{E}$. It will
(A) Go on moving in the same direction with increasing velocity.
(B) Go on moving in the same direction with constant velocity.
(C) Turn to its right.
(D) Turn to its left.

Q.12 A beam of ions with velocity 2×10^5 m/s enters normally into a uniform magnetic field of 4×10^{-2} tesla. If the specific charge of the ion is 5×10^7 C/kg, then the radius of the circular path described will be –
(A) 0.10 m (B) 0.16 m
(C) 0.20 m (D) 0.25 m

Q.13 A proton (mass m and charge +e) and an α-particle (mass 4m and charge +2e) are projected with the same kinetic energy at right angles to the uniform magnetic field. Which one of the following statements will be true
(A) The α-particle will be bent in a circular path with a small radius than that for the proton.
(B) The radius of the path of the α-particle will be greater than that of the proton.
(C) The α-particle and the proton will be bent in a circular path with the same radius.
(D) The α-particle and the proton will go through the field in a straight line.

Q.14 A uniform magnetic field acts at right angles to the direction of motion of electrons. As a result, the electron moves in a circular path of radius 2cm. If the speed of the electrons is doubled, then the radius of the circular path will be
(A) 2.0 cm (B) 0.5 cm
(C) 4.0 cm (D) 1.0 cm

Q.15 An α-particle and a proton travel with same velocity in a magnetic field perpendicular to the direction of their velocities, find the ratio of the radii of their circular path

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

Q.16 An electron and a proton have equal kinetic energies. They enter in a magnetic field perpendicularly, Then –

(A) Both will follow a circular path with same radius
(B) Both will follow a helical path
(C) Both will follow a parabolic path
(D) All the statements are false

Q.17 A proton of energy 8 eV is moving in a circular path in a uniform magnetic field. The energy of an alpha particle moving in the same magnetic field and along the same path will be

(A) 4 eV (B) 2 eV
(C) 8 eV (D) 6 eV

PART - 3 : CYCLOTRON

Q.18 The cyclotron frequency of an electron grating in a magnetic field of 1 T is approximately

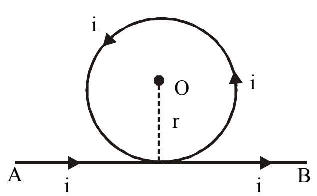
(A) 28 MHz (B) 280 MHz
(C) 2.8 GHz (D) 28 GHz

Q.19 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.

PART - 4 : BIOT-SAVART LAW

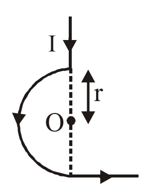
Q.20 A part of a long wire carrying a current i is bent into a circle of radius r as shown in figure. The net magnetic field at the centre O of the circular loop is –



(A) $\frac{\mu_0 i}{4r}$ (B) $\frac{\mu_0 i}{2r}$

(C) $\frac{\mu_0 i}{2\pi r}(\pi+1)$ (D) $\frac{\mu_0 i}{2\pi r}(\pi-1)$

Q.21 In the figure, what is the magnetic field at the point O.



(A) $\frac{\mu_0 I}{4\pi r}$ (B) $\frac{\mu_0 I}{4\pi r}+\frac{\mu_0 I}{2\pi r}$

(C) $\frac{\mu_0 I}{4r}+\frac{\mu_0 I}{4\pi r}$ (D) $\frac{\mu_0 I}{4r}-\frac{\mu_0 I}{4\pi r}$

Q.22 The strength of the magnetic field at a point r near a long straight current carrying wire is B. The field at a distance r/2 will be

(A) B/2 (B) B/4
(C) 2B (D) 4B

Q.23 Field at the centre of a circular coil of radius r, through which a current I flows is

(A) Directly proportional to r
(B) Inversely proportional to I
(C) Directly proportional to I
(D) Directly proportional to I^2

Q.24 The magnetic field at the centre of current carrying coil is

(A) $\frac{\mu_0 ni}{2r}$ (B) $\frac{\mu_0}{2\pi}\frac{ni}{r}$

(C) $\frac{\mu_0 ni}{4r}$ (D) $\mu_0 ni$

Q.25 The field due to a long straight wire carrying a current I is proportional to

(A) I (B) I^3
(C) $\sqrt{I}$ (D) 1/I

Q.26 The magnetic field at a point 50 mm from a long straight line carrying a current of 3A will be-

(A) 0.12 G (B) 1.2 G
(C) 12 G (D) 0.012 G

Q.27 To obtain maximum intensity of magnetic field at a point, the angle between the position vector of the point relative to the element and the direction of element will be :

(A) 0 (B) π/4
(C) π/2 (D) π

Q.28 Due to 10 ampere of current flowing in a circular coil of 10cm radius, the magnetic field produced at its centre is 3.14×10^{-3} weber/m^2. The number of turns in the coil will be

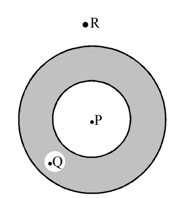
(A) 5000 (B) 100
(C) 50 (D) 25

Q.29 A straight wire carrying a current 10 A is bent into a semicircular arc of radius 5 cm. The magnitude of magnetic field at the center is

(A) 1.5×10^{-5} T (B) 3.14×10^{-5} T
(C) 6.28×10^{-5} T (D) 19.6×10^{-5} T

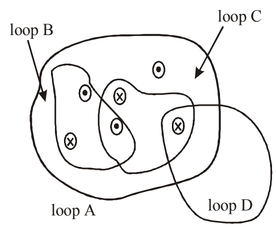
PART - 5 : AMPERE CIRCUITAL LAW

Q.30 Current is flowing through a conducting hollow pipe whose area of cross-section is shown as. The value of magnetic induction will be zero at-



(A) Point P, Q and R (B) Point R but not at P & Q
(C) Q but not at P and R (D) P but not at Q and R

Q.31 Consider six wires 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

Q.32 Ampere's law states $\oint \vec{B}.d\vec{\ell} = \mu_0 I_{enc}$. Which of the following statements are true for Ampere's law ?
(A) Ampere's law is correct if electric field inside the loop changes with time.
(B) Ampere's law is applicable only for symmetric condition.
(C) It is applicable for both symmetrical and unsymmetrical condition.
(D) Ampere's rule can be applied to find magnetic field due to solenoid and toroid only.

PART - 6 : THE SOLENOID AND THE TOROID

Q.33 A long solenoid of length L has a mean diameter D. It has n layers of windings of N turns each. If it carries a current 'i' the magnetic field at its centre will be
(A) Proportional to D
(B) Inversely proportional to D
(C) Independent of D
(D) Proportional to L

Q.34 There are 50 turns of a wire in every cm length of a long solenoid. If 4 ampere current is flowing in the solenoid, the approximate value of magnetic field along its axis at an internal point and at one end will be respectively
(A) 12.6×10^{-3} Weber / m^2, 6.3×10^{-3} Weber / m^2
(B) 12.6×10^{-3} Weber / m^2, 25.1×10^{-3} Weber / m^2
(C) 25.1×10^{-3} Weber / m^2, 12.6×10^{-3} Weber / m^2
(D) 25.1×10^{-5} Weber / m^2, 6.3×10^{-5} Weber / m^2

Q.35 A long solenoid has 200 turns per cm and carries a current of 2.5 amps. The magnetic field at its centre is ($\mu_0 = 4\pi \times 10^{-7}$ weber / amp-m)
(A) 3.14×10^{-2} weber / m^2 (B) 6.28×10^{-2} weber / m^2
(C) 9.42×10^{-2} weber / m^2 (D) 12.56×10^{-2} weber / m^2

Q.36 A current carrying long solenoid is placed on the ground with its axis vertical. A proton is falling along the axis of the solenoid with a velocity v. When the proton enters into the solenoid, it will
(A) Be deflected from its path.
(B) Be accelerated along the same path.
(C) Be decelerated along the same path.
(D) Move along the same path with no change in velocity.

Q.37 The average radius of a toroid made from a paramagnetic material is 0.1 m and it has 500 turns. If it carries 0.5 ampere current, then the magnetic field inside it will be :
(A) 5×10^{-4} tesla (B) 5×10^{-3} tesla
(C) 5×10^{-2} tesla (D) 2×10^{-3} tesla

Q.38 A long solenoid is formed by winding 20 turns/cm. The current necessary to produce a magnetic field of 20millitesla inside the solenoid will be approximately

$(\frac{\mu_0}{4\pi} = 10^{-7}$ tesla – metre / ampere)
(A) 8.0 A (B) 4.0 A
(C) 2.0 A (D) 1.0 A

PART - 7 : FORCE BETWEEN TWO PARALLEL CURRENTS

Q.39 An electric of 30 ampere is flowing in each of two parallel conducting wires places 5 cm apart. The force acting per unit length on either of the wires will be-
(A) 3.6×10^{-3} N/m (B) 3.6×10^{-3} Dyne/cm
(C) 3.6×10^{-5} N/m (D) 3.6×10^{-2} N/m.

Q.40 Two parallel wires of length 9 m each are separated by a distance 0.15 m. If they carry equal currents in the same direction and exerts a total force of 30×10^{-7} N on each other, then the value of current must be
(A) 2.5 amp (B) 3.5 amp
(C) 1.5 amp (D) 0.5 amp

Q.41 Through two parallel wires A and B, 10 and 2 ampere of currents are passed respectively in opposite direction. If the wire A is infinitely long and the length of the wire B is 2 m, the force on the conductor B, which is situated at 10cm distance from A will be
(A) 8×10^{-5} N (B) 4×10^{-4} N
(C) 4×10^{-5} N (D) $4\pi \times 10^{-7}$ N

Q.42 Two long parallel copper wires carry currents of 5A each in opposite directions. If the wires are separated by a distance of 0.5m, then the force between the two wires is
(A) 10^{-5} N, attractive (B) 10^{-5} N, repulsive
(C) 2×10^{-5} N, attractive (D) 2×10^{-5} N, repulsive

Q.43 Two parallel wires are carrying electric currents of equal magnitude and in the same direction. They exert
(A) An attractive force on each other
(B) A repulsive force on each other
(C) No force on each other
(D) A rotational torque on each other

PART - 8 : TORQUE ON CURRENT LOOP, MAGNETIC DIPOLE

Q.44 If an electron is moving with velocity v in an orbit of radius r in a hydrogen atom, then the equivalent magnetic moment will be :

(A) $\frac{\mu_0 e}{2r}$ (B) $\frac{ev}{r^2}$ (C) $\frac{ev \times 10^{-7}}{r^3}$ (D) $\frac{evr}{2}$

Q.45 On account of the orbital motion of an electron its magnetic moment will be (h - Plank constant, e-electronic charge and m-mass of an electron)

(A) $\frac{eh}{4\pi m}$ (B) $\frac{h}{4\pi m}$ (C) $\frac{eh}{2\pi}$ (D) $\frac{eh}{2\pi m}$

Q.46 A 5 cm × 12 cm coil with number of turns 600 is placed in a magnetic field of strength 0.10 Tesla. The maximum magnetic torque acting on it when a current of 10^{-5} A is passed through it will be-

(A) 3.6×10^{-6} N-m (B) 3.6×10^{-6} dyne-cm
(C) 3.6×10^{6} N-m (D) 3.6×10^{6} dyne-m

Q.47 A circular coil of diameter 7cm has 24 turns of wire carrying current of 0.75A. The magnetic moment of the coil is

(A) 6.9×10^{-2} amp-m^2 (B) 2.3×10^{-2} amp-m^2
(C) 10^{-2} amp-m^2 (D) 10^{-3} amp-m^2

Q.48 Torque on a current carrying loop of magnetic moment $\vec{m}$, placed in region of magnetic field $\vec{B}$ is

(A) $\vec{\tau} = \frac{1}{2}\vec{m} \times \vec{B}$ (B) $\vec{\tau} = \mu_0 \vec{m} \times \vec{B}$

(C) $\vec{\tau} = \frac{\mu_0}{4\pi}(\vec{m} \times \vec{B})$ (D) $\vec{\tau} = \vec{m} \times \vec{B}$

Q.49 A circular coil of 20 turns and radius 10cm is placed in uniform magnetic field of 0.10 T normal to the plane of the coil. If the current in the coil is 5A, then the torque acting on the coil will be -

(A) 31.4N-m (B) 3.14N-m
(C) 0.314N-m (D) zero

PART - 9 : THE BAR MAGNET

Q.50 Two identical thin bar magnets each of length ℓ and pole strength m are placed at right angle to each other with north pole of one touching south pole of the other. Magnetic moment of the system is –

(A) $m\ell$ (B) $2m\ell$

(C) $\sqrt{2}m\ell$ (D) $\frac{1}{2}m\ell$

Q.51 Two similar bar magnets P and Q, each of magnetic moment M, are taken, If P is cut along its axial line and Q is cut along its equatorial line, all the four pieces obtained have

(A) Equal pole strength (B) Magnetic moment M/4
(C) Magnetic moment M/2 (D) Magnetic moment M

Q.52 Due to a small magnet intensity at a distance x in the end on position is 9 Gauss. What will be the intensity at a distance x/2 on broad side on position

(A) 9 Gauss (B) 4 Gauss
(C) 36 Gauss (D) 4.5 Gauss

Q.53 A magnet is parallel to a uniform magnetic field. If it is rotated by 60°, the work done is 0.8 J. How much work is done in moving it 30° further

(A) 0.8×10^{7} ergs (B) 0.4 J
(C) 8 J (D) 0.8 ergs

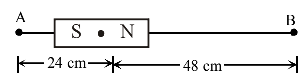
Q.54 Two small bar magnets are placed in a line with like poles facing each other at a certain distance d apart. If the length of each magnet is negligible as compared to d, the force between them will be inversely proportional to

(A) d (B) d^2
(C) $1/d^2$ (D) d^4

Q.55 The incorrect statement regarding the lines of force of the magnetic field B is

(A) Magnetic intensity is a measure of lines of force passing through unit area held normal to it.
(B) Magnetic lines of force form a close curve.
(C) Inside a magnet, its magnetic lines of force move from north pole of a magnet towards its south pole.
(D) Due to a magnet magnetic lines of force never cut each other.

Q.56 A bar magnet of length 3 cm has points A and B along its axis at distances of 24 cm and 48 cm on the opposite sides. Ratio of magnetic fields at these points will be



(A) 8 (B) $1/2\sqrt{2}$
(C) 3 (D) 4

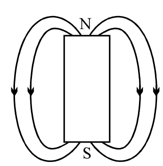
Q.57 A small bar magnet has a magnetic moment 1.2 A-m^2. The magnetic field at a distance 0.1 m on its axis will be : ($\mu_0 = 4\pi \times 10^{-7}$ T-m/A)

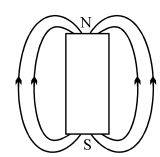
(A) 1.2×10^{-4} T (B) 2.4×10^{-4} T
(C) 2.4×10^{4} T (D) 1.2×10^{4} T

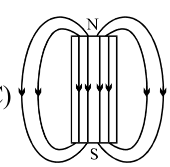
Q.58 A bar magnet of length 0.2 m and pole strength 5 Am is kept in a uniform magnetic induction field of strength 15Wbm^{-2} making an angle of 30° with the field. Find the couple acting on it.

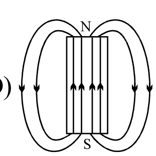
(A) 2.5 Nm (B) 5.5 Nm
(C) 7.5 Nm (D) 9.0 Nm

Q.59 The magnetic field lines due to a bar magnet are correctly shown in -

(A)


(B)


(C)


(D)


PART-10 : MAGNETISM AND GAUSS'S LAW

Q.60 Gauss is unit of which quantity

(A) H (B) B
(C) ϕ (D) I

Q.61 Gauss's law for magnetism is –

(A) the net magnetic flux through any closed surface is B.ΔS.
(B) the net magnetic flux through any closed surface is E ΔS.

(C) the net magnetic flux through any closed surface is zero.
(D) Both (A) and (C)

PART - 11 : THE EARTH'S MAGNETISM

Q.62 The vertical component of earth's magnetic field is zero at
(A) Magnetic poles (B) Geographical poles
(C) Every place (D) Magnetic equator

Q.63 The angle between the magnetic meridian and geographical meridian is called
(A) Angle of dip (B) Angle of declination
(C) Magnetic moment (D) Power of magnetic field

Q.64 At a certain place, the horizontal component of earth's magnetic field is $\sqrt{3}$ times the vertical component. The angle of dip at that place is
(A) 60° (B) 45°
(C) 90° (D) 30°

Q.65 At the magnetic north pole of the earth, the value of horizontal component of earth's magnetic field and angle of dip are, respectively
(A) Zero, maximum (B) Maximum, minimum
(C) Maximum, maximum (D) Minimum, minimum

Q.66 A compass needle will show which one of the following directions at the earth's magnetic pole
(A) Vertical
(B) No particular direction
(C) Bent at 45° to the vertical
(D) Horizontal

PART - 12 : TANGENT LAW

Q.67 The period of oscillation of a magnet in vibration magnetometer is 2 sec. The period of oscillation of a magnet whose magnetic moment is four times that of the first magnet is
(A) 1 sec (B) 4 sec
(C) 8 sec (D) 0.5 sec

Q.68 Vibration magnetometer works on the principle of
(A) Torque acting on the bar magnet
(B) Force acting on the bar magnet
(C) Both the force and the torque acting on the bar magnet
(D) None of these

Q.69 A thin magnetic needle oscillates in a horizontal plane with a period T. It is broken into n equals parts. The time period of each part will be
(A) T (B) T/n
(C) Tn^2 (D) T/n^2

PART - 13 : MAGNETISATION

Q.70 The magnetic susceptibility of a paramagnetic substance is 3×10^{-4}. It is placed in a magnetising field of 4×10^4 amp/m. The intensity of magnetisation will be
(A) 3×10^8 A/m (B) 12×10^8 A/m
(C) 12 A/m (D) 24 A/m

Q.71 A magnetising field of 2×10^3 amp/m produces a magnetic flux density of 8π Tesla in an iron rod. The relative permeability of the rod will be
(A) 10^2 (B) 10^0
(C) 10^4 (D) 10^1

Q.72 Demagnetisation of magnets can be done by
(A) Rough handling
(B) Heating
(C) Magnetising in the opposite direction
(D) All the above

PART - 14 : MAGNETIC PROPERTIES OF MATERIALS

Q.73 If a diamagnetic solution is poured into a U-tube and one arm of this U-tube placed between the poles of a strong magnet with the meniscus in a line with the field, the level of the solution will
(A) Rise (B) Fall
(C) Oscillate slowly (D) Remain as such

Q.74 The magnetic susceptibility is negative for
(A) Paramagnetic materials
(B) Diamagnetic materials
(C) Ferromagnetic materials
(D) Paramagnetic and ferromagnetic materials

Q.75 The universal property of all substances is
(A) Diamagnetism (B) Ferromagnetism
(C) Paramagnetism (D) All of these

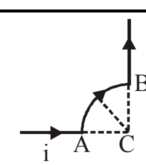
Q.76 If a ferromagnetic material is inserted in a current carrying solenoid, the magnetic field of solenoid
(A) Largely increases (B) Slightly increases
(C) Largely decreases (D) Slightly decreases

EXERCISE - 2 (LEVEL-2)

Choose one correct response for each question.

Q.1 A current of 1 ampere is passed through a straight wire of length 2.0 metres. The magnetic field at a point in air at a distance of 3 metres from either end of wire and lying on the axis of wire will be
(A) $\frac{\mu_0}{2\pi}$ (B) $\frac{\mu_0}{4\pi}$
(C) $\frac{\mu_0}{8\pi}$ (D) Zero

Q.2 A wire carrying current i is shaped as shown. Section AB is a quarter circle of radius r. The magnetic field is directed.



(A) At an angle $\pi/4$ to the plane of the paper.
(B) Perpendicular to the plane of the paper and directed into the paper.
(C) Along the bisector of the angle ACB towards AB.
(D) Along the bisector of the angle ACB away from AB.

