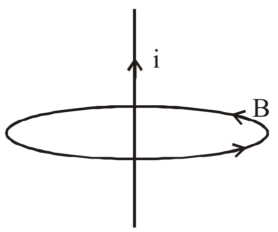
Chapter 19

Moving Charges and Magnetism

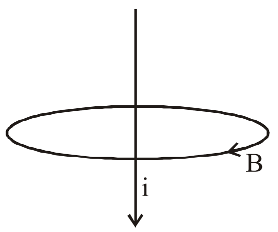
OERSTED EXPERIMENT

In 1802 Gian Domenico Romagnosi, an Italian lawyer and judge, found that a steady electric current flowing in wire affected a magnetic needle placed near it. He published his observation in a local newspaper (called Gazetta di Trentino). But nobody noticed this phenomenon.

In 1820 Hans Christian **Oersted** (a Danish Physicist) rediscovered this phenomenon. He noted that a magnetic compass needle, brought close to a straight wire carrying a steady electric current, aligned itself perpendicular to the wire i.e., the direction of magnetic field $\vec{B}$ is tangential to a circle which has the wire as centre, and which has its plane perpendicular to the wire (Fig 1-a). Oersted also noticed that on reversing the direction of current; the direction of magnetic field is reversed.



Clockwise
Fig. 1(a)



Anticlockwise
Fig. 1(b)

In first case when current is in upward direction, magnetic field is clockwise (Fig 1-a) and when the current is downward, magnetic field is anticlockwise (Fig. 1-b).

MAGNETIC FIELD

It is a region of space around a magnet or current carrying conductor or a moving charge in which its magnetic effect can be felt.

The conductor carrying current is electrically neutral but a magnetic field is associated with it.

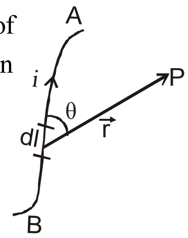
The **SI unit** of magnetic field induction is tesla (T) or weber/m^2 and **cgs unit** is gauss. 1 gauss = 10^{-4} T

Comparison between electric field and magnetic field

Electric field	*Magnetic field*
1. Source is an electric charge (q).	1. Source is a current element $(I\vec{d\ell})$.
2. Isolated charge exists	2. Isolated poles do not exist.
3. Electric field at a point due to a point charge is in the plane containing the point and the charge.	3. Magnetic field at a point due to a current element is perpendicular to the plane containing the point and the current element.
4. It obeys inverse square law (a long range force).	4. It also obeys inverse square law (a long range force).
5. It obeys principle of superposition as the field is linear related to charge.	5. It also obeys principle of superposition.
6. Angle dependence is not present.	6. Angle dependence is present.
7. Line of electric lines of force do not form closed loops.	7. Lines of magnetic lines of force form closed loops.
8. Electric field changes kinetic energy of a charged particle.	8. Magnetic field does not change kinetic energy of a charged particle.
9. A charged particle whether at rest or in motion in an electric field experiences a force due to electric field.	9. A charged particle at rest do not experience force due to magnetic field.

MAGNETIC FIELD DUE TO CURRENT CARRYING CONDUCTOR, BIOT-SAVART'S LAW

The magnetic induction $\vec{dB}$ at any point outside the current path due to a small current element of length $\vec{d\ell}$ (in the direction of the current) is given by Biot-Savart's law



$$\vec{dB} = \frac{\mu_0}{4\pi}\frac{I\,(\vec{d\ell}\times\vec{r})}{r^3}$$

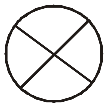
or, $$|\vec{dB}| = \frac{\mu_0}{4\pi}\frac{I\,d\ell\sin\theta}{r^2}$$

Also, $\vec{dB} = \frac{\mu_0}{4\pi}\frac{q(\vec{v}\times\vec{r})}{r^3}$ where $\vec{v}$ is the drift velocity of charge

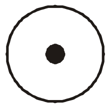
where $\mu_0 = 4\pi\times10^{-7}$ TmA^{-1}.