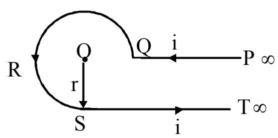
Q.3 An α-particle travels in a circular path of radius 0.45 m in a magnetic field $B = 1.2$ Wb/m^2 with a speed of 2.6×10^7 m/sec. The period of revolution of the α-particle is
(A) 1.1×10^{-5} sec (B) 1.1×10^{-6} sec
(C) 1.1×10^{-7} sec (D) 1.1×10^{-8} sec

Q.4 If there is no torsion in the suspension thread, then the time period of a magnet executing SHM

(A) $T = 2\pi\sqrt{\frac{I}{MB}}$ (B) $T = \frac{1}{2\pi}\sqrt{\frac{MB}{I}}$

(C) $T = 2\pi\sqrt{\frac{MB}{I}}$ (D) $T = \frac{1}{2\pi}\sqrt{\frac{I}{MB}}$

Q.5 A current i is flowing in a conductor shaped as shown in the figure. The radius of curved part is r and length of straight portions is very large. The value of magnetic field at the centre will be-



(A) $\frac{\mu_0 i}{4\pi r}\left[\frac{3\pi}{2}+1\right]$ (B) $\frac{\mu_0 i}{4\pi r}\left[\frac{3\pi}{2}-1\right]$

(C) $\frac{\mu_0 i}{4\pi r}\left[\frac{\pi}{2}+1\right]$ (D) $\frac{\mu_0 i}{4\pi r}\left[\frac{\pi}{2}-1\right]$

Q.6 A circular arc of wire of radius of curvature r subtends an angle of $\pi/4$ radian at its centre. If i current is flowing in it then the magnetic induction at its centre will be-

(A) $\frac{\mu_0 i}{8r}$ (B) $\frac{\mu_0 i}{4r}$

(C) $\frac{\mu_0 i}{16r}$ (D) 0

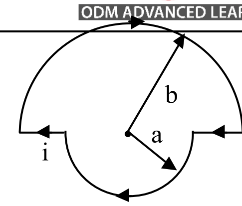
Q.7 A current of 30 A is flowing in a vertical straight wire. If the horizontal component of earth's magnetic field is 2×10^{-5} Tesla then the position of null point will be-
(A) 0.9 m (B) 0.3 mm
(C) 0.3 cm (D) 0.3 m

Q.8 A length L of wire carrying current I is bent into a circle of one turn. The field at the center of the coil is B_1. A similar wire of length L carrying current I is bent into a square of one turn. The field at its center is B_2. Then-
(A) $B_1 > B_2$ (B) $B_1 < B_2$
(C) $B_1 = B_2$ (D) None of these

Q.9 4 ampere current is passing through a coil of radius 5 cm and 100 turns. The magnetic moment of the coil is-
(A) 3.14 Am^2 (B) 3.14 cm^2
(C) 314 Am^2 (D) 0.0314 A cm^2

Q.10 The magnetic moment of a current carrying loop is 2.1×10^{-25} amp $\times$ m^2. The magnetic field (weber/m^2) at a point on its axis at a distance of 1Å is
(A) 4.2×10^{-2} (B) 4.2×10^{-3}
(C) 4.2×10^{-4} (D) 4.2×10^{-5}

Q.11 You are given a closed circuit with radii a and b as shown in fig carrying current i. The magnetic dipole moment of the circuit is-



(A) $\pi(a^2 + b^2)\, i$ (B) $\frac{1}{2}\pi(a^2 + b^2)\, i$

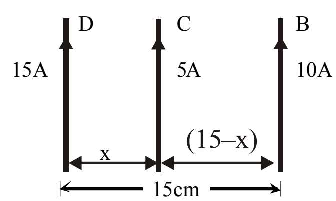
(C) $\pi(a^2 - b^2)\, i$ (D) $\frac{1}{2}\pi(a^2 - b^2)\, i$

Q.12 In hydrogen atom, an electron is revolving in the orbit of radius 0.53Å with 6.6×10^{15} rotations/second. Magnetic field produced at the centre of the orbit is
(A) 0.125 wb/m^2 (B) 1.25 wb/m^2
(C) 12.5 wb/m^2 (D) 125 wb/m^2

Q.13 A proton of energy 200 MeV enters the magnetic field of 5T. If direction of field is from south to north and motion is upward, the force acting on it will be
(A) Zero (B) 1.6×10^{-10} N
(C) 3.2×10^{-8} N (D) 1.6×10^{-6} N

Q.14 An electric field of 1500 V / m and a magnetic field of 0.40weber / meter^2 act on a moving electron. The minimum uniform speed along a straight line the electron could have is
(A) 1.6×10^{15} m / s (B) 6×10^{-16} m / s
(C) 3.75×10^3 m / s (D) 3.75×10^2 m / s

Q.15 Three long, straight and parallel wires carrying currents are arranged as shown in the figure. The wire C which carries a current of 5.0 amp is so placed that it experiences no force. The distance of wire C from wire D is then



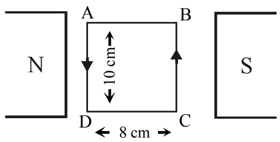
(A) 9 cm (B) 7 cm
(C) 5 cm (D) 3 cm

Q.16 A straight conductor carries a current of 5A. An e^- travelling with a speed of 5×10^6 m/s parallel to the wire at a distance of 0.1m from the conductor, experiences a force of
(A) 8×10^{-20} N (B) 3.2×10^{-19} N
(C) 8×10^{-18} N (D) 1.6×10^{-19} N

Q.17 An α particle is moving in a magnetic field of $(3\hat{i} + 2\hat{j})$ tesla with a velocity of $5 \times 10^5\ \hat{i}$ m/s. The magnetic force acting on the particle will be-
(A) 3.2×10^{-13} dyne (B) 3.2×10^{13} N
(C) 0 (D) 3.2×10^{-13} N

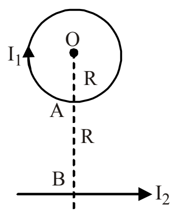
Q.18 A 100 turns coil shown in figure carries a current of

2amp in a magnetic field $B = 0.2\ Wb/m^2$. The torque acting on the coil is



(A) 0.32 Nm tending to rotate the side AD out of the page.
(B) 0.32 Nm tending to rotate the side AD into the page.
(C) 0.0032 Nm tending to rotate the side AD out of the page.
(D) 0.0032 Nm tending to rotate the side AD into the page.

Q.19 In the diagram, I_1, I_2 are the strength of the currents in the loop & straight conductors respectively OA = AB = R. The net magnetic field at the centre O is zero. Then the ratio of the currents in the loop and the straight conductors is



(A) π (B) 2π
(C) $1/\pi$ (D) $1/2\pi$

Q.20 A charged particle with a velocity 2×10^3 m/s passes undeflected through electric field and magnetic fields in mutually perpendicular directions. The magnetic field is 1.5 T. The magnitude of electric field will be
(A) 1.5×10^3 N/C (B) 2×10^3 N/C
(C) 3×10^3 N/C (D) 1.33×10^3 N/C

Q.21 A charged particle experiences magnetic force in the presence of magnetic field. Which of the following statement is correct?
(A) The particle is moving and magnetic field is perpendicular to the velocity.
(B) The particle is moving and magnetic field is parallel to velocity.
(C) The particle is stationary and magnetic field is perpendicular.
(D) The particle is stationary and magnetic field is parallel.

Q.22 If a velocity has both perpendicular and parallel components while moving through a magnetic field, what is the path followed by a charged particle?
(A) Circular (B) Elliptical
(C) Linear (D) Helical

Q.23 A solenoid has length 0.4 cm, radius 1 cm and 400 turns of wire. If a current of 5 A is passed through this solenoid, what is the magnetic field inside the solenoid?
(A) 6.28×10^{-4} T (B) 6.28×10^{-3} T
(C) 6.28×10^{-7} T (D) 0.628 T

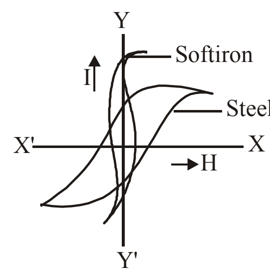
Q.24 A magnet is parallel to a uniform magnetic field. If it is rotated by 60°, the work done is 0.8 J. How much work is done in moving it 30° further
(A) 0.8×10^7 ergs (B) 0.4 J
(C) 8 J (D) 0.8 ergs

Q.25 Two short magnets having magnetic moments in the ratio 27 : 8, when placed on opposite sides of a deflection magnetometer, produce no deflection. If the distance of the weaker magnet is 0.12 m from the centre of deflection magnetometer, the distance of the stronger magnet from the centre is
(A) 0.06 m (B) 0.08 m
(C) 0.12 m (D) 0.18 m

Q.26 The magnetic needle of a tangent galvanometer is deflected at an angle 30^o due to a magnet. The horizontal component of earth's magnetic field 0.34×10^{-4} T is along the plane of the coil. The magnetic intensity is
(A) 1.96×10^{-4} T (B) 1.96×10^{-5} T
(C) 1.96×10^4 T (D) 1.96×10^5 T

Q.27 A bar magnet made of steel has a magnetic moment of 2.5 A-m^2 and a mass of 6.6×10^3 kg. If the density of steel is $7.9 \times 10^9\ kg/m^3$, find the intensity of magnetization of the magnet.
(A) 3.0×10^6 A/m (B) 2.0×10^6 A/m
(C) 5.0×10^6 A/m (D) 1.2×10^6 A/m

Q.28 The mass of a speciment of a ferromagnetic material is 0.6 kg. and its density is $7.8 \times 10^3\ kg/m^3$. If the area of hysteresis loop of alternating magnetising field of frequency 50Hz is 0.722 MKS units then the hysteresis loss per second will be –

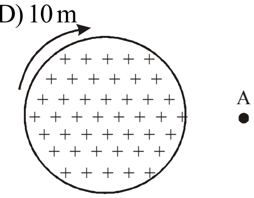


(A) 277.7×10^{-5} Joule (B) 277.7×10^{-6} Joule
(C) 277.7×10^{-4} Joule (D) 27.77×10^{-4} Joule

Q.29 A circular coil of radius 10 cm and 100 turns carries a current 1 A. What is the magnetic moment of the coil?
(A) $3.142 \times 10^4\ A m^2$ (B) $10^4\ A m^2$
(C) $3.142\ A m^2$ (D) $3\ A m^2$

Q.30 A proton beam enters a magnetic field of $10^{-4} Wb\ m^{-2}$ normally. If the specific charge of the proton is $10^{11} Ckg^{-1}$ and its velocity is $10^7\ ms^{-1}$, then the radius of the circle described will be
(A) 100 m (B) 0.1 m
(C) 1 m (D) 10 m

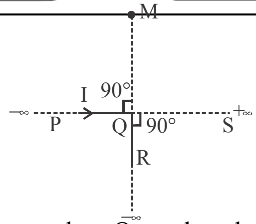
Q.31 A positively charged disk is rotated clockwise as shown in the figure. What is the direction of the magnetic field at point A in the plane of the disk.



(A) ⊗ (into the page) (B) ⟶
(C) ⟵ (D) ⊙ (out of the page)

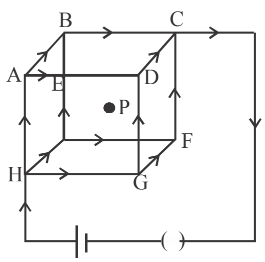
Q.32 An infinitely long conductor

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



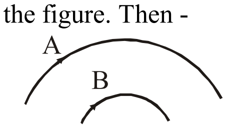
(A) 1/2 (B) 1
(C) 2/3 (D) 2

Q.33 A steady current is set up in a cubic network composed of wires of equal resistance and length d as shown in figure. What is the magnetic field at the centre P due to the cubic network –



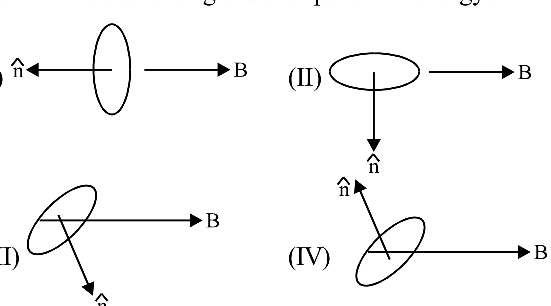
(A) $\frac{\mu_0}{4\pi}\frac{2I}{d}$ (B) $\frac{\mu_0}{4\pi}\frac{2I}{\sqrt{2}d}$ (C) 0 (D) $\frac{\mu_0}{4\pi}\frac{\theta\pi I}{d}$

Q.34 Two particles A and B of masses m_A and m_B respectively and having the same charge are moving 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 -



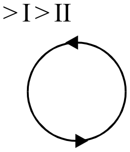
(A) $m_A v_A < m_B v_B$
(B) $m_A v_A > m_B v_B$
(C) $m_A < m_B$ and $v_A < v_B$
(D) $m_A = m_B$ and $v_A = v_B$

Q.35 A current carrying loop is placed in a uniform magnetic field in four different orientations, I, II, III and IV, arrange them in the decreasing order of potential energy :



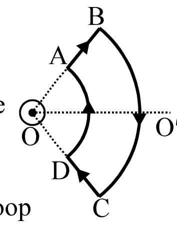
(A) I > III > II > IV (B) I > II > III > IV
(C) I > IV > II > III (D) III > IV > I > II

Q.36 The adjacent figure shows lines of a field. It cannot represent



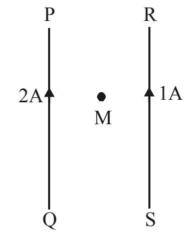
(A) an electrostatic field
(B) an induced electric field
(C) a gravitational field
(D) Both (A) and (C)

Q.37 The figure shows an infinitely long current carrying wire out of the plane of the paper (shown as a dot '⊙'). A current carrying loop ABCD is placed as shown in the figure. The loop



(A) experiences no net force
(B) experiences no torque
(C) turns clockwise as seen by an observer located at the dot ('⊙')
(D) Both (A) and (C)

Q.38 PQ and RS are long parallel conductors separated by certain distance. M is the midpoint between them (see the figure). The net magnetic field at M is B. Now, the current 2A is switched off. The field at M now becomes

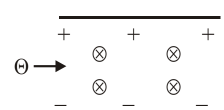


(A) 2 B (B) B
(C) B/2 (D) 3 B

Q.39 An electron enters the space between the plates of a charged capacitor as shown. The charge density on the plate is σ. Electric intensity in the space between the plates is E. A uniform magnetic field B also exists in that space perpendicular to the direction of E. The electron moves perpendicular to both $\vec{E}$ and $\vec{B}$ without any change in direction. The time taken by the electron to travel a distance ℓ in the space is –

(A) $\frac{\sigma\ell}{\varepsilon_0 B}$ (B) $\frac{\sigma B}{\varepsilon_0 \ell}$

(C) $\frac{\varepsilon_0 \ell B}{\sigma}$ (D) $\frac{\varepsilon_0 \ell}{\sigma B}$



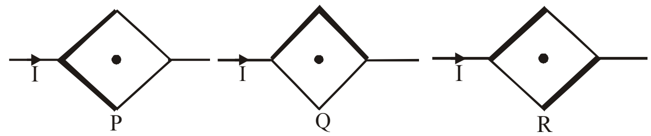
Q.40 A horizontal metal wire is carrying an electric current from the north to the south. Using a uniform magnetic field, it is to be prevented from falling under gravity. The direction of this magnetic field should be towards the

(A) north (B) south
(C) east (D) west

Q.41 Magnetic field at the centre of a circular coil of radius R due to current I flowing through it is B. The magnetic field at a point along the axis at distance R from the centre is –

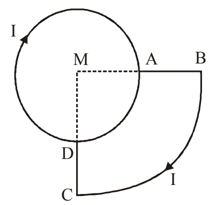
(A) B/2 (B) B/4
(C) $B/\sqrt{8}$ (D) $\sqrt{8}B$

Q.42 Two thick wires and two thin wires, all of same material and same length, form a square in three different ways P, Q and R as shown in the figure. With correct connections shown, the magnetic field due to the current flow, at the centre of the loop will be zero in case of –



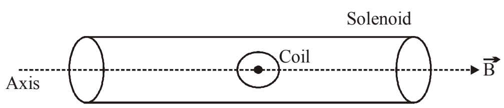
(A) Q and R only (B) P only
(C) P and Q only (D) P and R only

Q.43 A current I is flowing through the loop. The direction of the current and the shape of the loop are as shown in the figure. The magnetic field at the centre of the loop is $\frac{\mu_0 I}{R}$ times .... (MA = R, MB = 2R, $\angle$DMA = 90°)



(A) 5/16, but out of the plane of the paper
(B) 5/16, but into the plane of the paper
(C) 7/16, but out of the plane of the paper
(D) 7/16, but into the plane of the paper

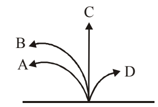
Q.44 The torque required to hold a small circular coil of 10 turns, area 1 mm^2 and carrying a current of (21/44) A s the middle of a long solenoid of 10^3 turns/m carrying a current of 2.5A, with its axis perpendicular to the axis of the solenoid is –



(A) $1.5 \times 10^{+8}$ N-m (B) $1.5 \times 10^{+6}$ N-m
(C) 1.5×10^{-8} N-m (D) 1.5×10^{-6} N-m

Q.45 A particle of charge e and mass m moves with a velocity u in a magnetic filed B applied perpendicular to the motion of the particle. The radius r of its path in the field is –
(A) Bv/em (B) ev/Bm
(C) Be/mv (D) mv/Be

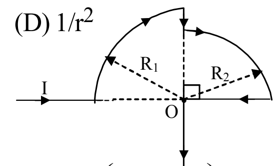
Q.46 A neutron, a proton, an electron and an α- particle enter a region of uniform magnetic field with the same velocities. The magnetic field is perpendicular and directed into the plane of the paper. The tracks of the particles are labelled in the figure. The electron follows the track



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

Q.47 Magnetic field at a distance r from an infinitely long straight conductor carrying a steady current varies as –
(A) 1/r (B) $1/r^3$
(C) $1/\sqrt{r}$ (D) $1/r^2$

Q.48 In the loop shown, the magnetic induction at the point O is



(A) $\frac{\mu_0 I}{8}\left(\frac{R_1 + R_2}{R_1 R_2}\right)$ (B) $\frac{\mu_0 I}{8}\left(\frac{R_1 R_2}{R_1 + R_2}\right)$

(C) zero (D) $\frac{\mu_0 I}{8}\left(\frac{R_1 - R_2}{R_1 R_2}\right)$

Q.49 An α-particle and a proton moving with the same kinetic energy enter a region of uniform magnetic field at right angles to the field. The ratio of the radii of the paths of α-particle to that of the proton is –
(A) 1 : 2 (B) 1 : 4
(C) 1 : 8 (D) 1 : 1

Q.50 A straight current carrying conductor is kept along the axis of circular loop carrying current. The force exerted by the straight conductor on the loop is
(A) in the plane of the loop, away from the center
(B) in the plane of the loop, towards the center
(C) zero
(D) perpendicular to the plane of the loop

Q.51 Pick out the WRONG statement.
(A) When an electron is shot at right angles to the electric field, it traces a parabolic path.
(B) An electron moving in the direction of the electric field gains K.E.
(C) An electron at rest experiences no force in the magnetic field.
(D) The gain in the K.E of the electron moving at right angles to the magnetic field is zero.

Q.52 The magnetic susceptibility of a paramagnetic material at –73°C is 0.0075 and its value at –173°C will be –
(A) 0.015 (B) 0.0045
(C) 0.0075 (D) 0.0030

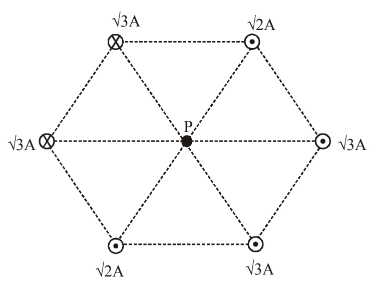
EXERCISE - 3 (NUMERICAL VALUE BASED QUESTIONS)

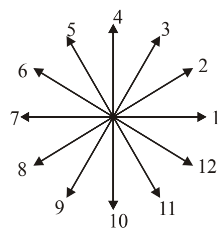
NOTE : The answer to each question is a NUMERICAL VALUE.

Q.1 A uniformly charged ring of radius 10cm. rotates at a frequency of 10^4 rps about its axis. The ratio of energy density of electric field to the energy density of the magnetic field at a point on the axis at distance 20cm. from the centre is 9.1×10^{a}. Find the value of a.

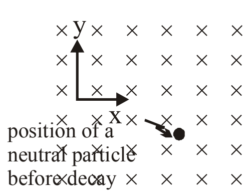
Q.2 A proton moves in a circular path perpendicular to a magnetic field B. If the intensity of the magnetic field is doubled but the radius of the circular path is constant, then new kinetic energy of the particle becomes x times the previous one. Find the value of x.

Q.3 Consider a set of six infinite long straight parallel wires arranged perpendicular to the plane of paper in a hexagon as shown. The length of the each side of the hexagon is 3cm. What is the magnitude and direction of the magnetic field at point P ? To express your answer, use the following method. Twelve direction at consecutive equal angles have been shown. If the strength of magnetic field is 70μT, directed along vector numbered 8, write your answer as 0870. Similarly if the strength of magnetic field is 70μT, directed along vector numbered 12, write your answer as 1270.

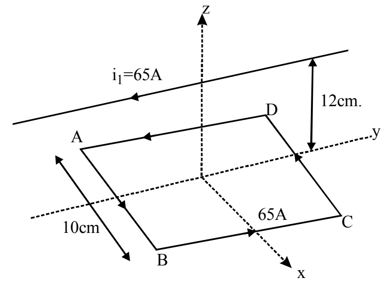




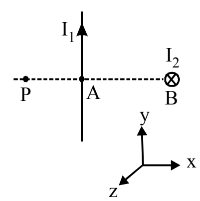
Q.4 A neutral particle is initially at rest in a uniform magnetic field B as shown in the diagram. The particle then spontaneously decays into two fragments, one with a positive charge +q and mass 3m and the other with a negative charge –q and mass m. Neglecting the interaction between the two charged particles and assuming that the speeds are much less than speed of light, determine the time (in μs) after the decay at which the two fragments first meet (use the following data $q = 1\mu C, B = 2\pi\mu T, m = 10^{-15}$ kg). Both the charges have initial velocities in x-y plane.



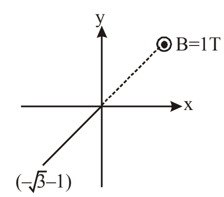
Q.5 Figure shows a square loop 10cm. on each side in the x-y plane with its centre at the origin. An infinite wire is at z = 12cm. above y-axis. What is torque on loop due to magnetic force ? If torque is expressed as $x \times 10^{-5}$ N-m, find the value of x.



Q.6 Two infinitely long linear conductors are arranged perpendicular to each other and are in mutually perpendicular planes as shown in figure. If $I_1 = 2A$ along the y-axis and $I_2 = 3A$ along –ve z-axis and AP=AB=1cm. The value of magnetic field strength $\vec{B}$ at P is $(a \times 10^{-5} T)\,\hat{j} + (b \times 10^{-5} T)\,\hat{k}$ then find the value of $a + b$.

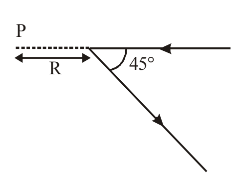


Q.7 A uniform magnetic field of magnitude 1T exists in region $y \geq 0$ is along $\hat{k}$ direction as shown. A particle of charge 1C is projected from point $(-\sqrt{3}, -1)$ towards origin with speed 1 m/s. If mass of particle is 1 kg, then co-ordinates of centre of circle in which particle moves are $\left(\frac{1}{a}, -\frac{\sqrt{b}}{2}\right)$ then find the value of a + b.



Q.8 An insulating rod of length ℓ carries a charge q distributed uniformly on it. The rod is pivoted at its mid point and is rotated at a frequency f about a fixed axis perpendicular to rod and passing through the pivot. The magnetic moment of the rod system is $\frac{1}{a}\pi q f \ell^2$. Find the value of a/2.

Q.9 A long straight wire, carrying current I, is bent at its midpoint to form an angle of 45°. Magnetic field at point P, distance R from point of bending is equal to $\frac{(\sqrt{a} - c)\mu_0 I}{b\pi R}$ then find the value of a + b + c.



EXERCISE - 4 [PREVIOUS YEARS JEE MAIN QUESTIONS]

PART - A : MAGNETIC EFFECTS OF CURRENT

Q.1 A circular coil 'A' has a radius R and the current flowing through it is I. Another circular coil 'B' has a radius 2R and if 2I is the current flowing through it, then the magnetic fields at the centre of the circular coil are in the ratio of (i.e. B_A to B_B) **[AIEEE 2002]**
(A) 4 : 1 (B) 2 : 1
(C) 3 : 1 (D) 1 : 1

Q.2 An electron and a proton with equal momentum enter perpendicularly into a uniform magnetic field, then –
(A) The path of proton shall be more curved than that of electron. **[AIEEE 2002]**
(B) The path of proton shall be less curved than that of electron.
(C) Both are equally curved
(D) Path of both will be straight line

Q.3 If a current is passed in a spring, it **[AIEEE 2002]**
(A) Gets compressed (B) Gets expanded
(C) Oscillates (D) Remains unchanged

Q.4 A charge moves in a circle perpendicular to a magnetic field. The time period of revolution is independent of –
(A) Magnetic field (B) Charge **[AIEEE 2002]**
(C) Mass of the particle (D) Velocity of the particle

Q.5 A particle of mass M and charge Q moving with velocity $\vec{v}$ describes a circular path of radius R when subjected to a uniform transverse magnetic field of induction B. The work done by the field when the particle completes one full circle is **[AIEEE 2003]**
(A) $BQv2\pi R$ (B) $\left(\frac{Mv^2}{R}\right)2\pi R$
(C) Zero (D) $BQ2\pi R$

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

Q.7 A long wire carries a steady current. It is bent into a circle of one turn and the magnetic field at the centre of the coil is B. It is then bent into a circular loop of n turns. The magnetic field at the centre of the coil will be
(A) nB (B) n^2B **[AIEEE 2004]**
(C) 2nB (D) $2n^2B$

Q.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 **[AIEEE 2004]**
(A) 250 μT (B) 150 μT
(C) 125 μT (D) 75 μT

Q.9 Two long conductors, separated by a distance d carry current I_1 and I_2 in the same direction. They exert a force F on each other. Now the current in one of them is increased to two times and its directions is reversed. The distance is also increased to 3d. The new value of the force between them is **[AIEEE 2004]**
(A) – 2F (B) F/3
(C) 2F/3 (D) – F/3

Q.10 Two concentric coils each of radius equal to 2π cm. are placed at right angles to each other. 3 ampere and 4 ampere are the currents flowing in each coil respectively. The magnetic induction in Weber/m^2 at the centre of the coils will be ($\mu_0 = 4\pi \times 10^{-7}$ Wb/A.m) **[AIEEE 2005]**
(A) 5×10^{-5} (B) 7×10^{-5}
(C) 12×10^{-5} (D) 10^{-5}

Q.11 A uniform electric field and a uniform magnetic field are produced, pointed in the same direction. An electron is projected with its velocity pointing in the same direction
(A) The electron will turn to its right **[AIEEE 2005]**
(B) The electron will turn to its left
(C) The electron velocity will increase in magnitude
(D) The electron velocity will decrease in magnitude

Q.12 A charged particle of mass m and charge q travels on a circular path of radius r that is perpendicular to a magnetic field B. The time taken by the particle to complete one revolution is – **[AIEEE 2005]**
(A) $\frac{2\pi qB}{m}$ (B) $\frac{2\pi m}{qB}$ (C) $\frac{2\pi mq}{B}$ (D) $\frac{2\pi q^2B}{m}$

Q.13 Two thin, long, parallel wires, separated by a distance 'd' carry a current of 'i' A in the same direction. They will **[AIEEE 2005]**
(A) Attract each other with a force of $\frac{\mu_0 i^2}{2\pi d^2}$
(B) Repel each other with a force of $\frac{\mu_0 i^2}{2\pi d^2}$
(C) Attract each other with a force of $\frac{\mu_0 i^2}{2\pi d}$
(D) Repel each other with a force of $\frac{\mu_0 i^2}{2\pi d}$

Q.14 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 – **[AIEEE 2006]**
(A) ellipse (B) circle
(C) helix (D) straight line

Q.15 A long solenoid has 200 turns per cm and carries a current i. The magnetic field at its centre is 6.28×10^{-2} W/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 **[AIEEE 2006]**
(A) 1.05×10^{-3} Weber/m^2 (B) 1.05×10^{-4} Weber/m^2
(C) 1.05×10^{-2} Weber/m^2 (D) 1.05×10^{-5} Weber/m^2

Q.16 A long straight wire of radius 'a' carries a steady current I. The current is uniformly distributed across its cross section. The ratio of the magnetic field at a/2 and 2a is – **[AIEEE 2007]**

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

Q.17 A current I flows along the length of an infinitely long, straight, thin walled pipe. Then – **[AIEEE 2007]**

(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.

Q.18 A charged particle with charge q enters a region of constant, uniform and mutually orthogonal fields $\vec{E}$ and $\vec{B}$, with a velocity $\vec{v}$ perpendicular to both $\vec{E}$ and $\vec{B}$, and comes out without any change in magnitude or direction of $\vec{v}$. Then **[AIEEE 2007]**

(A) $\vec{v} = \dfrac{\vec{E}\times\vec{B}}{B^2}$ (B) $\vec{v} = \dfrac{\vec{B}\times\vec{E}}{B^2}$

(C) $\vec{v} = \dfrac{\vec{E}\times\vec{B}}{E^2}$ (D) $\vec{v} = \dfrac{\vec{B}\times\vec{E}}{E^2}$

Q.19 A charged particle moves through a magnetic field perpendicular to its direction. Then – **[AIEEE 2007]**

(A) the momentum changes but the kinetic energy is constant.
(B) both momentum and kinetic energy of the particle are not constant.
(C) both momentum and kinetic energy of the particle are constant.
(D) kinetic energy changes but the momentum is constant

Q.20 Two identical conducting wire AOH 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 – **[AIEEE 2007]**

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

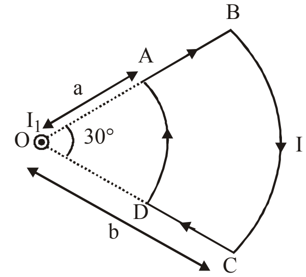
(C) $\dfrac{\mu_0}{2\pi d}(I_1+I_2)$ (D) $\dfrac{\mu_0}{2\pi d}(I_1^2+I_2^2)$

Q.21 A horizontal overhead powerline is at a height of 4m from the ground and carries a current of 100A from east to west. The magnetic field directly below it on the ground is ($\mu_0 = 4\pi\times10^{-7}$ TmA^{-1}) **[AIEEE 2008]**

(A) 5×10^{-6} T northward (B) 5×10^{-6} T southward
(C) 2.5×10^{-7} T northward (D) 2.5×10^{-7} T southward

Directions: Q. 22 and 23 are based on the following paragraph

A current loop ABCD is held fixed on the plane of the paper as shown in the figure. The arcs BC (radius = b) and DA (radius = a) of the loop are joined by two straight wires AB and CD. A steady current I is flowing in the loop. Angle made by AB and CD at the origin O is 30°. Another straight thin wire with steady current I_1 flowing out of the plane of the paper is kept at the origin. **[AIEEE 2009]**



Q.22 The magnitude of the magnetic field B due to the loop ABCD at the origin O is –

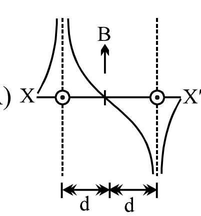
(A) $\dfrac{\mu_0 I}{4\pi}\left[2(b-a)+\dfrac{\pi}{3}(a+b)\right]$ (B) zero

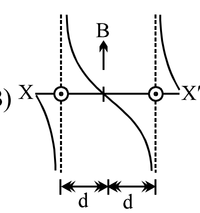
(C) $\dfrac{\mu_0 I\,(b-a)}{24ab}$ (D) $\dfrac{\mu_0 I}{4\pi}\left[\dfrac{b-a}{ab}\right]$

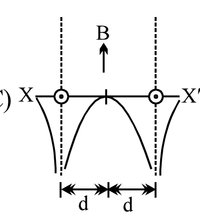
Q.23 Due to the presence of the current I_1 at the origin :

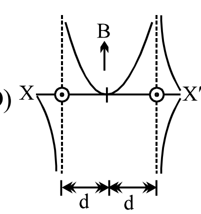
(A) The magnitude of the net force on the loop is given by $\dfrac{\mu_0 I I_1}{24ab}(b-a)$.
(B) The forces on AB and DC are zero.
(C) The forces on AD and BC are zero.
(D) The magnitude of the net force on the loop is given by $\dfrac{I_1 I}{4\pi}\mu_0\left[2(b-a)+\dfrac{\pi}{3}(a+b)\right]$

Q.24 Two long parallel wires are at a distance 2d apart. They carry steady equal current flowing out of the plane of the paper as shown. The variation of the magnetic field along the line XX' is given by – **[AIEEE 2010]**

(A) 

(B) 

(C) 

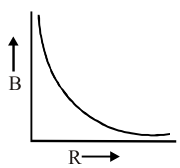
(D) 

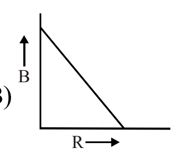
Q.25 A current I flows in an infinitely long wire with cross-section in the form of a semicircular ring of radius R. The magnitude of the magnetic induction along its axis is –

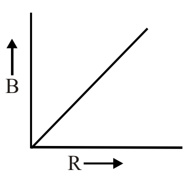
(A) $\frac{\mu_0 I}{\pi^2 R}$ (B) $\frac{\mu_0 I}{2\pi^2 R}$ **[AIEEE 2011]**

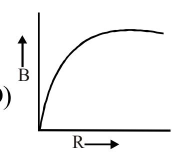
(C) $\frac{\mu_0 I}{2\pi R}$ (D) $\frac{\mu_0 I}{4\pi R}$

Q.26 A charge Q is uniformly distributed over the surface of non-condcting 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]**

(A) 

(B) 

(C) 

(D) 

Q.27 Proton, Deuteron and alpha particle of same kinetic energy are moving in circular trajectories in a constant magnetic field. The radii of proton, deuteron and alpha particle are respectively r_p, r_d and r_α. Which one of the following relation is correct? **[AIEEE 2012]**

(A) $r_\alpha = r_p = r_d$ (B) $r_\alpha = r_p < r_d$

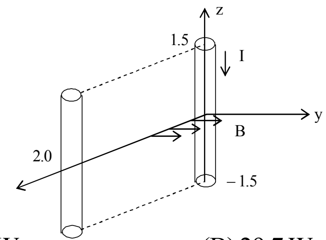
(C) $r_\alpha > r_d > r_p$ (D) $r_\alpha = r_d > r_p$

Q.28 Two short bar magnets of length ℓ 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 poining towards the South. They have a common magnetic equator and are separated by a distance of 20.0cm. The value of the result and horizontal magnetic induction at the mid - point O of the line joining their centres is close to –
(Horizontal component of earth's magnetic induction is 3.6×10^{-5} Wb/m^2) **[JEE MAIN 2013]**

(A) 3.6×10^{-5} Wb/m^2 (B) 2.56×10^{-4} Wb/m^2

(C) 3.50×10^{-4} Wb/m^2 (D) 5.80×10^{-4} Wb/m^2

Q.29 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 MAIN 2014]**



(A) 14.85 W (B) 29.7 W

(C) 1.57 W (D) 2.97 W

Q.30 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]**

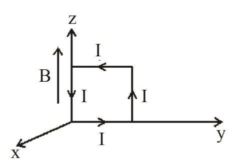
(A) $\vec{F}_1$ is radially inwards and $\vec{F}_2$ is radially outwards.

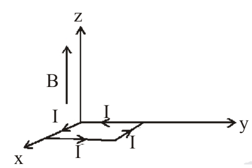
(B) $\vec{F}_1$ is radially inwards and $\vec{F}_2 = 0$

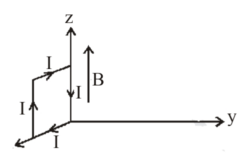
(C) $\vec{F}_1$ is radially outwards and $\vec{F}_2 = 0$

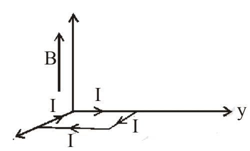
(D) $\vec{F}_1 = \vec{F}_2 = 0$

Q.31 A rectangular loop of sides 10 cm and 5 cm carrying a current I of 12 A is placed in different orientations as shown in the figures below: **[JEE MAIN 2015]**

(a) 

(b) 

(c) 

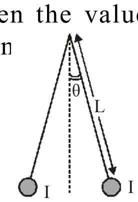
(d) 

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

(A) (a) and (c), respectively (B) (b) & (d), respectively

(C) (b) and (c), respectively (D) (a) & (b), respectively

Q.32 Two long current carrying thin wires, both with current I, are held by insulating threads of length L and are in equilibrium as shown in the figure, with threads making an angle θ with the vertical. If wires have mass λ per unit length then the value of I is (g = gravitational acceleration **[JEE MAIN 2015]**



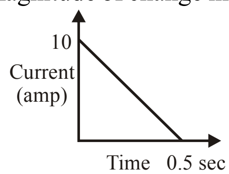
(A) $2\sin\theta\sqrt{\frac{\pi\lambda g L}{\mu_0 \cos\theta}}$ (B) $2\sqrt{\frac{\pi g L}{\mu_0}\tan\theta}$

(C) $\sqrt{\frac{\pi\lambda g L}{\mu_0}\tan\theta}$ (D) $\sin\theta\sqrt{\frac{\pi\lambda g L}{\mu_0 \cos\theta}}$

Q.33 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 .... $_A$ and B_B are the values of magnetic field at the centres of the circle and square respectively, then the ratio B_A/B_B is **[JEE MAIN 2016]**

(A) $\frac{\pi^2}{16\sqrt{2}}$ (B) $\frac{\pi^2}{16}$ (C) $\frac{\pi^2}{8\sqrt{2}}$ (D) $\frac{\pi^2}{8}$

Q.34 In a coil of resistance 100Ω, a current is induced by changing the magnetic flux through it as shown in the figure. The magnitude of change in flux through the coil is: **[JEE MAIN 2017]**



(A) 225 Wb (B) 250Wb
(C) 275 Wb (D) 200 Wb

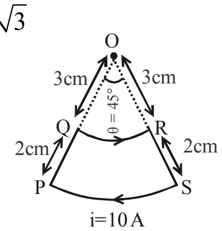
Q.35 An electron, a proton and an alpha particle having the same kinetic energy are moving in circular orbits of radii r_e, r_p, r_α respectively, in a uniform magnetic field B. The relation between r_e, r_p, r_α is: **[JEE MAIN 2018]**

(A) $r_e < r_p < r_\alpha$ (B) $r_e < r_\alpha < r_p$
(C) $r_e > r_p = r_\alpha$ (D) $r_e < r_p = r_\alpha$

Q.36 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 B_1 / B_2 is : **[JEE MAIN 2018]**

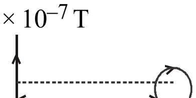
(A) $\sqrt{2}$ (B) $1/\sqrt{2}$
(C) 2 (D) $\sqrt{3}$

Q.37 A current loop, having two circular arcs joined by two radial lines is shown in the figure. It carries a current of 10 A. The magnetic field at point O will be close to : **[JEE MAIN 2019(JAN)]**



(A) 1.0×10^{-5} T (B) 1.5×10^{-5} T
(C) 1.0×10^{-7} T (D) 1.0×10^{-7} T

Q.38 An infinitely long current carrying wire and a small current carrying loop are in the plane of the paper as shown. The radius of the loop is a and distance of its centre from the wire is d (d >> a). If the loop applies a force F on the wire then : **[JEE MAIN 2019(JAN)]**

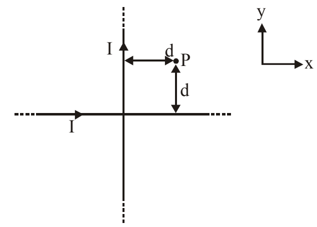


(A) $F \propto (a^2 / d^3)$ (B) $F \propto (a / d)$
(C) $F \propto (a / d)^2$ (D) F = 0

Q.39 A circular coil having N turns and radius r carries a current I. It is held in the XZ plane in a magnetic field $B\hat{i}$. The torque on the coil due to the magnetic field is : **[JEE MAIN 2019 (APRIL)]**

(A) $B\pi r^2 IN$ (B) $\frac{Br^2 I}{\pi N}$ (C) Zero (D) $\frac{B\pi r^2 I}{N}$

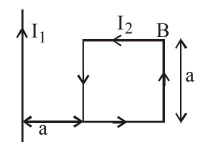
Q.40 Two very long, straight, and insulated wires are kept at 90° angle from each other in xy-plane as shown in the figure. These wires carry currents of equal magnitude I, whose directions are shown in the figure. The net magnetic field at point P will be **[JEE MAIN 2019 (APRIL)]**



(A) Zero (B) $\frac{+\mu_0 I}{\pi d}(\hat{z})$

(C) $-\frac{\mu_0 I}{2\pi d}(\hat{x}+\hat{y})$ (D) $\frac{\mu_0 I}{2\pi d}(\hat{x}+\hat{y})$

Q.41 A rigid square loop of side 'a' and carrying current I_2 is lying on a horizontal surface near a long current I_1 carrying wire in the same plane as shown in figure. The net force on the loop due to wire will be : **[JEE MAIN 2019 (APRIL)]**



(A) Attractive and equal to $\frac{\mu_0 I_1 I_2}{3\pi}$

(B) Repulsive and equal to $\frac{\mu_0 I_1 I_2}{4\pi}$

(C) Repulsive and equal to $\frac{\mu_0 I_1 I_2}{2\pi}$

(D) Zero

Q.42 A rectangular coil (Dimension 5 cm × 2.5 cm) with 100 turns, carrying a current of 3 A in the clock-wise direction is kept centered at the origin and in the X-Z plane. A magnetic field of 1 T is applied along X-axis. If the coil is tilted through 45° about Z-axis, then the torque on the coil is : **[JEE MAIN 2019 (APRIL)]**

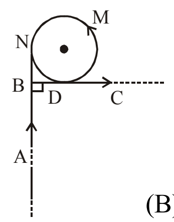
(A) 0.55 Nm (B) 0.27 Nm
(C) 0.38 Nm (D) 0.42 Nm

Q.43 Consider a circular coil of wire carrying constant current I, forming a magnetic dipole. The magnetic flux through an infinite plane that contains the circular coil and excluding the circular coil area is given by ϕ_i. The magnetic flux through the area of the circular coil area is given by ϕ_o. Which of the following option is correct ? **[JEE MAIN 2020 (JAN)]**

(A) $\phi_i > \phi_o$ (B) $\phi_i < \phi_o$
(C) $\phi_i = -\phi_o$ (D) $\phi_i = \phi_o$

Q.44 Consider a loop ABCDEFA with coordinates A (0, 0, 0), B(5, 0, 0), C(5, 5, 0), D(0, 5, 0) E(0,5,5) and F(0, 0, 5). Find magnetic flux through loop due to magnetic field $\vec{B} = 3\hat{i} + 4\hat{k}$. **[JEE MAIN 2020 (JAN)]**

Q.45 A very long wire ABDMNDC is shown in figure carrying current I. AB and BC parts are straight, long and at right angle. At D wire forms a circular turn DMND of radius R. AB, BC parts are tangential to circular turn at N and D. Magnetic field at the centre of circle is : **[JEE MAIN 2020 (JAN)]**



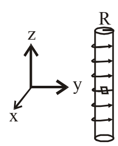
(A) $\frac{\mu_0 I}{2R}$ (B) $\frac{\mu_0 I}{2\pi R}(\pi + 1)$

(C) $\frac{\mu_0 I}{2\pi R}\left(\pi + \frac{1}{\sqrt{2}}\right)$ (D) $\frac{\mu_0 I}{2\pi R}\left(\pi - \frac{1}{\sqrt{2}}\right)$

Q.46 A long, straight wire of radius a carries a current distributed uniformly over its cross-section. The ratio of the magnetic fields due to the wire at distance a/3 and 2a, respectively from the axis of the wire is : **[JEE MAIN 2020 (JAN)]**

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

Q.47 An electron gun is placed inside a long solenoid of radius R on its axis. The solenoid has n turns/length and carries a current I. The electron gun shoots an electron along the radius of the solenoid with speed v. If the electron does not hit the surface of the solenoid, maximum possible value of v is (all symbols have their standard meaning) : **[JEE MAIN 2020 (JAN)]**



(A) $\frac{e\mu_0 nIR}{m}$ (B) $\frac{e\mu_0 nIR}{2m}$

(C) $\frac{2e\mu_0 nIR}{m}$ (D) $\frac{e\mu_0 nIR}{4m}$

Q.48 A small circular loop of conducting wire has radius a and carries current I. It is placed in a uniform magnetic field B perpendicular to its plane such that when rotated slightly about its diameter and released, it starts performing simple harmonic motion of time period T. If the mass of the loop is m then : **[JEE MAIN 2020 (JAN)]**

(A) $T = \sqrt{\frac{\pi m}{2IB}}$ (B) $T = \sqrt{\frac{2\pi m}{IB}}$

(C) $T = \sqrt{\frac{\pi m}{IB}}$ (D) $T = \sqrt{\frac{2m}{IB}}$

PART - B : MAGNETISM

Q.1 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) 1/2 (B) 2
(C) 1/4 (D) $1/2\sqrt{2}$

Q.2 A magnetic needle lying parallel to a magnetic field requires W units of work to turn it through 60º. The torque needed to maintain the needle in this position will be **[AIEEE-2003]**

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

Q.3 The magnetic lines of force inside a bar magnet –
(A) Do not exist. **[AIEEE-2003]**
(B) Depend upon the area of cross-section of the bar magnet.
(C) Are from south-pole to north-pole of the magnet.
(D) Are from north-pole to south-pole of the magnet.

Q.4 Curie temperature is the temperature above which – **[AIEEE-2003]**
(A) A paramagnetic material becomes diamagnetic.
(B) A ferromagnetic material becomes diamagnetic.
(C) A paramagnetic material becomes ferromagnetic.
(D) A ferromagnetic material becomes paramagnetic

Q.5 The length of a magnet is large compared to its width and breadth. The time period of its oscillation in a vibration magnetometer is 2s. The magnet is cut along its length into three equal parts and these parts are then placed on each other with their life poles together. The time period of this combination will be **[AIEEE-2004]**

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

Q.6 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

Q.7 A magnetic needle is kept in a non-uniform magnetic field. It experiences– **[AIEEE-2005]**
(A) a torque but not a force
(B) neither a force nor a torque
(C) a force and a torque
(D) a force but not a torque

Q.8 Needles N_1, N_2 and N_3 are made of a ferromagnetic, a paramagnetic and a diamagnetic substance respectively. A magnet when brought close to them will –**[AIEEE 2006]**
(A) attract N_1 strongly, but repel N_2 and N_3 weakly.
(B) attract all three of them
(C) attract N_1 and N_2 strongly but repel N_3
(D) attract N_1 strongly, N_2 weakly and repel N_3 weakly

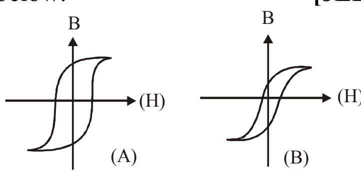
Q.9 Relative permittivity and permeability of a material are ε_r and μ_r, respectively. Which of the following values of these quantities are allowed for a diamagnetic material ? **[AIEEE 2008]**

(A) $\varepsilon_r = 1.5$, $\mu_r = 0.5$ (B) $\varepsilon_r = 0.5$, $\mu_r = 0.5$
(C) $\varepsilon_r = 1.5$, $\mu_r = 1.5$ (D) $\varepsilon_r = 0.5$, $\mu_r = 1.5$

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

(A) 3A (B) 6A
(C) 30 mA (D) 60 mA

Q.11 Hysteresis loops for two magnetic materials A and B are given below: **[JEE MAIN 2016]**



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

(A) A for electromagnets and B for electric generators.
(B) A for transformers and B for electric generators.
(C) B for electromagnets and transformers.
(D) A for electric generators and transformers.

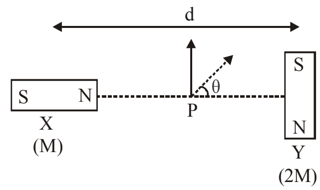
Q.12 A magnetic needle of magnetic moment 6.7×10^{-2} Am^2 and moment of inertia 7.5×10^{-6} kg m^2 is performing simple harmonic oscillations in a magnetic field of 0.01T. Time taken for 10 complete oscillations is: **[JEE MAIN 2017]**

(A) 8.89 s (B) 6.98s
(C) 8.76 s (D) 6.65s

Q.13 A bar magnet is demagnetized by inserting it inside a solenoid of length 0.2 m, 100 turns, and carrying a current of 5.2 A. The coercivity of the bar magnet is : **[JEE MAIN 2019(JAN)]**

(A) 1200 A/m (B) 2600 A/m
(C) 520 A/m (D) 285 A/m

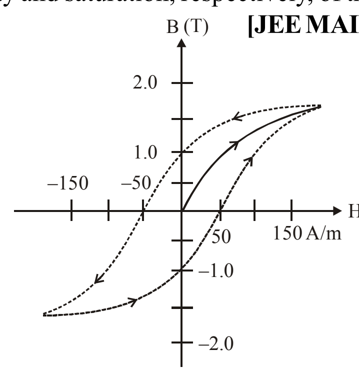
Q.14 Two magnetic dipoles X and Y are placed at a separation d, with their axes perpendicular to each other. The dipole moment of Y is twice that of X. A particle of charge q is passing, through their midpoint P, at angle $\theta = 45°$ with the horizontal line, as shown in figure. What would be the magnitude of force on the particle at that instant ? (d is much larger than the dimensions of the dipole) **[JEE MAIN 2019 (APRIL)]**



(A) $\sqrt{2}\left(\frac{\mu_0}{4\pi}\right)\frac{M}{(d/2)^3} \times qv$ (B) $\left(\frac{\mu_0}{4\pi}\right)\frac{2M}{(d/2)^3} \times qv$

(C) $\left(\frac{\mu_0}{4\pi}\right)\frac{M}{(d/2)^3} \times qv$ (D) 0

Q.15 The figure gives experimentally measured B vs. H variation in a ferromagnetic material. The retentivity, co-ercivity and saturation, respectively, of the material are: **[JEE MAIN 2020 (JAN)]**



(A) 50 A/m, 1T, 1.5 T (B) 1.5 T, 50 A/m, 1T
(C) 1 T, 50 A/m, 1.5 T (D) 50 A/m, 1.5 T, 1 T

Q.16 Photon with kinetic energy of 1 MeV moves from south to north. It gets an acceleration of 10^{12} m/s^2 by an applied magnetic field (west to east). The value of magnetic field : (Rest mass of proton is 1.6×10^{-27} kg) : **[JEE MAIN 2020 (JAN)]**

(A) 71 mT (B) 7.1 mT
(C) 0.071 mT (D) 0.71 mT

EXERCISE - 5 [PREVIOUS YEARS AIPMT / NEET QUESTIONS]

Q.1 An electron moves in a circular orbit with a uniform speed v. It produces a magnetic field B at the centre of the circle. The radius of the circle is proportional to – **[AIPMT 2005]**

(A) $\sqrt{B/v}$ (B) B/v

(C) $\sqrt{v/B}$ (D) v/B

Q.2 A coil in the shape of an equilateral triangle of side ℓ is suspended between the pole pieces of a permanent magnet such that $\vec{B}$ is in the plane of the coil. If due to a current i in the triangle a torque τ acts on it, the side ℓ of the triangle is – **[AIPMT 2005]**

(A) $\frac{2}{\sqrt{3}}\left(\frac{\tau}{B.i}\right)^{1/2}$ (B) $2\left(\frac{\tau}{\sqrt{3}\,B.i}\right)^{1/2}$

(C) $\frac{2}{\sqrt{3}}\left(\frac{\tau}{B.i}\right)$ (D) $\frac{1}{\sqrt{3}}\left(\frac{\tau}{B.i}\right)$

Q.3 If the magnetic dipole moment of an atom of diagmagnetic material paramagnetic material and ferromagnetic material are denoted by μ_d , μ_p and μ_f respectively, then – **[AIPMT 2005]**

(A) $\mu_d = 0$ and $\mu_p \neq 0$ (B) $\mu_d \neq 0$ and $\mu_p = 0$
(C) $\mu_p = 0$ and $\mu_f \neq 0$ (D) $\mu_d \neq 0$ and $\mu_f \neq 0$

Q.4 When a charged particle moving with velocity $\vec{v}$ is subjected to a magnetic field of induction $\vec{B}$, the force on it is non-zero. This implies that – **[AIPMT 2006]**

(A) angle between $\vec{v}$ and $\vec{B}$ can have any value other than 90°.

(B) angle between $\vec{v}$ and $\vec{B}$ can have any value other than zero and 180°.

(C) angle between $\vec{v}$ and $\vec{B}$ is either zero or 180°.

(D) angle between $\vec{v}$ and $\vec{B}$ is necessarily 90°.

Q.5 Two circular coils 1 and 2 are made from the same wire but the radius of the 1st coil is twice that of the 2nd coil. What potential difference in volts should be applied across them so that the magnetic field at their centres is the same **[AIPMT 2006]**

(A) 4 (B) 6
(C) 2 (D) None

Q.6 Above Curie temperature – **[AIPMT 2006]**

(A) a paramagnetic substance becomes diamagnetic
(B) a diamagnetic substance becomes paramagnetic
(C) a paramagnetic substance becomes ferromagnetic
(D) a ferromagnetic substance becomes paramagnetic

Q.7 A beam of electron passes undeflected through mutually perpendicular electric and magnetic fields. If the electric field is switched off, and the same magnetic field is maintained, the electrons moves – **[AIPMT 2007]**

(A) in a circular orbit
(B) along a parabolic path
(C) along a straight line
(D) in an elliptical orbit

Q.8 A charged particle (charge q) is moving in a circle of radius R with uniform speed v. The associated magnetic moment μ is given by – **[AIPMT 2007]**

(A) qvR^2 (B) $qvR^2/2$
(C) qvR (D) $qvR/2$

Q.9 Under the influence of a uniform magnetic field a charged particle is moving in a circle of radius R with constant speed v. The time period of the motion – **[AIPMT 2007]**

(A) depends on both R and v
(B) is independent of both R and v
(C) depends on R and not on v
(D) depends on v and not on R

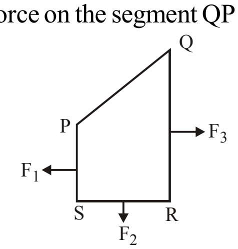
Q.10 Nickel shows ferromagnetic property at room temperature. If the temperature is increased beyond Curie temperature, then it will show – **[AIPMT 2007]**

(A) antiferromagnetism (B) no magnetic property
(C) diamagnetism (D) paramagnetism

Q.11 A particle of mass m, charge Q and kinetic energy T enters a transverse uniform magnetic field of induction $\vec{B}$. After 3 seconds the kinetic energy of the particle will be **[AIPMT 2008]**

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

Q.12 A closed loop PQRS carrying a current is placed in a uniform magnetic field. If the magnetic forces on segments PS, SR and RQ are F_1, F_2 and F_3 respectively and are in the plane of the paper and along the directions shown, the force on the segment QP is – **[AIPMT 2008]**



(A) $F_3 - F_1 + F_2$ (B) $F_3 - F_1 - F_2$
(C) $\sqrt{(F_3 - F_1)^2 + F_2^2}$ (D) $\sqrt{(F_3 - F_1)^2 - F_2^2}$

Q.13 The magnetic force acting on a charged particle of charge $-2\mu C$ in a magnetic field of 2T acting in y direction, when the particle velocity is $(2\hat{i} + 3\hat{j}) \times 10^6\ ms^{-1}$, is: **[AIPMT 2009]**

(A) 4 N is z direction (B) 8 N is y direction
(C) 8 N in z direction (D) 8 N in – z direction

Q.14 A bar magnet having a magnetic moment of $2 \times 10^4\ JT^{-1}$ is free to rotate in a horizontal plane. A horizontal magnetic field $B = 6 \times 10^{-4}$ T exists in the space. The work done in taking the magnet slowly from a direction parallel to the field to a direction 60° from the field is: **[AIPMT 2009]**

(A) 12 J (B) 6 J
(C) 2 J (D) 0.6 J

Q.15 If a diamagnetic substance is brought near the north or the south pole of a bar magnet, it is: **[AIPMT 2009]**
(A) repelled by the north pole & attracted by the south pole.
(B) attracted by the north pole and repelled by the south pole.
(C) attracted by both the poles
(D) repelled by both the poles

Q.16 A vibration magnetometer placed in magnetic meridian has a small bar magnet. The magnet executes oscillations with a time period of 2 sec in earth's horizontal magnetic field of 24 microtesla. When a horizontal field of 18 microtesla is produced opposite to the earth's field by placing a current carrying wire, the new time period of magnet will be **[AIPMT (PRE) 2010]**
(A) 1s (B) 2s
(C) 3s (D) 4s

Q.17 Electromagnets are made of soft iron because soft iron has **[AIPMT (PRE) 2010]**
(A) low retentivity and high coercive force
(B) high retentivity and high coercive force
(C) low retentivity and low coercive force
(D) high retentivity and low coercive force

Q.18 A beam of cathode rays is subjected to crossed electric (E) and magnetic fields (B). The fields are adjusted such that the beam is not deflected. The specific charge of the cathode rays is given by **[AIPMT (PRE) 2010]**
(A) $\frac{B^2}{2VE^2}$ (B) $\frac{2VB^2}{E^2}$ (C) $\frac{2VE^2}{B^2}$ (D) $\frac{E^2}{2VB^2}$
(V is the potential difference between cathode & anode)

Q.19 A thin ring of radius R meter has charge q coulomb uniformly spread on it. The ring rotates about its axis with a constant frequency of f revolutions/s. The value of magnetic induction in Wb/m^2 at the centre of the ring **[AIPMT (PRE) 2010]**
(A) $\frac{\mu_0 qf}{2\pi R}$ (B) $\frac{\mu_0 q}{2\pi fR}$ (C) $\frac{\mu_0 q}{2fR}$ (D) $\frac{\mu_0 qf}{2R}$

Q.20 A square current carrying loop is suspended in a uniform magnetic field acting in the plane of the loop. If the force on one arm of the loop is $\vec{F}$, the net force on the remaining three arms of the loop is **[AIPMT (PRE) 2010]**
(A) $3\vec{F}$ (B) $-\vec{F}$
(C) $-3\vec{F}$ (D) $\vec{F}$

Q.21 A current loop consists of two identical semicircular parts each of radius R, one lying in the x-y plane and the other in x-z plane. If the current in the loop is i. The resultant magnetic field due to the two semicircular parts at their common centre is **[AIPMT (MAINS) 2010]**
(A) $\frac{\mu_0 i}{2\sqrt{2}R}$ (B) $\frac{\mu_0 i}{2R}$ (C) $\frac{\mu_0 i}{4R}$ (D) $\frac{\mu_0 i}{\sqrt{2}R}$

Q.22 A closely wound solenoid of 2000 turns and area of cross-section 1.5×10^{-4} m^2 carries a current of 2.0 A. It is suspended through its centre and perpendicular to its length, allowing it to turn in a horizontal plane in a uniform magnetic field 5×10^{-2} tesla making an angle of 30° with the axis of the solenoid. The torque on the solenoid will be **[AIPMT (MAINS) 2010]**
(A) 3×10^{-3} N m (B) 1.5×10^{-3} Nm
(C) 1.5×10^{-2} N m (D) 3×10^{-2} N m

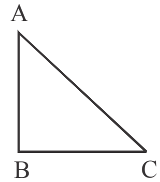
Q.23 A particle having a mass of 10^{-2} kg carries a charge of 5×10^{-8} C. The particle is given an initial horizontal velocity of 10^5 ms^{-1} in the presence of electric field $\vec{E}$ and magnetic field $\vec{B}$. To keep the particle moving in a horizontal direction, it is necessary that **[AIPMT (MAINS) 2010]**
(i) $\vec{B}$ should be perpendicular to the direction of velocity and $\vec{E}$ should be along the direction of velocity.
(ii) Both $\vec{B}$ and $\vec{E}$ should be along the direction of velocity.
(iii) Both $\vec{B}$ and $\vec{E}$ are mutually perpendicular and perpendicular to the direction of velocity.
(iv) $\vec{B}$ should be along the direction of velocity and $\vec{E}$ should be perpendicular to the direction of velocity
Which one of the following pairs of statements is possible
(A) (i) and (iii) (B) (iii) and (iv)
(C) (ii) and (iii) (D) (ii) and (iv)

Q.24 The magnetic moment of a diamagnetic atom is **[AIPMT (MAINS) 2010]**
(A) much greater than one
(B) one
(C) between zero and one
(D) equal to zero

Q.25 There are four light-weight-rod samples, A, B, C, D separately suspended by threads. A bar magnet is slowly brought near each sample and the following observations are noted – **[AIPMT (PRE) 2011]**
(i) A is feebly repelled (ii) B is feebly attracted
(iii) C is strongly attracted (iv) D remains unaffected
Which one of the following is true?
(A) A is of a non-magnetic material
(B) B is of a paramagnetic material
(C) C is of a diamagnetic material
(D) D is of a ferromagnetic material

Q.26 A uniform electric field and a uniform magnetic field are acting along the same direction in certain region. If an electron is projected in the region such that its velocity is pointed along direction of fields, then the electron **[AIPMT (PRE) 2011]**
(A) Will turn towards left of direction of motion
(B) Will turn towards right of direction of motion
(C) Speed will decrease
(D) Speed will increase

Q.27 A current carrying closed loop in the form of a right angle isosceles triangle ABC is placed in a uniform magnetic field acting along AB. If the magnetic force on the arm BC is $\vec{F}$, the force on the arm AC is – **[AIPMT (PRE) 2011]**



(A) $\sqrt{2}\vec{F}$ (B) $-\sqrt{2}\vec{F}$

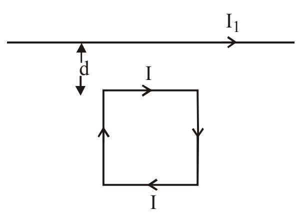
(C) $-\vec{F}$ (D) $\vec{F}$

Q.28 A short bar magnet of magnetic moment 0.4J T^{-1} is place in a uniform magnetic field of 0.16 T. The magnet is stable equilibrium when the potential energy is **[AIPMT (MAINS) 2011]**

(A) –0.064 J (B) zero

(C) – 0.082 J (D) 0.064

Q.29 A square loop, carrying a steady current I, is placed in a horizontal plane near a long straight conductor carrying a steady current I_1 at a distance d from the conductor as shown in figure. The loop will experience



(A) a net repulsive force away from the conductor.

(B) a net torque acting upward perpendicular to the horizontal plane.

(C) a net torque acting downward normal to the horizontal plane.

(D) a net attractive force towards the conductor.

Q.30 A compass needle which is allowed to move in a horizontal plane is taken to a geomagnetic pole. It : **[AIPMT (PRE) 2012]**

(A) will become rigid showing nomovement

(B) will stay in any position

(C) will stay in north-south direction only

(D) will stay in east-west direction only

Q.31 Two similar coils of radius R are lying concentrically with their planes at right angles to each other. The currents flowing in them are I and 2I, respectively. The resultant magnetic field induction at the centre will be: **[AIPMT (PRE) 2012]**

(A) $\frac{\sqrt{5}\mu_0 I}{2R}$ (B) $\frac{3\mu_0 I}{2R}$ (C) $\frac{\mu_0 I}{2R}$ (D) $\frac{\mu_0 I}{R}$

Q.32 An alternating electric field, of frequency ν, is applied across the dees (radius = R) of a cyclotron that is being used to accelerate protons (mass = m). The operating magnetic field(B) used in the cyclotron & the kinetic energy (K) of the proton beam, produced by it, are given **[AIPMT (PRE) 2012]**

(A) $B = \frac{m\nu}{e}, K = 2m\pi^2\nu^2R^2$ (B) $B = \frac{2\pi m\nu}{e}, K = m^2\pi\nu R^2$

(C) $B = \frac{2\pi m\nu}{e}, K = 2m\pi^2\nu^2R^2$ (D) $B = \frac{m\nu}{e}, K = m^2\pi\nu R^2$

Q.33 A proton carrying 1 MeV kinetic energy is moving in a circular path of radius R in uniform magnetic field. What should be the energy of an α-particle to describe a circle of same radius in the same field ? **[AIPMT (MAINS) 2012]**

(A) 2 MeV (B) 1 MeV

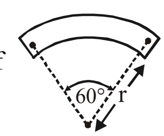
(C) 0.5 MeV (D) 4 MeV

Q.34 A magnetic needle suspended parallel to a magnetic field requires $\sqrt{3}$J of work to turn it through 60°. The torque needed to maintain the needle in this position will be – **[AIPMT (MAINS) 2012]**

(A) $2\sqrt{3}$J (B) 3J

(C) $\sqrt{3}$J (D) $\frac{3}{2}$J

Q.35 A bar magnet of length 'ℓ' and magnetic dipole moment 'M' is bent in the form of an arc as shown in figure. The new magnetic dipole moment will be –



(A) M/2 (B) M **[NEET 2013]**

(C) (3/π) M (D) (2/π) M

Q.36 A current loop in a magnetic field – **[NEET 2013]**

(A) Can be in equilibrium in two orientations, one stable while the other is unstable.

(B) Experiences a torque whether the field is uniform or non uniform in all orientations.

(C) Can be in equilibrium in one orientation.

(D) Can be in equilibrium in two orientations, both the equilibrium states are unstable.

Q.37 When a proton is released from rest in a room, it starts with an initial acceleration a_0 towards west. When it is projected towards north with a speed v_0 it moves with an initial acceleration $3a_0$ towards west. The electric and magnetic fields in the room are – **[NEET 2013]**

(A) $\frac{ma_0}{e}$ east, $\frac{3ma_0}{ev_0}$ down (B) $\frac{ma_0}{e}$ west, $\frac{2ma_0}{ev_0}$ up

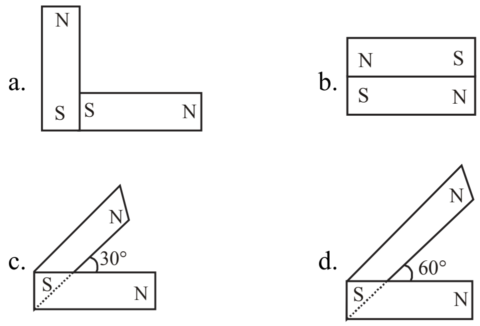
(C) $\frac{ma_0}{e}$ west, $\frac{2ma_0}{ev_0}$ down (D) $\frac{ma_0}{e}$ east, $\frac{3ma_0}{ev_0}$ up

Q.38 Two identical long conducting wires AOB and COD are placed at right angle to each other, with one above other such that O is their common point for the two. The wires carry I_1 and I_2 currents, respectively. Point P is lying at distance d from O along a direction perpendicular to the plane containing the wires. The magnetic field at the point P will be – **[AIPMT 2014]**

(A) $\frac{\mu_0}{2\pi d}\left(\frac{I_1}{I_2}\right)$ (B) $\frac{\mu_0}{2\pi d}(I_1 + I_2)$

(C) $\frac{\mu_0}{2\pi d}(i_1^2 - i_2^2)$ (D) $\frac{\mu_0}{2\pi d}(I_1^2 + I_2^2)^{1/2}$

Q.39 Following figures show the arrangement of bar magnets in different configurations. Each magnet has magnetic dipole moment $\vec{m}$. Which configuration has highest net magnetic dipole moment? **[AIPMT 2014]**



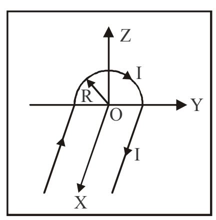
(A) a (B) b
(C) c (D) d

Q.40 An electron moving in a circular orbit of radius r makes n rotations per second. The magnetic fileld produced at the centre has magnitude : **[AIPMT 2015]**

(A) Zero (B) $\frac{\mu_0 n^2 e}{r}$

(C) $\frac{\mu_0 ne}{2r}$ (D) $\frac{\mu_0 ne}{2\pi r}$

Q.41 A wire carrying current I has the shape as shown in adjoining figure. Linear parts of the wire are very long and parallel to X-axis while semicircular portion of radius R is lying in Y-Z plane. Magnetic field at point O is – **[AIPMT 2015]**



(A) $\vec{B} = -\frac{\mu_0}{4\pi}\frac{I}{R}(\mu\hat{i} \times 2\hat{k})$ (B) $\vec{B} = -\frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{i} + 2\hat{k})$

(C) $\vec{B} = \frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{i} - 2\hat{k})$ (D) $\vec{B} = \frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{i} + 2\hat{k})$

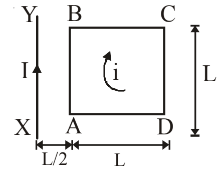
Q.42 A rectangular coil of length 0.12m and width 0.1m having 50 turns of wire is suspended vertically in a uniform magnetic field of strength 0.2 Weber/m^2. The coil carries a current of 2 A. If the plane of the coil is inclined at an angle of 30° with the direction of the field, the torque required to keep the coil in stable equilibrium will be : **[RE-AIPMT 2015]**

(A) 0.12 Nm (B) 0.15 Nm
(C) 0.20 Nm (D) 0.24 Nm

Q.43 A proton and an alpha particle both enter a region of uniform magnetic field, B, moving at right angles to the field B. If the radius of circular orbits for both the particles is equal and the kinetic energy acquired by proton is 1 MeV, the energy acquired by the alpha particle will be :- **[RE-AIPMT 2015]**

(A) 1 MeV (B) 4 MeV
(C) 0.5 MeV (D) 1.5 MeV

Q.44 A square loop ABCD carrying a current i, is placed near and coplanar with a long straight conductor XY carrying a current I, the net foce on the loop will be **[NEET 2016 PHASE-1]**



(A) $\frac{2\mu_0 Ii}{3\pi}$ (B) $\frac{\mu_0 Ii}{2\pi}$

(C) $\frac{2\mu_0 IiL}{3\pi}$ (D) $\frac{\mu_0 IiL}{2\pi}$

Q.45 A long straight wire of radius a carries a steady current I. The current is uniformly distributed over its cross-section. The ratio of the magnetic fields B and B' at radial distances a/2 and 2a respectively, from the axis of the wire is **[NEET 2016 PHASE-1]**

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

Q.46 The magnetic susceptibility is negative for **[NEET 2016 PHASE-1]**

(A) Diamagnetic material only
(B) Paramagnetic material only
(C) Ferromagnetic material only
(D) Paramagnetic and ferromagnetic materials.

Q.47 A long wire carrying a steady current is bent into a circular loop of one turn. The magnetic field at the centre of the loop is B. It is then bent into a circular coil of n turns. The magnetic field at the centre of this coil of n turns will be **[NEET 2016 PHASE-2]**

(A) nB (B) n^2B
(C) 2nB (D) $2n^2$B

Q.48 A bar magnet is hung by a thin cotton thread in a uniform horizontal magnetic field and is in equilibrium state. The energy required to rotate it by 60° is W. Now the torque required to keep the magnet in this new position is **[NEET 2016 PHASE-2]**

(A) $W/\sqrt{3}$ (B) $\sqrt{3}$ W

(C) $\frac{\sqrt{3}\,W}{2}$ (D) $\frac{2W}{\sqrt{3}}$

Q.49 An electron is moving in a circular path under the influence of a transverse magnetic field of 3.57×10^{-2} T. If the value of e/m is 1.76×10^{11} C/kg, the frequency of revolution of the electron is **[NEET 2016 PHASE-2]**

(A) 1 GHz (B) 100 MHz
(C) 62.8 MHz (D) 6.28 MHz

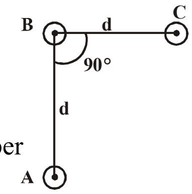
Q.50 If θ_1 and θ_2 be the apparent angles of dip observed in two vertical planes at right angles to each other, then the true angle of dip θ is – **[NEET 2017]**

(A) $\tan^2\theta = \tan^2\theta_1 + \tan^2\theta_2$
(B) $\cot^2\theta = \cot^2\theta_1 - \cot^2\theta_2$
(C) $\tan^2\theta = \tan^2\theta_1 - \tan^2\theta_2$
(D) $\cot^2\theta = \cot^2\theta_1 + \cot^2\theta_2$

Q.51 A 250-Turn rectangular coil of length 2.1 cm and width 1.25cm carries a current of 85 μA and subjected to magnetic field of strength 0.85 T. Work done for rotating the coil by 180º against the torque is – **[NEET 2017]**

(A) 4.55 μJ (B) 2.3 μJ
(C) 1.15 μ J (D) 9.1 μ J

Q.52 An arrangement of three parallel straight wires placed perpendicular to plane of paper carrying same current I along the same direction is shown in fig. Magnitude of force per unit length on the middle wire B is given by – **[NEET 2017]**



(A) $\frac{2\mu_0 i^2}{\pi d}$ (B) $\frac{\sqrt{2}\mu_0 i^2}{\pi d}$

(C) $\frac{\mu_0 i^2}{\sqrt{2}\pi d}$ (D) $\frac{\mu_0 i^2}{2\pi d}$

Q.53 A metallic rod of mass per unit length 0.5 kg m^{-1} is lying horizontally on a smooth inclined plane which makes an angle of 30° with the horizontal. The rod is not allowed to slide down by flowing a current through it when a magnetic field of induction 0.25T is acting on it in the vertical direction. The current flowing in the rod to keep it stationary is **[NEET 2018]**

(A) 14.76 A (B) 5.98 A
(C) 7.14 A (D) 11.32 A

Q.54 A thin diamagnetic rod is placed vertically between the poles of an electromagnet. When the current in the electromagnet is switched on, then the diamagnetic rod is pushed up, out of the horizontal magnetic field. Hence the rod gains gravitational potential energy. The work required to do this comes from **[NEET 2018]**

(A) The lattice structure of the material of the rod
(B) The magnetic field
(C) The current source
(D) The induced electric field due to the changing magnetic field.

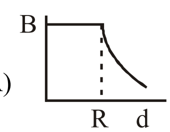
Q.55 Ionized hydrogen atoms and α-particles with same momenta enters perpendicular to a constant magnetic field, B. The ratio of their radii of their paths $r_H : r_\alpha$ will be

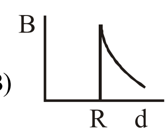
(A) 2 : 1 (B) 1 : 2 **[NEET 2019]**
(C) 4 : 1 (D) 1 : 4

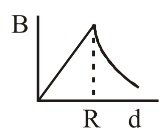
Q.56 At a point A on the earth's surface the angle of dip, δ = +25°. At a point B on the earth's surface the angle of dip, δ = –25°. We can interpret that: **[NEET 2019]**

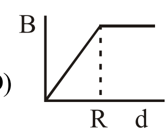
(A) A and B are both located in the northern hemisphere.
(B) A is located in the southern hemisphere and B is located in the northern hemisphere.
(C) A is located in the northern hemisphere and B is located in the southern hemisphere.
(D) A and B are both located in the southern hemisphere.

Q.57 A cylindrical conductor of radius R is carrying a constant current. The plot of the magnitude of the magnetic field. B with the distance d from the centre of the conductor, is correctly represented by the figure : **[NEET 2019]**

(A)


(B)


(C)


(D)


ANSWER KEY

EXERCISE - 1

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A	D	A	D	B	C	A	B	B	C	C	A	A	C	C	C	D	C	D	A	C	C	C	C	A	A
Q	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
A	A	C	C	C	D	C	C	C	C	B	D	A	A	A	D	A	B	A	D	A	A	A	D	D	C
Q	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
A	C	C	A	D	C	A	B	C	D	B	C	D	B	D	A	A	A	A	B	C	C	D	B	B	A
Q	76																								
A	A																								

EXERCISE - 2

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A	D	B	C	A	A	C	D	B	A	A	B	C	B	C	A	C	D	A	D	C	A	D	D	A	D
Q	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
A	B	A	A	C	C	D	C	C	B	C	D	D	B	C	C	C	D	D	C	D	A	A	A	D	C
Q	51	52																							
A	B	A																							

EXERCISE - 3

Q	1	2	3	4	5	6	7	8	9
A	9	4	940	750	6	7	5	6	7

EXERCISE - 4 (PART-A)

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	D	C	A	D	C	B	B	A	C	A	D	B	C	D	C	C	C	A	A	B
Q	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
A	B	C	C	A	A	A	B	B	D	D	B	A	C	B	D	A	A	C	A	A
Q	41	42	43	44	45	46	47	48												
A	B	B	C	175	C	A	B	B												

EXERCISE - 4 (PART-B)

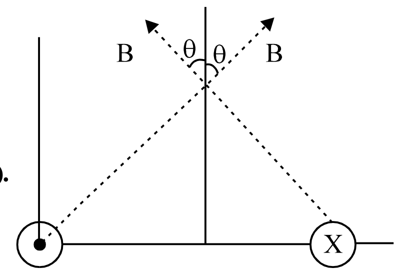
Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	A	D	C	D	B	B	C	D	A	A	C	D	B	D	C	D

EXERCISE - 5

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A	D	B	A	B	A	D	A	D	B	D	D	C	D	B	D	D	C	D	D	B	A	C	C	D	B
Q	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
A	C	C	A	D	B	A	C	B	B	C	A	C	D	C	C	B	C	A	A	C	A	B	B	A	D
Q	51	52	53	54	55	56	57																		
A	D	C	D	C	A	C	C																		

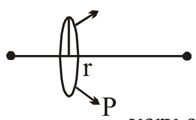
SOLUTIONS
MAGNETIC FIELD
TRY IT YOURSELF-1

(1) (C).



(2) (A). $-\frac{\mu I}{2a}\left(\frac{\theta}{2\pi}\right)+\frac{\mu_0 I}{4a\pi}=0$; $\theta = 2$ radian

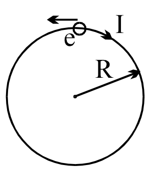
(3) (D). Circular for finite length of wire



very close to wire

$$B=\frac{\mu_0 I}{4\pi r}[\sin\theta_1-\sin\theta_2]$$

(4) (B).



This is equivalent to a current loop of radius R

$I = ne$

$$\begin{pmatrix}\text{Magnetic}\\ \text{field}\end{pmatrix} B=\frac{\mu_0}{4\pi}\left(\frac{2\pi IR}{R^2}\right)=\frac{\mu_0 ne}{2R}$$

(5) (A). Magnetic field on the axis of a circular loop

$$B=\left(\frac{\mu_0}{4\pi}\right)\times\frac{2\pi IR^2}{(R^2+z^2)^{3/2}},$$

where R = radius of loop = 3×10^{-2} m

$$=10^{-7}\times\frac{2\pi\times2.5\times3^2\times10^{-4}}{125\times10^{-6}}\hat{k}=\left(\frac{9\pi}{25}\times10^{-5}\,T\right)\hat{k}$$

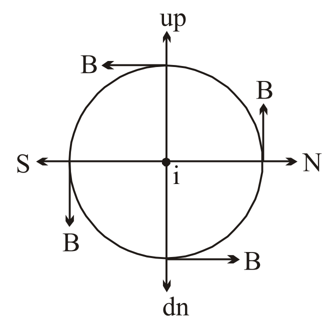
$$=(36\pi\times10^{-7}\,T)\,\hat{k}$$

(6) (B). $B=\frac{\mu_0}{2\pi\,(d/2)}(i_1-i_2)=20;\ \frac{\mu_0}{2\pi\,(d/2)}(i_1+i_2)=50$

$$\frac{i_1-i_2}{i_1+i_2}=\frac{2}{5}\ ;\ \text{Treading}\ \frac{i_1}{i_2}=x\ ;\ x=\frac{7}{3}$$

(7) (D). $B=\frac{\mu_0 NiR^2}{2(R^2+x^2)^{3/2}}$; $B_{max}\Rightarrow x_{min}=0$

(8) (AB). When seen from E to W megnetic line of forces are shown



]

(9) (B). Magnetic field at the centre of a semicircular current carrying conductor is given by the expression

$B=\frac{\mu_0}{4\pi}\frac{i(\pi a)}{a^2}d=\frac{\mu_0 i}{4a}$ where a is the radius of the first semicircle. Note that the current in all the turns is the same but its sense is alternately opposite and the radii are in the proportion 1 : 2 : 4 : 8....... Then, the net magnetic field =

$$\frac{\mu_0 i}{4a}\left[1-\frac{1}{2}+\frac{1}{4}-\frac{1}{8}+\frac{1}{16}......\right].$$

The terms in the bracket form a geometric progression which adds to (2/3) and then the answer follows.

(10) (D). B_P is only because of single current.
B_Q is because of two currents in same direction.
B_R is because of two currents in opposite direction.

(11) (C). loop B $=\mu_0(2i-i)=\oint B\cdot d\ell$

loop C $=\mu_0(i-2i)=\oint B\cdot d\ell$

loop A $=\mu_0(3i-3i)=\oint B\cdot d\ell$

loop D $=\mu_0(0-i)=\oint B\cdot d\ell$

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

TRY IT YOURSELF-2

(1) (B)

(2) (B)

(3) **(BD).** Stationary magnet generates magnetic field only which does not affect piece of paper. When it moves, it generates electric field also which affects pieces of paper. Torque due to magnetic force $\tau = MB \sin\theta$

Here $\vec{B}$ is $\perp$ to plane $\Rightarrow$ parallel to $\vec{M}$ $\therefore \tau = 0$

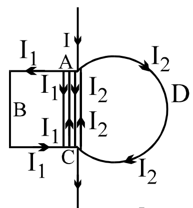
(4) **(B).** Magnetic moment of loop $\mu = NIA = 100 \times \frac{1}{2} \times \pi r^2$

(Potential Energy) $U = -\vec{\mu}\cdot\vec{B}$

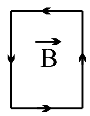
$\Delta U = U_f - U_i = -(-\mu B) - (-\mu B) = 2\mu B$

$= 2 \times 100 \times \frac{1}{2} \times \pi \left(\frac{1}{10}\right)^2 \times 2 = 2\pi J$

5) **(B).** Introducing two equal and opposite current I_1 and also I_2 between A & C.
Force on ABCA closed loop zero
Force on ADCA closed loop zero
Force on extra I_1 & I_2
$F = (I_1 + I_2)\,lB = IlB$



(6) **(C).** M inside page $\Rightarrow$ $\vec{M}\times\vec{B}$ is $\uparrow$ direction
$\Rightarrow$ left edge is lifted up



(7) **(BCD).**
The loops is alwsys attracted towards wire as the region part of loop getting attracted is experiencing stronger magnetic field.

(8) **(A).** $\vec{\tau} = \vec{M}\times\vec{B} = I\left[8a^2 + \frac{\pi a^2}{2}\right]B\sin 90°$

$= I\left(\frac{\pi a^2}{2} + 8a^2\right)B$

(9) **(B).** $F = BI\vec{\ell}_{eff}$

(10) (C)

TRY IT YOURSELF-3

(1) **(A).**

(2) **(C).** The magnetic for a on electron between (1) & (2) is downwards and between (3) & (4) plates upwards. (From the shape of the curve) so electric force must be opposite the magnetic force as the path is straight line.

(3) **(D).** Radius of the helix $r = \frac{m\theta\sin\theta}{13q}$

$\therefore$ The max. distance from x-axis is 2r.

Time period $T = \frac{2\pi m}{13q} \Rightarrow$ pitch $= \frac{2\pi m}{13q}\, v\cos\theta = 2r$

$\Rightarrow \tan\theta = \pi$

(4) **(A).** $\vec{F} = q(\vec{V}\times\vec{B})$; $B = B_1\hat{k}$; $V = V\hat{j}$
Force at origin is along x axis.

$\hat{j}\times\hat{k} = \hat{i}$ so q should be positive.

$r = \frac{mV}{qB}$ $\because r_2 < r_1$ $\therefore |B_2| > |B_1|$

(5) **(B).**

(6) **(C).** Radius should be $r_2 - r_1$

$r = \frac{mu}{qB}$; $(r_2 - r_1) = \frac{u}{\sigma B}$, thus $u = \sigma B(r_2 - r_1)$

(7) **(A).** $qvB = qE \Rightarrow vB = \frac{V}{D} \Rightarrow v = \frac{V}{BD}$

(8) **(B).** $T = 2\pi m/(qB)$ $\Rightarrow T \propto m/q$ [B & v same]
$T_\alpha / T_P = (4m/m)\times(q/2q) = 2:1$

(9) **(AD).** For a uniform helical path,

$T = \frac{2\pi m}{qB}$; Pitch $= \frac{2\pi m v\cos\theta}{qB}$; $R = \frac{mv\sin\theta}{qB}$

MAGNETISM
TRY IT YOURSELF

(1) Apparent dip θ' is given by

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

or $\tan\theta = (\tan\theta')\cos\beta = (\tan 60°)(1/3)$

$= \sqrt{3}\times\frac{1}{3} = \frac{1}{\sqrt{3}} = \tan 30°$

$\therefore \theta = 30°$, this is the true dip.

(2) (D)

(3) **(A).** Cosmic rays are stream of charged particles coming from outer space.

(4) **(C).** $B = \frac{2.4\times10^{-5}}{0.24\times10^{-4}}$, $H = 1600$; $\mu = \frac{B}{H}$

$\mu_r = \frac{\mu}{\mu_0} = \frac{B/H}{\mu_0}$ and then $x = \mu_r - 1$

(5) **(A).** Coercivity has the unit of

$H = \frac{B}{\mu_0} = \frac{\mu_0 nI}{\mu_0}$ $\therefore H = nI$

(6) **(C).** $B = \mu H = 8\times10^{-3}\times160 = 1.28\ Wb/m^2$

(7) **(C)** **(8)** **(B)**

(9) (AD) **(10)** (ACD)

(11) (BCD)

CHAPTER-3 : MAGNETIC EFFECTS OF CURRENT AND MAGNETISM
EXERCISE-1

(1) **(D).** Fleming's left hand rule is used to the determine the direction of force.

(2) **(A).** By Fleming left hand rule.

(3) **(D).** $\vec{F} = q(\vec{v} \times \vec{B}) = 0$ as $\vec{v}$ and $\vec{B}$ are parallel.

(4) **(B).** $\therefore F = Bi\ell$ or $1 \times 9.8 = 0.98 \times i \times 1 \Rightarrow i = 10A$.

(5) **(C).** $|F| = qvB\sin\theta$

F will be maximum. when $\theta = 90°$

(6) **(A).** $F = Bi\ell\sin\theta$

$$\Rightarrow \sin\theta = \frac{F}{Bi\ell} = \frac{15}{2 \times 10 \times 1.5} = \frac{1}{2} \Rightarrow \theta = 30°$$

(7) **(B).** When field is parallel to the direction of motion of charge, magnetic force on it is zero.

(8) **(B).** $r = \frac{p}{qB} \Rightarrow r \propto p$

(9) **(C).** When particle enters at angle other than 0° or 90° or 180°, path followed is helix.

(10) **(C).** When particle enters perpendicularly in a magnetic field, it moves along a circular path with constant speed.

(11) **(A).** Here magnetic force is zero, but the velocity increases due to electric force.

(12) **(A).** $r = \frac{mv}{Bq} = \frac{v}{(q/m)B} = \frac{2 \times 10^5}{5 \times 10^7 \times 4 \times 10^{-2}} = 0.1\text{m}$

(13) **(C).** $r = \frac{\sqrt{2mK}}{qB}$ i.e. $r \propto \frac{\sqrt{m}}{q}$

Here kinetic energy K and B are same.

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

(14) **(C).** $r = \frac{mv}{qB} \Rightarrow r \propto v \Rightarrow r_2 = 2r_1 = 2 \times 2 = 4\text{cm}$

(15) **(C).** $r = \frac{mv}{qB} \Rightarrow \frac{r_\alpha}{r_p} = \frac{m_\alpha}{m_p} \times \frac{q_p}{q_\alpha} = \frac{4}{1} \times \frac{1}{2} = \frac{2}{1}$

(16) **(D).** Particles entering perpendicularly, hence they will describe circular path. Since their masses are different so they will describe path of different radii.

(17) **(C).** $r = \frac{\sqrt{2mK}}{qB} \Rightarrow q \propto \sqrt{mK} \Rightarrow K \propto \frac{q^2}{m}$

$$\Rightarrow \frac{K_\alpha}{K_p} = \left(\frac{q_\alpha}{q_p}\right)^2 \times \frac{m_p}{m_\alpha} \Rightarrow \frac{K_\alpha}{8} = \left(\frac{2q_p}{q_p}\right)^2 \times \frac{m_p}{4m_p} = 1$$

$\Rightarrow K_\alpha = 8$ eV

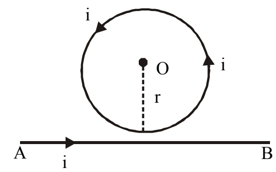
(18) **(D).** Cyclotron frequency $v = \frac{Bq}{2\pi m}$

$$\Rightarrow v = \frac{1 \times 1.6 \times 10^{-19}}{2 \times 3.14 \times 9.1 \times 10^{-31}} = 2.79 \times 10^{10}\text{Hz}$$

$= 27.9 \times 10^9$ HZ $\cong$ 28 GHZ

(19) **(A).** Chaged particles accelerate due to electric field.

(20) **(C).** The given circuit can be considered as :

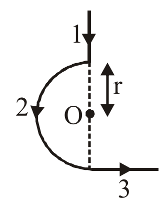


$$B_{loop} = \frac{\mu_0 i}{2r} \odot; \quad B_{conductor} = \frac{\mu_0 i}{2\pi r} \odot$$

$$B_{net} = \frac{\mu_0 i}{2\pi r}(\pi + 1) \odot$$

(21) **(C).** Magnetic field due to different parts are

$B_1 = 0$



$$B_2 = \frac{\mu_0}{4\pi} \cdot \frac{\pi i}{r} \odot \quad ; \quad B_3 = \frac{\mu_0}{4\pi} \cdot \frac{i}{r} \odot$$

$$\therefore B_{net} = B_2 + B_3 = \frac{\mu_0 i}{4r} + \frac{\mu_0 i}{4\pi r}$$

(22) **(C).** $B \propto \frac{1}{r} \Rightarrow \frac{B_1}{B_2} = \frac{r_2}{r_1} \Rightarrow \frac{B}{B_2} = \frac{r/2}{r} \Rightarrow B_2 = 2B$

(23) **(C).** Field at the centre of a circular coil of radius r is

$$B = \frac{\mu_0 I}{2r}$$

(24) **(A).** Magnetic field at the centre of current carrying coil is $B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi ni}{r} = \frac{\mu_0 ni}{2r}$

(25) **(A).** $B = \frac{\mu_0}{4\pi} \cdot \frac{2i}{r} \Rightarrow B \propto i$

(26) **(A).** We know magnetic field due to a long straight wire

$$B = \frac{\mu_0 i}{2\pi r} = \frac{4\pi \times 10^{-7} \times 3}{2\pi \times 50 \times 10^{-3}} \text{ (Note } \mu_0 = 4\pi \times 10^{-7})$$

$= 1.20 \times 10^{-5}$ Tesla $= 0.12$ G. [1 Gauss $= 10^{-4}$ Tesla]

(27) **(C).** $\delta B = \frac{\mu_0}{4\pi} \frac{i\delta\ell\sin\theta}{r^2}$

When $\theta = 90°$, then $\sin 90° = 1$

$$\therefore \quad \delta B = \frac{\mu_0 i\delta\ell}{4\pi r^2} = \text{maximum}$$

(28) **(C).** $B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi Ni}{r}$

$$\Rightarrow \quad 3.14 \times 10^{-3} = \frac{10^{-7} \times 2 \times 3.14 \times N \times 10}{(10 \times 10^{-2})}$$

$\Rightarrow \quad N = 50$

(29) **(C).** $B = \frac{\mu_0}{4\pi} \times \frac{\pi i}{r} \Rightarrow B = 10^{-7} \times \frac{\pi \times 10}{5 \times 10^{-2}} = 6.28 \times 10^{-5}$ T

(30) **(D).** Applying ampere's law at P, Q and R respectively, we find that there is no current enclosed by the circle of P. So magnetic induction at P is zero while that at Q and R is non- zero.

(31) **(C).** loop $B = \mu_0 (2i - i) = \oint B.d\ell$

loop $C = \mu_0 (i - 2i) = \oint B.d\ell$

loop $A = \mu_0 (3i - 3i) = \oint B.d\ell$

loop $D = \mu_0 (0 - i) = \oint B.d\ell$

So, $B > A > C = D$

(32) **(C).** Ampere's law is applicable for both symmetrical and unsymmetrical condition

(33) **(C).** Magnetic field due to solenoid is independent of diameter (Because $B = \mu_0 ni$).

(34) **(C).** The magnetic field in the solenoid along its axis (i) At an internal point $= \mu_0 ni$

$= 4\pi \times 10^{-7} \times 5000 \times 4 = 25.1 \times 10^{-3}$ Wb / m^2

(Here n = 50 turns / cm = 5000 turns / m)

(ii) At one end

$$B_{end} = \frac{1}{2} B_{in} = \frac{\mu_0 ni}{2} = \frac{25.1 \times 10^{-3}}{2}$$

(35) **(B).** $B = \mu_0 ni = 4\pi \times 10^{-7} \times \frac{200}{10^{-2}} \times 2.5 = 6.28 \times 10^{-2}$ Wb / m^2

(36) **(D).** Moves along same path without change in velocity.

(37) **(A).** $B_0 = \mu_0 \frac{Ni}{2\pi R} = \frac{4\pi \times 10^{-7} \times 500 \times 0.5}{2\pi \times 0.1} = 5 \times 10^{-4}$ T

(38) **(A).** $B = \mu_0 ni \Rightarrow i = \frac{B}{\mu_0 n} = \frac{20 \times 10^{-3}}{4\pi \times 10^{-7} \times 20 \times 100}$

$= 7.9\text{amp} = 8$ amp

(39) **(A).** $F' = \frac{\mu_0 i_1 i_2}{2\pi r}$ or $F' = \frac{4\pi \times 10^{-7} \times 30 \times 30}{2 \times \pi \times 5 \times 10^{-2}}$

$= 3.6 \times 10^{-3}$ N/m.

(40) **(D).** $F = 10^{-7} \times \frac{2i^2}{a} \times \ell \Rightarrow 30 \times 10^{-7} = 10^{-7} \times \frac{2i^2}{0.15} \times 9$

$\Rightarrow i = 0.5$ A

(41) **(A).** $F = \frac{\mu_0}{4\pi} . \frac{2i_1 i_2}{a} \times \ell \Rightarrow F = 10^{-7} \times \frac{2 \times 10 \times 2}{(10 \times 10^{-2})} \times 2 = 8 \times 10^{-5}$ N

(42) **(B).** $F = 10^{-7} \frac{2i_1 i_2}{a} = 10^{-7} \times \frac{2 \times 5 \times 5}{0.5} = 10^{-5}$ N (repulsive)

(43) **(A).** Two straight conductors carry current in same direction, then attractive force acts between them.

(44) **(D).** The equivalent magnetic moment is $M = iA = ef(\pi r^2)$

but $f = \frac{v}{2\pi r}$ $\therefore M = \frac{ev}{2\pi r} \pi r^2 = \frac{evr}{2}$

(45) **(A).** Magnetic moment on account of orbital motion of an electron $M = evr/2$

From Bohr's quantum condition $mvr = \frac{nh}{2\pi}$ but $n = 1$

$\therefore vr = \frac{h}{2\pi m}$ $\therefore M = \frac{evr}{2} = \frac{eh}{4\pi m}$

(46) $\tau_{max} = MB = niAB = ni(\ell \times b) B$

$\tau_{max} = 600 \times 10^{-5} \times 5 \times 10^{-2} \times 12 \times 10^{-2} \times 0.10$

$= 3.6 \times 10^{-6}$ N-m.

(47) **(A).** $M = NiA = 24 \times 0.75 \times 3.14 \times (3.5 \times 10^{-2})^2$

$= 6.9 \times 10^{-2}$ A-m^2

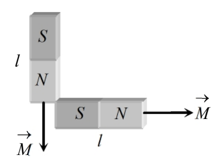
(48) **(D).** Torque on a current carrying loop of magnetic moment $\vec{m}$, placed in region of magnetic field $\vec{B}$ is

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

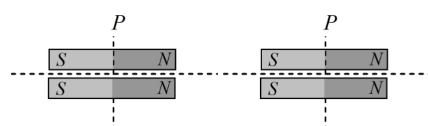
(49) **(D).** Torque acting on coil, $\tau = NBIA \sin\theta$

Here $\theta = 0°$, $\therefore \tau = 0$

(50) **(C).** $M_{net} = \sqrt{2}M = \sqrt{2}m\ell$.



(51) **(C).** If pole strength, magnetic moment and length of each part are m', M' and L' respectively then



$m' = \frac{m}{2}$ $\quad$ $m' = m$

$L' = L$ $\quad$ $L' = L/2$

$\Rightarrow M' = \frac{M}{2}$ $\quad$ $\Rightarrow M' = \frac{M}{2}$

(52) **(C).** In C.G.S. $B_{axial} = 9 = \frac{2M}{x^3}$ .....(i)

$B_{equaterial} = \frac{M}{(x/2)^3} = \frac{8M}{x^3}$ .....(ii)

From equation (i) and (ii)

$B_{equaterial} = 36$ Gauss.

(53) **(A).** $W = MB(\cos\theta_1 - \cos\theta_2)$

When the magnet is rotated from 0° to 60°, then work done is 0.8 J

$0.8 = MB(\cos 0° - \cos 60°) = \frac{MB}{2} \Rightarrow MB = 1.6$ N – m

In order to rotate the magnet through an angle of 30°, i.e., from 60° to 90°, the work done is

$$W' = MB(\cos 60° - \cos 90°) = MB\left(\frac{1}{2} - 0\right)$$

$$= \frac{MB}{2} = \frac{1.6}{2} = 0.8\,J = 0.8 \times 10^7\ ergs$$

(54) **(D).** $F = \frac{\mu_0}{4\pi}\left(\frac{6MM'}{d^4}\right)$ in end-on position.

(55) **(C).** Inside a magnet, magnetic lines of force move form south pole to north pole.

(56) **(A).** Both points A and B lying on the axis of the magnet and on axial position

$$B \propto \frac{1}{d^3} \Rightarrow \frac{B_A}{B_B} = \left(\frac{d_B}{d_A}\right)^3 = \left(\frac{48}{24}\right)^3 = \frac{8}{1}$$

(57) **(B).** $B = \frac{\mu_0}{4\pi}.\frac{2M}{d^3} \Rightarrow B = 10^{-7} \times \frac{2 \times 1.2}{(0.1)^3} = 2.4 \times 10^{-4}\,T$

(58) **(C).** Couple acting on a bar magnet of dipole moment M when placed in a magnetic field, is given by $\tau = MB \sin\theta$, where θ is the angle made by the axis of magnet with the direction of field.

Given that $m = 5$ Am, $2\ell = 0.2$ m, $\theta = 30°$ and $B = 15$ Wbm^{-2}

$\therefore\ \tau = MB \sin\theta = (m \times 2\ell)\, B \sin\theta$

$$= 5 \times 0.2 \times 15 \times \frac{1}{2} = 7.5\ Nm.$$

(59) **(D).** Magnetic lines form closed loop. Inside magnet these are directed from south to north pole.

(60) **(B).** B represents the magnetic field.

(61) **(C).** The net magnetic flux through any closed surface is zero.

(62) **(D).** At magnetic equator, the angle of dip is 0^o. Hence the vertical component $V = I \sin\phi = 0$.

(63) **(B).** Angle of declination: The angle between the magnetic meridian and geographical meridian.

(64) **(D).** $B_H = \sqrt{3}\,B_V$, also $\tan\theta = \frac{B_V}{B_H} = \frac{1}{\sqrt{3}} \Rightarrow \theta = 30^o$

(65) **(A).** At the magnetic north pole of the earth, the value of horizontal component of earth's magnetic field and angle of dip are, respectively zero and maximum.

(66) **(A).** At poles magnetic field is perpendicular to the surface of earth.

(67) **(A).** $\frac{T_1}{T_2} = \sqrt{\frac{M_2}{M_1}} = \sqrt{\frac{4M}{M}} = 2 \Rightarrow \frac{2}{T_2} = 2$; $T_2 = 1$ sec

(68) **(A).** Vibration magnetometer works on the principle of torque acting on the bar magnet.

(69) **(B).** $T = 2\pi\sqrt{\frac{I}{MB}} = 2\pi\sqrt{\frac{m\ell^2/12}{m_p \ell B}}$ or $T \propto m\ell$

$$\frac{T'}{T} = \left(\frac{\frac{m}{n}\frac{\ell}{n}}{m\ell}\right)^{1/2} \quad \text{or} \quad T' = \frac{T}{n}$$

(70) **(C).** $I = XH = 3 \times 10^{-4} \times 4 \times 10^3 = 12$ A/m

(71) **(C).** $\mu_r = \frac{\mu}{\mu_0} = \frac{B}{H\mu_0} = \frac{8\pi}{2 \times 10^3 \times 4\pi \times 10^{-7}} = 10^4$

(72) **(D).** Demagnetisation of magnets can be done by rough handling, heating and magnetising in the opposite direction

(73) **(B).** Because, diamagnetic substance, moves from stronger magnetic field to weaker field.

(74) **(B).** The magnetic susceptibility is negative for diamagnetic materials

(75) **(A).** The universal property of all substances is diamagnetism.

(76) **(A).** If a ferromagnetic material is inserted in a current carrying solenoid, the magnetic field of solenoid largely increases.

EXERCISE-2

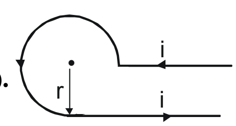
(1) **(D).** The magnetic field at any point on the axis of wire be zero.

(2) **(B).** Use Right hand palm rule or Maxwell's Cork screw rule.

(3) **(C).** $T = \frac{2\pi m}{qB} = \frac{2\pi r}{v} = \frac{2 \times 3.14 \times 0.45}{2.6 \times 10^7} = 1.08 \times 10^{-7}$ sec

(4) **(A).** $T = 2\pi\sqrt{\frac{I}{MB}}$

(5) **(A).**



$$B_0 = B_{PQ} + B_{QR} + B_{ST},\ B_{ST} = \frac{1}{2}\left[\frac{\mu_0 i}{2\pi r}\right]$$

$$B_{PQ} = 0,\ B_{QRS} = \frac{\mu_0 i}{4\pi r^2} \times \frac{3}{4} \times 2\pi r.$$

$$B_0 = \frac{\mu_0 i}{4\pi r} + \frac{3}{4}\frac{\mu_0 i}{2r} = \frac{\mu_0 i}{4r}\left[\frac{3}{2} + \frac{1}{\pi}\right] = \frac{\mu_0 i}{4\pi r}\left[\frac{3\pi}{2} + 1\right]$$

(6) **(C).** The magnetic induction produced due to a current carrying arc at its centre of curvature is

$$B = \frac{\mu_0\, i\alpha}{4\pi r} \quad ......(1)\ \therefore \quad \alpha = \frac{\pi}{4} \quad .....(2)$$

From eqs. (1) and (2), $B = \frac{\mu_0 i\pi}{4 \times \pi r} = \frac{\mu_0\, i}{16r}$

(7) **(D).** $B = \frac{\mu_0}{2\pi r}$ At null point the value of B must be equal to the horizontal component of earth's magnetic field (H) but its direction must be opposite to that of H.

$\therefore\ H = \frac{\mu_0}{2\pi r} \Rightarrow 2 \times 10^{-5} = \frac{4\pi \times 10^{-7} \times 30}{2 \times \pi \times r}$

$\Rightarrow\ r = 0.3$ m.

(8) **(B).** For circular coil $B_1 = \frac{\mu_0 I}{2r}$

Circumference of the coil = $2\pi r = L$.
Thus $B_1 = \pi\mu_0 I/L = 3.14\ \mu_0 I/L$
For square loop

$B_2 = 2\sqrt{2}\ \mu_0 I/L = 3.60\ \mu_0 I/L$
Thus $B_1 < B_2$.

(9) **(A).** $m = NiA = 100 \times 4 \times \pi r^2$
$= 400 \times 3.14 \times 25 \times 10^{-4} = 3.14\ Am^2$.

(10) **(A).** Field at a point x from the centre of a current carrying loop on the axis is

$$B = \frac{\mu_0}{4\pi}.\frac{2M}{x^3} = \frac{10^{-7} \times 2 \times 2.1 \times 10^{-25}}{(10^{-10})^3}$$

$$= 4.2 \times 10^{-32} \times 10^{30} = 4.2 \times 10^{-2}\ W/m^2$$

(11) **(B).** m = current × area

$$= i\left(\frac{1}{2}\pi a^2 + \frac{1}{2}\pi b^2\right) = \frac{1}{2} i\pi (a^2 + b^2).$$

(12) **(C).** $B = \frac{\mu_0}{4\pi}.\frac{2\pi(qv)}{r}$

$$= 10^{-7} \times \frac{2 \times 3.14 \times (1.6 \times 10^{-19} \times 6.6 \times 10^{15})}{0.53 \times 10^{-10}} = 12.5\ Wb/m^2$$

(13) **(B).** F = qvB also Kinetic energy

$$K = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2K}{m}} \quad \therefore\ F = q\sqrt{\frac{2K}{m}}B$$

$$= 1.6 \times 10^{-19}\sqrt{\frac{2 \times 200 \times 10^6 \times 1.6 \times 10^{-19}}{1.67 \times 10^{-27}}} \times 5$$

$$= 1.6 \times 10^{-10} N$$

(14) **(C).** When electron moves in both electric and magnetic field then qE = qvB.

$$\therefore\ v = \frac{E}{B} = \frac{1500}{0.40} = 3750\ m/s = 3.75 \times 10^3\ m/s$$

(15) **(A).** For no force on wire C, force on wire C due to wire D = force on wire C due to wire B

$$\Rightarrow \frac{\mu_0}{4\pi} \times \frac{2 \times 15 \times 5}{x} \times \ell = \frac{\mu_0}{4\pi} \times \frac{2 \times 5 \times 10}{(15 - x)} \times \ell \Rightarrow x = 9\text{cm}.$$

(16) **(C).** Magnetic field produced by wire is perpendicular to the motion of electron and it is given by

$$B = \frac{\mu_0}{4\pi}\cdot\frac{2i}{a} = 10^{-7} \times \frac{2 \times 5}{0.1} = 10^{-5}\ Wb/m^2$$

Hence force on electron

$F = qvB = (1.6 \times 10^{-19}) \times 5 \times 10^6 \times 10^{-5}$

$= 8 \times 10^{-18}$ N

(17) **(D).** $\vec{F} = q(\vec{V} \times \vec{B})$

$$\vec{V} \times \vec{B} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 3 & 2 & 0 \\ 5 \times 10^5 & 0 & 0 \end{vmatrix}$$

$= \hat{k}\ (-10 \times 10^5) = (-\hat{k}\ 10^6)$
$q = 2e = 2 \times 1.6 \times 10^{-19}$
$= 3.2 \times 10^{-19}$ Coulomb

$\vec{F} = 3.2 \times 10^{-19} (-\hat{k} \times 10^6)$

$\Rightarrow\ \vec{F} = -3.2 \times 10^{-13}\ \hat{k}$.
$\therefore\ |F| = 3.2 \times 10^{-13}$ N

(18) **(A).** $\tau = NBiA = 100 \times 0.2 \times 2 \times (0.08 \times 0.1)$

$= 0.32 N \times m$
Direction can be found by Fleming's left hand rule.

(19) **(D).** Magnetic field at O due to circular coil and straight conductor should be equal and opposite then the net magnetic field at O is zero.

$$\frac{\mu_0 I_1}{2R} = \frac{\mu_0 I_2}{2\pi(2R)} \Rightarrow I_1 = \frac{I_2}{2\pi}\ ;\ \frac{I_1}{I_2} = \frac{1}{2\pi}$$

(20) **(C).** $F_m = F_e$; $evB \sin\theta = eE$
$E = vB\sin\theta = 2 \times 10^3 \times 1.5 \times \sin 90^o$
$= 3 \times 10^3$ V/m

(21) **(A).** No force acts in other cases.

(22) **(D).** Parallel component drags the particle to side and perpendicular component gives circular path. Hence the path is helical.

(23) **(D).** $B = \mu_0 nI \quad (n = N/L)$

$$= 4 \times 3.14 \times 10^{-7} \times \frac{400}{0.4 \times 10^{-2}} \times 5$$
$= 0.628$ T

(24) **(A).** $W = MB(\cos\theta_1 - \cos\theta_2)$

When the magnet is rotated from 0° to 60°, then work done is 0.8 J

$$0.8 = MB(\cos 0° - \cos 60°) = \frac{MB}{2}$$

$\Rightarrow\ MB = 1.6\ N - m$

In order to rotate the magnet through an angle of 30°, i.e., from 60° to 90°, the work done is

$$W' = MB(\cos 60° - \cos 90°) = MB\left(\frac{1}{2} - 0\right)$$

$$= \frac{MB}{2} = \frac{1.6}{2} = 0.8 J = 0.8 \times 10^7\ \text{ergs}$$

(25) **(D).** $\frac{M_1}{M_2}=\left(\frac{d_1}{d_2}\right)^3 \Rightarrow \frac{27}{8}=\left(\frac{d_1}{0.12}\right)^3$

$\Rightarrow \frac{3}{2}=\frac{d_1}{0.12} \Rightarrow 0.18\text{ m}$

(26) **(B).** $B = B_H \tan\theta = 0.34\times10^{-4}\tan 30° = 1.96\times10^{-5}\text{ T}$

(27) **(A).** The volume of the bar magnet is

$$V=\frac{\text{mass}}{\text{density}}=\frac{6.6\times10^{-3}\text{kg}}{7.9\times10^{3}\text{kg/m}^3}$$

$= 8.3\times10^{-7}\text{ m}^3.$

The intensity of magnetization is

$$I=\frac{M}{V}=\frac{2.5\text{ A-m}^2}{8.3\times10^{-7}\text{ m}^2}=3.0\times10^{6}\text{ A/m}$$

(28) $W_H = VAft = \frac{m}{d}Aft$

or $W_H=\frac{0.6}{7.8\times10^3}\times0.722\times50$

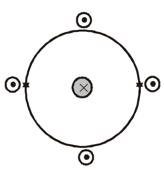
$= 277.7\times10^{-5}$ Joule

(29) **(C).** $M = NIA = NI\pi r^2$

$= 10^2\times1\times3.142\times10^{-2} = 3.142\text{ A m}^2$

(30) **(C).** $r=\frac{mv}{qB}=\frac{v}{(q/m)B}=\frac{10^7}{(10^{11})10^{-4}}=1\text{ m}$

(31) **(D).** For circular wire



(32) **(C).** $H_1=\frac{\mu_0 L}{4\pi L}$,

$H_2=\frac{\mu_0 I}{4\pi L}+\frac{\mu_0 I/2}{4\pi L}=\frac{3}{2}\frac{\mu_0 I}{4\pi L}$ $\therefore \frac{H_1}{H_2}=\frac{2}{3}$

(33) **(C).** By symmetry, the magnetic field at the centre P is zero.

(34) **(B).** Radius of the circle $=\frac{mv}{Bq}$

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

$(\text{Radius})_A > (\text{Radius})_B$

$\therefore$ $m_A v_A > m_B v_B$

(35) **(C).** $U=-\vec{M}\vec{B}=-MB\cos\theta$

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

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

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

(36) **(D).** Electrostatic & gravitational field does not form closed loop.

(37) **(D).** Magnetic force on wire BC would be perpendicular to the plane of the loop along the outward direction and on wire DA the magnetic force would be along the inward normal, so net force on the wire loop is zero and torque on the loop would be along the clock-wise sense as seen from O.

(38) **(B).** $B_R = B_1 - B_2 = 2B - B = B.$

If $2B = 0$, $B_R = B$

(39) **(C).** $qE = qvB$; $v=\frac{E}{B}=\frac{\sigma}{\varepsilon_0 B}$ $\left(\because E=\frac{\sigma}{\varepsilon_0}\right)$

$$t=\frac{\ell}{v}=\frac{\ell}{\frac{\sigma}{\varepsilon_0 B}}=\frac{\varepsilon_0 \ell B}{\sigma}$$

(40) **(C).** $F_m = mg$

$\vec{F}=i(\vec{\ell}\times\vec{B})$; $\vec{F}\to\hat{k}$, $\vec{\ell}\to-\hat{j}$; $\vec{B}\Rightarrow\hat{i}$

(41) **(C).** $B_A=\frac{B_C}{\sqrt{8}}$ if $x = R$

(42) **(D).** Resistance of the two branches are identical in P & R

(43) **(D).** $B=\frac{\mu_0 I}{4\pi r}$ [θ in rad]

$$B_1=\frac{\mu_0 I}{4\pi r}\times\frac{3\pi}{2}=\frac{3\mu_0 I}{8r}$$

$$B_2=\frac{\mu_0 I}{4\pi(2R)}\times\frac{\pi}{2}=\frac{\mu_0 I}{16r}$$

$$B_1+B_2=\frac{7}{16}\frac{\mu_0 I}{r}$$

(44) **(C).** $\tau = MB = (n_1 I_1 A)(\mu_0 n_2 I_2)$

$=\left(10\times\frac{21}{44}\times10^{-6}\right)\left(4\times\frac{22}{7}\times10^{-7}\times10^3\times2.5\right)$

$= 1.5\times10^{-8}$ N-m

(45) **(D).** $r=\frac{mv}{Bq}=\frac{mv}{Be}$

(46) **(A).** $r=\frac{mv}{Bq}$; r is least when (m/q) is least

(m/q) is least for electron. i.e. path is D

(47) **(A).** $B=\frac{\mu_0 i}{2\pi r}$; $B\propto\frac{1}{r}$

(48) **(A).** $B=\frac{\mu_0 I}{4\pi r}$; $B_1=\frac{\mu_0 I}{4\pi r_1}\times\frac{\pi}{2}=\frac{\mu_0 I}{8R_1}$

$B_2=\frac{\mu_0 I}{8R_2}$; $B_R=\frac{\mu_0 I}{8}\left(\frac{R_1+R_2}{R_1 R_2}\right)$

B due to st. wire along the wire = 0

(49) **(D).** $r=\frac{mv}{qB}=\frac{\sqrt{2Em}}{qB}$

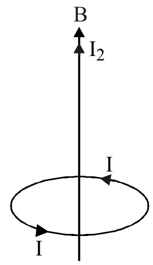
$$r\propto\frac{\sqrt{m}}{q}\Rightarrow\frac{r_\alpha}{r_p}=\sqrt{\frac{m_\alpha}{m_p}}\times\frac{q_p}{q_\alpha}=\sqrt{\frac{4m}{m}}\times\frac{e}{2e}$$

$r_\alpha : r_p = 1 : 1$

(50) **(C).** $F = BIL \sin\theta$

As B and I are parallel,

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



(51) **(B).** A positive moving in the direction of electric field gains kinetic energy while a negative charge looses kinetic energy.

(52) **(A).** $\chi \propto \frac{1}{T}$; $\frac{\chi_2}{\chi_1} = \frac{T_1}{T_2}$

$\frac{\chi_2}{0.0075} = \frac{273-73}{273-173}$; $\frac{\chi_2}{0.0075} = \frac{200}{100}$

$\chi = 0.0150$

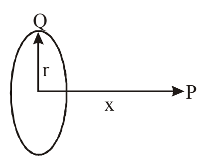
EXERCISE-3

(1) **9.** Electric field at P is $E = \frac{Qx}{4\pi \in_0 (x^2+r^2)^{3/2}}$

Magnetic field P is

$$B = \frac{\mu_0}{4\pi}\frac{2\pi i r^2}{(x^2+r^2)^{3/2}} = \frac{\mu_0}{4\pi}\frac{2\pi Q f r^2}{(x^2+r^2)^{3/2}} \quad [i = Qf]$$

f = frequency of revolution



Electric energy density $= \frac{1}{2}\varepsilon_0 E^2$

Magnetic energy density $= \frac{B^2}{2\mu_0}$

$$\frac{\text{Electric field density}}{\text{Magnetic energy density}} = \frac{\frac{1}{2}\varepsilon_0 E^2}{\frac{B^2}{2\mu_0}}$$

$$= \frac{E^2}{c^2B^2} = \frac{x^2c^2}{4\pi^2 f^2 r^4} = \frac{9}{\pi^2}\times 10^{10} = 9.1\times 10^9.$$

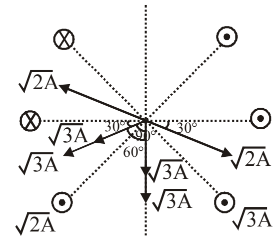
(2) **4.** The kinetic energy of a proton will be $E_p = \frac{R^2q^2B^2}{2m}$

$E_p' = \frac{R^2q^2B'^2}{2m}$ but $B' = 2B$

$\therefore E_p' = \frac{R^2q^2 4B'^2}{2m} = 4E_P$

(3) **940.** $B_1 = \frac{\mu_0}{4\pi}\times\frac{\sqrt{3}\times 2}{3\times 10^{-2}} = 10^{-5}\times\frac{2}{\sqrt{3}} = \frac{2}{\sqrt{3}}\times 10^{-5}$

$B = (\sqrt{(2B_1)^2 + (2B_2)^2 + 2(2B_1)\times(2B_2)\cos 60°}$

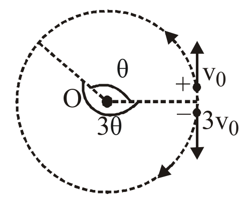


$= B\sqrt{4+4+4} = 2\sqrt{3}\times\frac{2}{\sqrt{3}}\times 10^{-5}$

$= 4\times 10^{-5} = 40\times 10^{-6}$

(4) **750.** $r = \frac{p}{qB}$ = same , $T_+ = \frac{2\pi m_+}{qB} = \frac{6\pi m}{qB}$, $T_- = \frac{2\pi m}{qB}$

As $T_+ = 3T_-$, They will meet at $\theta = \pi/2$



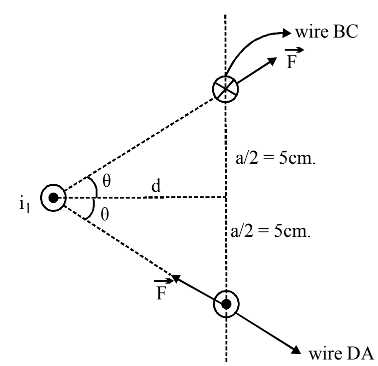
$q = 1\ \mu C, B = 2\pi\mu T,\ m = 10^{-15}$ kg

The time is $\frac{T_+}{4} = \frac{6\pi m}{4qB} = \frac{6\times\pi\times 10^{-15}}{4\times 1\times 10^{-6}\times 2\pi\times 10^{-6}}$

$= 0.75\times 10^{-3}\ S = 750\ \mu S$

(5) **6.** $\cos\theta = \frac{d}{r}$

$r = \sqrt{d^2 + \frac{a^2}{4}} = 13$cm. Torque $= \left(\frac{\mu_0 i_1 i_2}{2\pi r} a\cos\theta\right) a$



$$= \frac{2\times10^{-7}\times65\times65\times10}{13}\times\frac{12}{13}\times10\times10^{-2}$$

$= 6 \times 10^{-5}$ N-m

(6) **7.** Magnetic field strength at P due the I_1

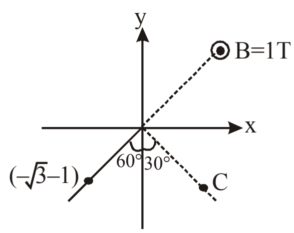
$$\vec{B}_1 = \frac{\mu_0 I_1}{2\pi(AP)}\hat{k} = \frac{4\pi\times10^{-7}\times2}{2\pi\times1\times10^{-2}}\hat{k} = (4\times10^{-5}T)\,\hat{k}$$

Magnetic field strength at P due the I_2

$$\vec{B}_2 = \frac{\mu_0 I_2}{2\pi(BP)}\hat{j} = \frac{4\pi\times10^{-7}\times3}{2\pi\times2\times10^{-2}}\hat{j} = (3\times10^{-5}T)\,\hat{j}$$

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

(7) **5.** The centre will be at C as shown :
Coordinates of the centre are (r cos 60°, – r sin 60°)

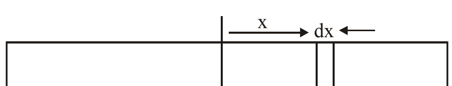


where r = radius of circle $= \frac{mv}{Bq} = \frac{1\times1}{1\times1} = 1$ i.e.,

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

(8) **6.** At a distance x consider small element of width dx.
Magnetic moment of the small element is

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



$$M = \int_{-\ell/2}^{\ell/2}\frac{q\omega}{2\ell}x^2dx \;;\; M = \frac{q\omega\ell^2}{24} = \frac{q\pi f\ell^2}{12} \quad \therefore\ a/2 = 6$$

(9) **7.** $B = \frac{\mu_0 I}{4\pi\frac{R}{\sqrt{2}}}(\sin 90° + \sin 135°) = \frac{\mu_0 I}{4\pi R}(\sqrt{2}-1)$

EXERCISE-4

PART - A : MAGNETIC EFFECTS OF CURRENT

(1) **(D).** $B_A = \frac{\mu_0 I}{2R}$; $B_B = \frac{\mu_0(2I)}{2(2R)}$ $\therefore B_A : B_B = 1$

(2) **(C).** $r = \frac{\rho}{qB}$
Same momentum and same charge
So r = constant.

(3) **(A).** There is attraction between consecutive turns carrying current in same direction so spring is compressed.

(4) **(D).** Time period $T = \frac{2\pi m}{qB}$

(5) **(C).** $F_m \perp v \Rightarrow$ Workdone = 0

(6) **(B).** $qvB = qE \qquad \therefore B = \frac{E}{v}$

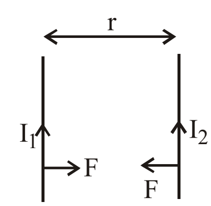
(7) **(B).** $B_{Coil} = \frac{\mu_0 NI}{2R}$
For same length of wire $N \propto 1/R$
$\therefore\ B_{Coil} \propto N^2$
$\therefore\ B' = n^2B$

(8) **(A).** $B = \frac{\mu_0 NIR^2}{2(R^2+x^2)^{3/2}} = \frac{\mu_0 NI}{2R}\left(\frac{1}{\left(1+\frac{x^2}{R^2}\right)^{3/2}}\right)$

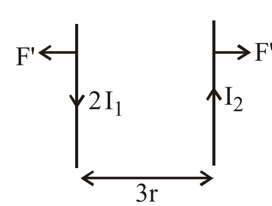
$$B = B_{centre}\left(1+\frac{x^2}{R^2}\right)^{-\frac{3}{2}}$$

$$B = B_{centre} = (54\mu T)\left[1+\left(\frac{4}{3}\right)^2\right]^{3/2} = 250\ \mu T$$

(9) **(C).** $F = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{r}I_1$

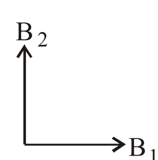


$$F' = \frac{\mu_0}{2\pi}\frac{(2I_1)I_2}{3r} = \frac{2}{3}F$$



(10) **(A).** $B_1 = \frac{\mu_0(3)}{2(2\pi\times10^{-2})}$

$$B_2 = \frac{\mu_0(4)}{2(2\pi\times10^{-2})}$$



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

(11) **(D).** Magnetic force = 0
Due to electric force in opposite direction velocity will decrease.

(12) **(B).** $T = \dfrac{2\pi m}{qB}$

(13) **(C).** Force per unit length = $\dfrac{\mu_0 i_1 i_2}{2\pi d}$

(14) **(D).** Due to electric force particle moves on straight line and magnetic force is zero.

(15) $B_{solenoid} = \mu_0 nI$

(16) **(C).** $B_{inside} = \dfrac{\mu_0 Ir}{2\pi R^2} = \dfrac{\mu_0 I(a/2)}{2\pi a^2}$

$B_{outside} = \dfrac{\mu_0 I}{2\pi R} = \dfrac{\mu_0 I}{2\pi(2a)}$ $\quad\therefore \dfrac{B_{a/2}}{B_{2a}} = 1$

(17) **(C).** The magnetic field at any point inside the pipe is zero.

(18) **(A).** $\vec{F}_e + \vec{F}_m = 0$

$q\vec{E} + q(\vec{v}\times\vec{B}) = 0 \Rightarrow \vec{E} = \vec{B}\times\vec{v}$

Now, $\vec{E}\times B = (\vec{B}\times\vec{v})\times\vec{B} = (\vec{B}.\vec{B})\vec{v} - (\vec{B}.\vec{v})\vec{B} = B^2\vec{v} - 0$

$\therefore \vec{v} = \dfrac{\vec{E}\times B}{B^2}$

(19) **(A).** The momentum changes but the kinetic energy is constant.

(20) **(B).** $B_1 = \dfrac{\mu_0 I_1}{2\pi d}$; $B_2 = \dfrac{\mu_0 I_2}{2\pi d}$

$B = \sqrt{B_1^2 + B_2^2} = \dfrac{\mu_0}{2\pi d}(I_1^2 + I_2^2)^{1/2}$

(21) **(B).** $B = \dfrac{\mu_0 I}{2\pi d} = \dfrac{4\pi\times 10^{-7}\times 100}{2\pi\times 4} = 5\times 10^{-6}$ T Southward.

(22) (C), (23) (C).

(i) $B_{\text{due to ABCD}} = \left[\dfrac{\mu_0 I}{2a} - \dfrac{\mu_0 I}{2b}\right]\times\dfrac{1}{12} = \dfrac{\mu_0 I(b-a)}{24ab}$

(ii) Due to current I_1, force on DA and BC will be zero

(24) **(A).** The magnetic field in between because of each will be in opposite direction

$B_{\text{in between}} = \dfrac{\mu_0 i}{2\pi x}\hat{j} - \dfrac{\mu_0 i}{2\pi(2d-x)}(-\hat{j})$

$= \dfrac{\mu_0 i}{2\pi}\left[\dfrac{1}{x} - \dfrac{\mu_0 i}{2d-x}\right](\hat{j})$

At x = d, $B_{\text{in between}} = 0$

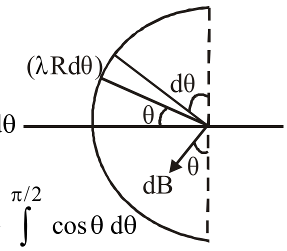
For x < d, $B_{\text{in between}} = (\hat{j})$

For x > d, $B_{\text{in between}} = (-\hat{j})$

towards x net magnetic field will add up and direction will be $(-\hat{j})$

towards x' net magnetic field will add up and direction will be $(\hat{j})$

(25) **(A).** $v = \dfrac{1}{\pi R}$



$dB = \left(\dfrac{\mu_0}{4\pi}\right)\dfrac{2I}{R}$; $I = \lambda R d\theta$

$\therefore B = \int_{-\pi/2}^{\pi/2} dB\cos\theta = \dfrac{\mu_0\lambda}{2\pi}\int_{-\pi/2}^{\pi/2}\cos\theta\, d\theta$

$= \dfrac{\mu_0\lambda}{\pi} = \dfrac{\mu_0 I}{\pi^2 R}$

(26) **(A).** $dB = \dfrac{\mu_0(dq)}{2r}\left(\dfrac{\omega}{2\pi}\right)$

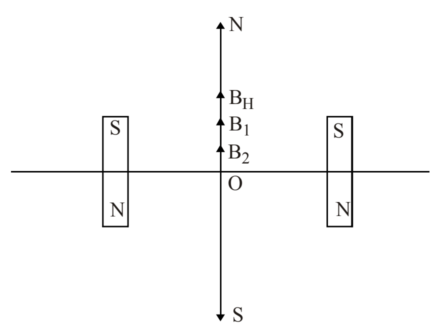
$B = \int dB = \dfrac{\mu_0\omega}{4\pi}.\dfrac{Q}{\pi R^2}2\pi\int_0^r \dfrac{r\,dr}{r}$

$B = \dfrac{\mu_0\omega Q}{2\pi R^2}.R$; $B = \dfrac{\mu_0\omega Q}{2\pi R}$; $B \propto \dfrac{1}{R}$

(27) **(B).** $r = \dfrac{\sqrt{2mE}}{3q}$; $r \propto \dfrac{\sqrt{m}}{q}$; $r_p = k\dfrac{\sqrt{m}}{q}$; $r_d = k\dfrac{\sqrt{2m}}{q}$;

$r_\alpha = k\dfrac{\sqrt{4m}}{2q} = \dfrac{k\sqrt{m}}{q}$ $\quad\therefore\ r_p = r_\alpha < r_d$

(28) **(B).** $B_{net} = B_1 + B_2 + B_H$



$B_{net} = \dfrac{\mu_0}{4\pi}\dfrac{(M_1 + M_2)}{r^3} + B_H$

$= \dfrac{10^{-7}(1.2+1)}{(0.1)^3} + 3.6\times 10^{-5} = 2.56\times 10^{-4}$ wb/m^2

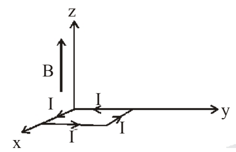
(29) **(D).** $P = \dfrac{\text{Work Done}}{\text{Time}} = \dfrac{\int F\,dx}{t} = \dfrac{\int I\ell bB.dx}{t}$

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

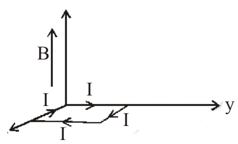
$$= \frac{9\times10^{-3}}{5\times10^{-3}}\left[\frac{e^{-0.2x}}{-0.2}\right]_0^2 = 9\,[1-e^{-0.4}] = 2.97\text{ W}$$

(30) **(D).** Net force on each of them would be zero.

(31) **(B).** Stable equilibrium $\vec{M}\,||\,\vec{B}$



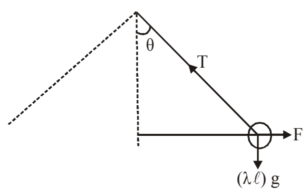
Unstable equilibrium $\vec{M}\,||\,(-\vec{B}$



(32) **(A).** $T\cos\theta = \lambda g\ell$

$$T\sin\theta = \frac{\mu_0}{2\pi}\cdot\frac{I\times I\ell}{(2L\sin\theta)}$$

$$\Rightarrow\quad I = 2\sin\theta\sqrt{\frac{\pi\lambda gL}{\mu_0\cos\theta}}$$



(33) **(C).** $2\pi R = \ell \Rightarrow\ R = \dfrac{\ell}{2\pi}$

$$B_A = \frac{\mu_0 I}{2R} = \frac{\mu_0 I\pi}{\ell}$$

$$B_B = 4\frac{\mu_0 I}{4\pi\,(a/2)}(\sin 45° + \sin 45°)$$

$$B_B = \frac{8\sqrt{2}\mu_0 I}{\pi\ell}\quad ;\quad \frac{B_A}{B_B} = \frac{\pi^2}{8\sqrt{2}}$$

(34) **(B).** $q = \dfrac{\Delta\phi}{R}$; Area of I-t graph $= \dfrac{\Delta\phi}{R}$

$$\Rightarrow\quad \frac{1}{2}\times10\times0.5 = \frac{\Delta\phi}{100}$$

$$\Rightarrow\quad \Delta\phi = \frac{1}{2}\times10\times0.5\times100 = 250\text{ Wb}$$

(35) **(D).** $r = \dfrac{mv}{qB} = \dfrac{\sqrt{2mK}}{qB}$

$$r_e = \frac{\sqrt{2m_eK}}{eB}\quad ;\quad r_\alpha = \frac{\sqrt{2\times4m_pK}}{2eB}\quad ;\quad r_p = \frac{\sqrt{2m_pK}}{eB}$$

Comparing (1), (2) and (3), $r_e < r_\alpha = r_p$

(36) **(A).** $B_1 = \dfrac{\mu_0 I}{2r_1}$; $m_1 = I\,(\pi r_1^2)$

$$B_2 = \frac{\mu_0 I}{2r_2}\ ;\ m_2 = I\,(\pi r_2^2)$$

$$\frac{m_2}{m_1} = \frac{r_2^2}{r_1^2} \Rightarrow 2 = \left(\frac{r_2}{r_1}\right)^2 \Rightarrow \frac{r_2}{r_1} = \sqrt{2}\ ;\ \frac{B_1}{B_2} = \frac{r_2}{r_1} = \sqrt{2}$$

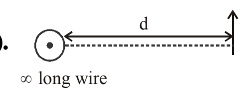
(37) **(A).** $\vec{B} = \dfrac{\mu_0 \hat{i}}{4\pi}\theta\left[\dfrac{1}{r_1} - \dfrac{1}{r_2}\right]\hat{k}$; $r_1 = 3\text{ cm} = 3\times10^{-2}\text{ m}$

$r_2 = 5\text{ cm} = 5\times10^{-2}\text{ m}$; $\theta = \pi/4$, $i = 10\text{ A}$

$$\Rightarrow\quad \vec{B} = \frac{4\pi\times10^{-7}}{16}\times10\left[\frac{1}{3\times10^{-2}} - \frac{1}{5\times10^{-2}}\right]\hat{k}$$

$$\Rightarrow\quad |\vec{B}| = \frac{\pi}{3}\times10^{-5}\text{ T} \approx 1\times10^{-5}\text{ T}$$

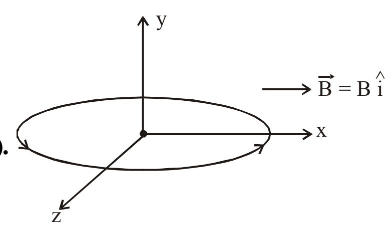
(38) **(C).**



$$F = -\frac{dU}{dx}\ ;\ U = -\vec{M}\cdot\vec{B}\ ;\ \frac{dB}{dx} = \frac{d}{dx}\left(\frac{\mu_0 I}{2\pi x}\right) \propto \frac{1}{x^2}$$

So, $F \propto \dfrac{M}{x^2}$ [$\because M = NIA$] $\therefore\quad F \propto \dfrac{a^2}{d^2}$

(39) **(A).**



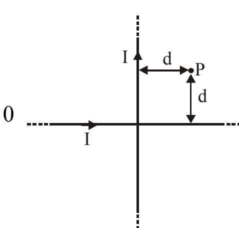
Magnetic moment of coil $= NIA\ \hat{j} = NI\,(\pi r^2)\ \hat{j}$

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

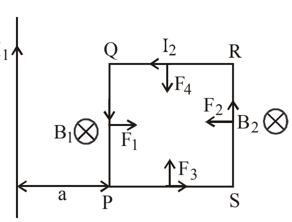
$= NI\,(\pi r^2)\,B\sin 90°\ (-\hat{k})\ = NI\pi r^2 B\,(-\hat{k})$

(40) **(A).** Magnetic field at point P

$$\vec{B}_{net} = \frac{\mu_0 I}{2\pi d}(-\hat{k}) + \frac{\mu_0 I}{2\pi d}(\hat{k}) = 0$$



(41) **(B).**



F_3 & F_4 cancel each other

Force on PQ will be $F_1 = I_2 B_1 a$

$= I_2 \dfrac{\mu_0 I_1}{2\pi} a = \dfrac{\mu_0 I_1 I_2}{2\pi}$

Force on RS will be

$F_2 = I_2 B_2 a = I_2 \dfrac{\mu_0 I_1}{2\pi\, 2a} a = \dfrac{\mu_0 I_1 I_2}{4\pi}$

Net force $= F_1 - F_2 = \dfrac{\mu_0 I_1 I_2}{4\pi}$ repulsion.

(42) **(B).** $|\vec{\tau}| = |\vec{M} \times \vec{B}|$

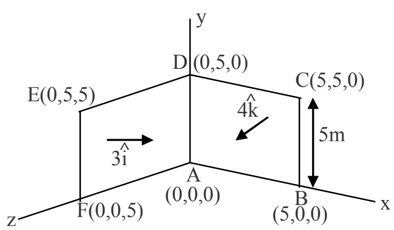
$\tau = NI \times A \times B \times \sin 45°$

$\tau = 0.27$ Nm

(43) **(C).** As magnetic field lines always form a closed loop, hence every magnetic field line creating magnetic flux in the inner region must be passing through the outer region. Since flux in two regions are in opposite direction,

$\therefore \ \phi_i = -\phi_o$

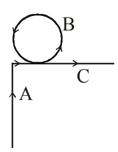
(44) **175.**



$\phi = \vec{B} \cdot \vec{A} = (3\hat{i} + 4\hat{k}) \cdot (25\hat{i} + 25\hat{k})$

$\phi = (3 \times 25) + (4 \times 25) = 175$ weber

(45) **(C).** We say we have 3 parts (A, B, C)



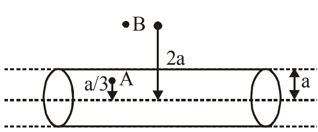
$B = B_A + B_B + B_C$

$= \dfrac{\mu_0 I}{4\pi R}(\sin 90° - \sin 45°) \otimes$

$+ \dfrac{\mu_0 I}{2R} \odot + \dfrac{\mu_0 I}{4\pi R}(\sin 45° + \sin 90°) \odot$

$= \dfrac{\mu_0 I}{2\pi R}(\sin 45° + \pi) = \dfrac{\mu_0 I}{2\pi R}\left(\pi + \dfrac{1}{\sqrt{2}}\right)$

(46) **(A).**



Let current density be J.

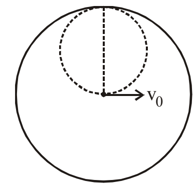
Applying Ampere's law

$\oint \vec{B} \cdot d\vec{\ell} = \mu_0 i \Rightarrow B_A 2\pi \dfrac{a}{3} = \mu_0 J \pi \left(\dfrac{a}{3}\right)^2$

$\therefore \ B_A = \dfrac{\mu_0 J a}{6}$. Similarly, $B_B = \dfrac{\mu_0 J a}{4}$

$\therefore \ \dfrac{B_A}{B_B} = \dfrac{\mu_0 J a \times 4}{\mu_0 J 6a} = \dfrac{2}{3}$

(47) **(B).** Top view of solenoid

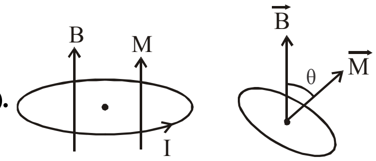


Maximum possible radius of electron = R/2

$\therefore \ \dfrac{R}{2} = \dfrac{mv}{qB} = \dfrac{mv_{max}}{e(\mu_0 n i)}$

$v_{max} = \dfrac{R}{2} \dfrac{e\mu_0 n i}{m}$

(48) **(B).**



$\vec{T} = \vec{M} \times \vec{B} = -MB\sin\theta$; $I\alpha = -MB\sin\theta$

For small θ, $\alpha = -\dfrac{MB}{I}\theta$

$\omega = \sqrt{\dfrac{MB}{I}} = \sqrt{\dfrac{(i)(\pi R^2) B}{\left(\dfrac{mR^2}{2}\right)}} = \sqrt{\dfrac{2i\pi B}{m}}$

$T = \dfrac{2\pi}{\omega} = \sqrt{\dfrac{2\pi m}{iB}}$

PART - B : MAGNETISM

(1) **(A).** $T = 2\pi\sqrt{\dfrac{I}{MB}}$; $I' = \dfrac{1}{8}$, $M' = \dfrac{M}{2}$

$T' = 2\pi\sqrt{\dfrac{I/8}{\dfrac{M}{2}B}} = \dfrac{T}{2} \ \therefore \dfrac{T'}{T} = \dfrac{1}{2}$

(2) **(D).** W = MB ($\cos\theta_1 - \cos\theta_2$)

= MB (cos 0º – cos 60º) = MB/2

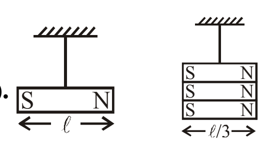
$\tau = MB\sin 60° = \dfrac{\sqrt{3}}{2} MB = \sqrt{3} W$

(3) **(C).** Outside magnet N to S

Inside magnet S to N

(4) **(D).** A ferromagnetic material becomes paramagnetic.

(5) **(B).**



; $T = 2\pi\sqrt{\dfrac{I}{MB}} = 2\sec$

$T = 2\pi\sqrt{\dfrac{I'}{M'B}} = 2\pi\sqrt{\dfrac{I/9}{MB}} = \dfrac{T}{3} = \dfrac{2}{3}\sec$

(6) **(B).** For electromagnet, soft ferromagnetic material is required which has low retentivity and low coercivity.

(7) **(C).** A force and a torque.

(8) **(D).** Attract N_1 strongly, N_2 weakly and repel N_3 weakly

(9) **(A).** For diamagnetic $0 < \mu_r < 1$

For every material $\varepsilon_r > 1$

(10) **(A).** $\mu_0 H = \mu_0 nI\ ;\ 3\times10^3 = \dfrac{100}{0.1}\times i \Rightarrow i = 3A$

(11) **(C).** For electromagnets and transformers, energy loss should below. $\Rightarrow$ Thin hysteris curves.

Also, $B \to 0$ when $H = 0$ and $|H|$ should be small when $B \to 0$. So option fulfills.

(12) **(D).** $T = MB\sin\theta = MB\theta$ (if θ is small)

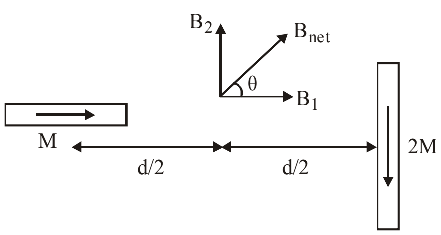
$$T = 2\pi\sqrt{\frac{I}{MB}} = 2\pi\sqrt{\frac{7.5\times10^{-6}}{6.7\times10^{-2}\times0.01}} = 0.665$$

Time taken for 10 oscillation = 6.65s.

(13) **(B).** $\text{Coercivity} = H = B/\mu_0 = ni = \dfrac{N}{\ell}i = \dfrac{100}{0.2}\times5.2$

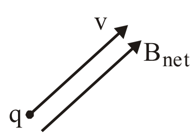
$= 2600$ A/m

(14) **(D).**



$$B_1 = 2\left(\frac{\mu_0}{4\pi}\right)\frac{M}{(d/2)^3}$$

$$B_2 = \left(\frac{\mu_0}{4\pi}\right)\frac{2M}{(d/2)^3}$$

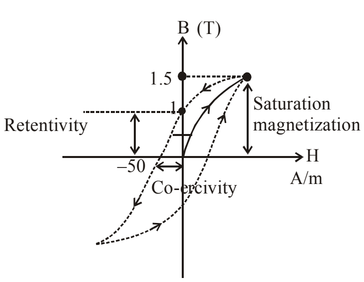


$B_1 = B_2$

B_{net} is at 45° ($\theta = 45°$)

Velocity of charge and B_{net} are parallel so by $\vec{F} = q(\vec{v}\times\vec{B})$ force on charge particle is zero.

(15) **(C).**

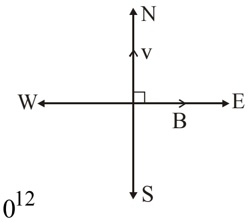


Retentivity = 1.0 T

Coercivity = 50 A/m

Saturation = 1.5 T

(16) **(D).** $a = \dfrac{qvB}{m}$

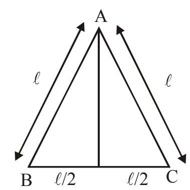


$$B = \frac{ma}{qv} = \frac{ma\sqrt{m}}{\sqrt{2k}} = \frac{m^{3/2}a}{e\sqrt{2k}}$$

$$= \frac{(1.6\times10^{-27})^{3/2}\times10^{12}}{1.6\times10^{-19}\sqrt{2\times1\times10^{6}\times1.6\times10^{-19}}} = 0.71\text{ mT}$$

EXERCISE-5

(1) **(D).** $r = \dfrac{mv}{qB} \Rightarrow r \propto \dfrac{v}{B}$



(2) **(B).** $\tau = mB\sin\theta$;

$\tau = iAB\sin 90°$

$\therefore\ A = \dfrac{\tau}{iB}$

$$A = \frac{1}{2}(BC)(AD) = \frac{1}{2}(\ell)\sqrt{\ell^2 - \left(\frac{\ell}{2}\right)^2} = \frac{\sqrt{3}}{4}\ell^2$$

$$\Rightarrow \frac{\sqrt{3}}{4}(\ell)^2 = \frac{\tau}{Bi} \quad \therefore\ \ell = 2\left(\frac{\tau}{\sqrt{3}\,Bi}\right)^{1/2}$$

(3) **(A).** The magnetic dipole moment of diamagnetic material is zero as each of its pair of electrons have opposite spins, i.e., $\mu_d = 0$

Paramagnetic substances have dipole moment > 0 i.e. $\mu_p \neq 0$, because of excess of electrons in molecules spinning in the same direction.

Ferromagnetic substances are very strong magnets and they also have permanent magnetic moment i.e. $\mu_f \neq 0$.

(4) **(B).** Force on a particle moving with velocity v in a magnetic field B is $\vec{F} = q(\vec{v}\times\vec{B})$

If angle between $\vec{v}$ & $\vec{B}$ is either zero or 180°, the value of F will be zero as cross product of $\vec{v}$ & $\vec{B}$ will be zero.

(5) **(A).** Magnetic field at the centre of circular coil = $\dfrac{\mu_0 I}{2r}$

$B_1 = B_2\ ;\ \dfrac{I_1}{r_1} = \dfrac{I_2}{r_2}\ ;\ r_1 = 2r_2\ ;\ i_1 = 2i_2$

$\dfrac{V_2}{V_1} = \dfrac{i_2 r_2}{i_1 r_1} = \dfrac{1}{4}\ ;\ \dfrac{V_1}{V_2} = 4$

(6) **(D).** Above Curie temperature, a ferromagnetic substance becomes paramagnetic.

(7) **(A).** If the electric field is switched off, and the same magnetic field is maintained, the electrons move in a circular orbit and electron will travel a magnetic field ⊥ to its velocity.

(8) **(D).** Magnetic moment, $m = IA = \frac{qv}{2\pi R}(\pi R^2) = \frac{qvR}{2}$

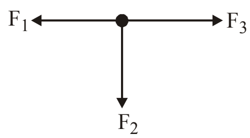
$$\left[\because I = \frac{q}{T} \text{ and } T = \frac{2\pi R}{v}\right]$$

(9) **(B).** $\frac{mv^2}{R} = qvB;\ T = \frac{2\pi R}{v} = \frac{2\pi m}{qB}$

(10) **(D).** Beyond Curie temperature, ferromagnetic substances behaves like a paramagnetic substance.

(11) **(D).** Magnetic field can never increase the energy of a charge particle so its kinetic energy will remain T.

(12) **(C).** Force on QP will be equal and opposite to sum of forces on other 3 sides



So, $F_{QP} = \sqrt{(F_3 - F_1)^2 + F_2^2}$

(13) **(D).** $\vec{F} = q(\vec{V} \times \vec{B}) = -2 \times 10^{-6}[(2\hat{i} + 3\hat{j}) \times 10^6 \times 2\hat{j}]$

$= -2 \times 10^{-6}(2 \times 2 \times 10^6\ \hat{k}] = -8\text{N z-axis}$

(14) **(B).** Work done = MB $(\cos\theta_1 - \cos\theta_2)$

$= nB\left(1 - \frac{1}{2}\right) = \frac{2 \times 10^4 \times 6 \times 10^{-4}}{2} = 6\text{J}$

(15) **(D).** Diamagnetic substances are repelled in an external magnetic field i.e., it is repelled by both north and south poles of a bar magnet.

(16) **(D).** The time period T of oscillation of a magnet is given by $T = 2\pi\sqrt{\frac{I}{MB}}$

As the I, M remains the same

$T \propto \sqrt{\frac{1}{B}}$ or $\frac{T_2}{T_1} = \sqrt{\frac{B_1}{B_2}}$

According to given problem,
$B_1 = 24\ \mu T, B_2 = 24\mu T - 18\mu T = 6\mu T, T_1 = 2s$

$\therefore\ T_2 = (2s)\sqrt{\frac{24\mu T}{6\mu T}} = 4s$

(17) **(C).** Electromagnetics are made of soft iron because soft iron has low retentivity and low coercive force or low coercivity. Soft iron is a soft magnetic material.

(18) **(D).** When a beam of cathode rays (or electrons) are subjected to crossed electric (E) and magnetic (B) fields, the beam is not deflected, if

Force on e^- due to MF = Force on electron due to EF

$Beu = eE$ or $u = E/B$ ....(i)

If V is the potential difference between the anode and the cathode, then

$\frac{1}{2}mu^2 = eV\ ;\ \frac{e}{m} = \frac{u^2}{2V}$ ....(ii)

Substituting the value of u from eq. (i) in eq. (ii),

we get $\frac{e}{m} = \frac{E^2}{2VB^2}$

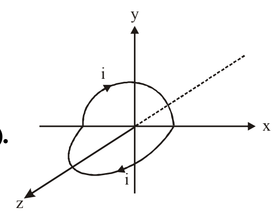
(19) **(D).** Current produced due to circular motion of charge q is $I = qf$

Magnetic field induction at the centre of the ring of radius R is $B = \frac{\mu_0 2\pi I}{4\pi R} = \frac{\mu_0 I}{2R} = \frac{\mu_0 qf}{2R}$

(20) **(B).** $\Sigma\vec{F} = 0$

In this way force F acting on one side of loop and force –F acting on remaining side of loop.

(21) **(A).**



Magnetic field at the centre due to semicircular loop lying in x-y plane, $B_{xy} = \frac{1}{2}\left(\frac{\mu_0 i}{2R}\right)$ –ve z direction.

Similarly field due to loop in x-z plane,

$B_{xz} = \frac{1}{2}\left(\frac{\mu_0 i}{2R}\right)$ in negative y direction.

$\therefore$ Magnitude of result an tmagnetic field,

$B = \sqrt{B_{xy}^2 + B_{xz}^2} = \sqrt{\left(\frac{\mu_0 i}{4R}\right)^2 + \left(\frac{\mu_0 i}{4R}\right)^2} = \frac{\mu_0 i}{2\sqrt{2}R}$

(22) **(C).** Magnetic moment of the loop.
$M = NIA = 2000 \times 2 \times 1.5 \times 10^{-4} = 0.6\ \text{J/T}$

$\tau = MB\sin 30° = 0.6 \times 5 \times 10^{-2} \times \frac{1}{2} = 1.5 \times 10^{-2}\ \text{Nm}$

(23) **(C).** (i) **B** and **E** in same direction.
$F_m = 0\ ;\ F_e \neq 0$
Electric force in direction of motion.
(ii) $qvB = qE$

(24) **(D).** The magnetic momentum of a diamagnetic atom is equal to zero.

(25) **(B).** Diamagnetic will be feebly repelled. Paramagnetic will be feebly attracted. Ferromagnetic will be strongly attracted.

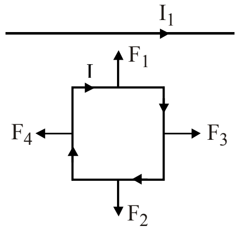
(26) **(C).** B field will not apply any force. E field will apply a force opposite to velocity of the electron hence, speed will decrease.

(27) **(C).** $\vec{F} = I\vec{L} \times \vec{B}\ ;\ \vec{F}_{AB} = 0\ ;\ \vec{F}_{AB} + \vec{F}_{BC} + \vec{F}_{CA} = 0$

$\vec{F}_{CA} = -\vec{F}_{BC} = -\vec{F}$

(28) **(A).** For stable equ.
$U = -MB = -(0.4)(0.16) = -0.064$ J

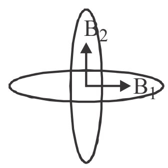
(29) **(D).**



$F_1 > F_2$. hence net attraction force will be towards conductor.7

(30) **(B).** Since magnetic field is in vertical direction and Needle is free to rotate in horizontal plane only so magnetic force can not rotate the needle in horizontal plane so needle can stay in any position.

(31) **(A).** $B_1 = \frac{\mu_0 I}{R}$, $B_1 = \frac{\mu_0(2I)}{2R}$



$B_{net} = \sqrt{B_1^2 + B_2^2} = \frac{\mu_0(2I)}{2R}\sqrt{1+4}$

$= \frac{\sqrt{5}\mu_0 I}{2R}$

(32) **(C).** Time period of cyclotron is

$T = \frac{1}{\nu} = \frac{2\pi m}{eB}$; $B = \frac{2\pi m}{e}\nu$; $R = \frac{mv}{eB} = \frac{p}{eB}$

$\Rightarrow \; p = eBR = e \times \frac{2\pi m\nu}{e}R = 2\pi m\nu R$

$KE = \frac{p^2}{2m} = \frac{(2\pi m\nu R)^2}{2m} = 2\pi^2 m\nu^2 R^2$

(33) **(B).** $R = \frac{\sqrt{2mK}}{qB}$; $q_\alpha = 2q, m_\alpha = 4m$

$R_\alpha = \frac{\sqrt{2(4m)K'}}{2qB}$; $\frac{R}{R_\alpha} = \sqrt{\frac{K}{K'}}$

but $R = R_\alpha$ then $K = K' = 1$ MeV

(34) **(B).** $W = U_{final} - Uinitial = MB(\cos 0° - \cos 60°)$

$W = \frac{MB}{2} = \sqrt{3}J$ .... (1)

$\vec{\tau} = \vec{M} \times \vec{B} = MB\sin 60° = \left(\frac{MB\sqrt{3}}{2}\right)$ .... (2)

From eq. (1) and (2), $\tau = \frac{2\sqrt{3}\times\sqrt{3}}{2} = 3J$

(35) **(C).** Let magnetic pole strength be m then, $M = m\,\ell$

In new situation $M' = (m)\left(2r\sin\frac{60°}{2}\right)$,

where $r\left(\frac{\pi}{3}\right) = \ell$; $M' = 2m\left(\frac{2\ell}{\pi}\right)\left(\frac{1}{2}\right) = \frac{3m\ell}{\pi} = \frac{3M}{\pi}$

(36) **(A).** For parallel M equilibrium is stable and for antiparallel unstable.

(37) **(C).** Acceleration of charged particle $\vec{a} = \frac{q}{m}(\vec{E} + \vec{v}\times\vec{B})$

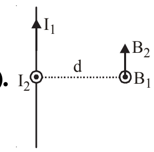
Released from rest

$\Rightarrow \; \vec{a} = \frac{q}{m}\vec{E} = a_0$ (west) $\Rightarrow \vec{E} = \frac{ma_0}{e}$ (west)

when it is projected towards north, acceleration due to magnetic force $= 2a_0$

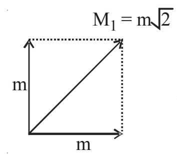
Therefore, magnetic field $= \frac{2ma_0}{ev_0}$ (down)

(38) **(D).**



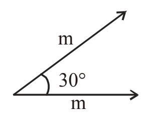
$B = \sqrt{B_1^2 + B_2^2} = \frac{\mu_0}{2\pi d}(I_1^2 + I_2^2)^{1/2}$

(39) **(C).** (a)



(b) $\xrightarrow{m}$ $\xleftarrow[m]{}$; $M_2 = 0$

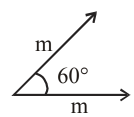
(c)



$M_3 = m\sqrt{(1+\cos 30°)\,2}$

$= m\sqrt{\left(1+\frac{\sqrt{3}}{2}\right)2} = m\sqrt{2+\sqrt{3}}$

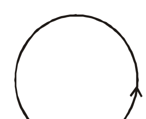
(d)



$M_4 = 2m\cos 30° = m\sqrt{3}$

(40) **(C).** $i = \frac{e}{T} = \frac{e}{1/n} = en$

= equivalent current



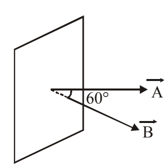
$B = \frac{\mu_0 i}{2r} = \frac{\mu_0 ne}{2r}$

(41) **(B).** Due to straight wire, $B_1 = \frac{2\mu_0 I}{4\pi R}(-\hat{k})$

Due to semi-circular wire $B_2 = \frac{\mu_0 I}{4R}(-\hat{i})$

(42) **(C).** $\vec{\tau} = \vec{M} \times \vec{B}$

$|\vec{\tau}| = MB\sin\theta = NIAB\sin\theta$



$= 50 \times 2 \times 0.12 \times 0.1 \times 0.2 \times \frac{\sqrt{3}}{2}$

$= 0.20$ Nm

(43) **(A).** $R = \frac{mv}{qB} = \frac{\sqrt{2mK}}{qB}$ $\quad \because R_\alpha = R_p$

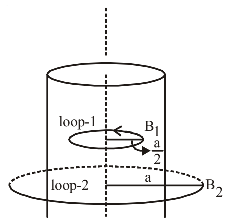
$$\frac{4m_\alpha k_a}{q_\alpha^2 B^2} = \frac{4m_p K_p}{q_p^2 B^2}$$

$$\frac{4m_\alpha k_a}{4e^2} = \frac{m_p\ (1\text{MeV})}{e^2}$$

$k_a = 1$ MeV

(44) **(A).** $F_{Loop} = F_{BA} - F_{CD} = \frac{\mu_0 iIL}{2\pi}\left[\frac{1}{\frac{L}{2}} - \frac{1}{\frac{3L}{2}}\right] = \frac{2\mu_0 iI}{3\pi}$

(45) **(C).** Using Ampere circuital law



Loop-1 : $B_1 2\pi \frac{a}{2} = \mu_0 \frac{I}{\pi a^2} \times \frac{\pi a^2}{4}$

$B_1 = \frac{\mu_0 I}{4\pi a}$ ...... (1)

$_2\, 2\pi\, 2a = \mu_0 I$

$\Rightarrow\ B_2 = \frac{\mu_0 I}{4\pi a}$ ...... (2) $\quad \therefore\ \frac{B_1}{B_2} = 1$

(46) **(A).** Susceptibility of diamagnetic substance is negative while that of para and ferromagnetic substance is positive.

(47) **(B).** $B = \frac{\mu_0 I}{2r}$, when made n turns radius becomes r'

$n \times 2\pi r' = 2\pi r \Rightarrow r' = \frac{r}{n}$

Now, $B' = \frac{\mu_0 nI}{2r'} = n^2 \frac{\mu_0 I}{2r} = n^2 B$

(48) **(B).** $W = MB\ (\cos\theta_1 - \cos\theta_2)$
$W = MB\ (\cos 0 - \cos 60°) = MB/2 \Rightarrow MB = 2W$
$\tau = MB \sin\theta = 2W \sin 60° = \sqrt{3}\ W$

(49) **(A).** $f = \frac{qB}{2\pi m} = \frac{1.76\times10^{11}\times3.57\times10^{-2}}{2\times3.14} = 10^9\text{Hz} = 1\text{ GHz}$

(50) **(D).** $\tan\theta_1 = \frac{\tan\theta}{\cos\alpha} \Rightarrow \tan\theta_2 = \frac{\tan\theta}{\cos(90-\alpha)} = \frac{\tan\theta}{\sin\alpha}$

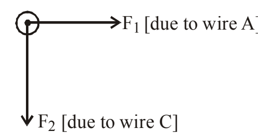
$\Rightarrow\ \sin^2\alpha + \cos^2\alpha = 1 \Rightarrow \cot^2\theta_2 + \cot^2\theta_1 = \cot^2\theta$

(51) **(D).** Work $= MB\ [\cos\theta_1 - \cos\theta_2]$
Work $= MB\ [\cos 0 - \cos 180°]$
$W = NiAB\ [1 - (-1)] = 9.1\ \mu J$

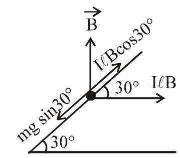
(52) **(C).** $F = \frac{\mu_0 i_1 i_2}{2\pi d}$ = force per unit length

$F_1 = \frac{(\mu_0 i)\, i}{2\pi d} = \frac{\mu_0 i^2}{2\pi d} = F_2$

$F_{net} = \sqrt{F_1^2 + F_2^2} = \frac{\mu_0 i^2}{\sqrt{2}\pi d}$



(53) **(D).** For equilibrium,
$mg \sin 30° = I\,\ell\,B \cos 30°$

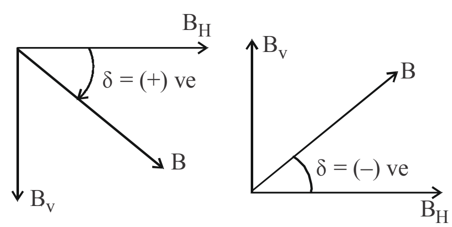


$I = \frac{mg}{\ell B}\tan 30° = \frac{0.5\times9.8}{0.25\times\sqrt{3}} = 11.32$ A

(54) **(C).** Energy of current source will be converted into potential energy of the rod.

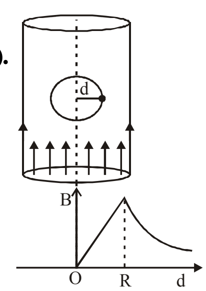
(55) **(A).** $r_H = \frac{p}{eB}$; $r_\alpha = \frac{p}{2eB}$; $\frac{r_H}{r_\alpha} = \frac{p/eB}{p/2eB} = \frac{2}{1}$

(56) **(C).** Angle of dip is the angle between earth's resultant magnetic field from horizontal. Dip is zero at equator and positive in northern hemisphere.



In southern hemisphere dip angle is considered as negative.

(57) **(C).**



Inside (d < R) Magnetic field inside conductor

$B = \frac{\mu_0}{2\pi}\frac{i}{R^2}d$ or $B = Kd$ ...(i)

Straight line passing through origin
At surface (d = R)

$B = \frac{\mu_0}{2\pi}\frac{i}{R}$ ...(ii)

Maximum at surface **Outside (d > R)**

$B = \frac{\mu_0}{2\pi}\frac{i}{d}$ or $B \propto \frac{1}{d}$ (Hyperbolic)