Direction of $\overrightarrow{dB}$

The direction of $\overrightarrow{dB}$ is perpendicular to both $\overrightarrow{d\ell}$ and $\vec{r}$, governed by the right hand thumb rule of the cross-product of $\overrightarrow{d\ell}$ and $\vec{r}$. The magnetic fields going into the page and coming out of the page are represented as follows :



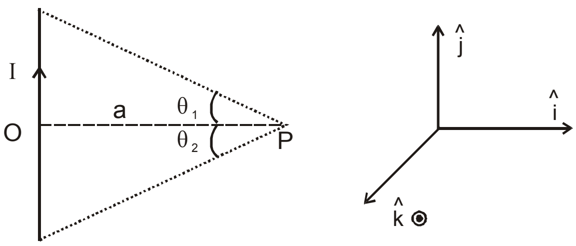
Magnetic field going into the page



Magnetic field coming out of the page.

Magnetic Field due to Various Current Carrying Conductors

Magnetic field due to finite sized conductor :



$$\vec{B}_{(\text{at P})} = \frac{\mu_0 I}{2\pi a}(\sin\theta_1 + \sin\theta_2)(-\hat{k})$$

$$\Rightarrow B = \frac{\mu_0}{4\pi}\frac{2I}{a}(\sin\theta_1 + \sin\theta_2)$$

Elucidation

$$d\vec{B} = \frac{\mu_0 I}{4\pi r^3}\left(d\vec{\ell} \times \vec{r}\right) \quad r = a\sec\theta, \quad \ell = a\tan\theta$$

$$\Rightarrow d\ell = a\sec^2\theta\, d\theta \Rightarrow d\vec{\ell} = a\sec^2\theta\, d\theta\hat{j}$$

$$\vec{r} = -a\tan\theta\hat{j} + a\hat{i}$$

$$\Rightarrow d\vec{B} = \frac{\mu_0 I a\sec^2\theta d\theta}{4\pi a^3\sec^3\theta}\hat{j} \times (-a\tan\theta\hat{j} + a\hat{i})$$

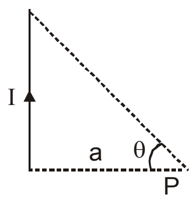
$$= \frac{\mu_0 I\sec^2\theta d\theta}{4\pi a\sec^3\theta}(-\hat{k}) = \frac{\mu_0 I\cos\theta d\theta}{4\pi a}(-\hat{k})$$

$$\therefore B = \int_{-\theta_1}^{\theta_2}\frac{\mu_0 I}{4\pi a}\cos\theta d\theta = \frac{\mu_0 I}{4\pi a}\int_{(-\theta_1)}^{\theta_2}\cos\theta d\theta$$

$$\Rightarrow B = \frac{\mu_0 I}{4\pi a}[\sin\theta_2 + \sin\theta_1] \text{ (Pointing into the plane of paper)}$$

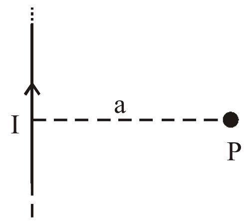
Magnetic field near the end of a finite sized conductor :

$$\underset{(at\ P)}{\vec{B}} = \frac{\mu_0 I}{4\pi a}\sin\theta$$



Magnetic field due to an infinitely long conductor :

$$\underset{(\text{at P})}{\vec{B}} = \frac{\mu_0 I}{2\pi a}(-\hat{k}) \Rightarrow B = \frac{\mu_0}{4\pi}\frac{2I}{a}$$

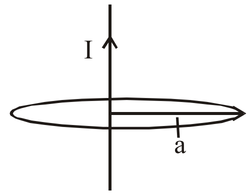


Elucidation

Magnetic field in the case of infinitely long wire

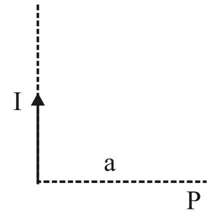
$$dB = \int_{-\pi/2}^{\pi/2}\frac{\mu_0 I}{4\pi a}\cos\theta d\theta$$

$$\Rightarrow \vec{B} = \frac{\mu_0 I(-\hat{k})}{2\pi a}$$



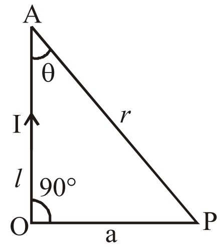
Magnetic field near the end of a long conductor :

$$\underset{(at\ P)}{B} = \frac{\mu_0 I}{4\pi a}$$



Elucidation

$r = a \operatorname{cosec}\theta$, $\ell = a\cot\theta$,
$d\ell = a\operatorname{cosec}^2\theta\, d\theta$



$$d\vec{B} = \frac{\mu_0 \vec{dl} \times r}{4\pi r^3}$$

$$= \frac{\mu_0 I a \operatorname{cosec}^2\theta d\theta\hat{j}}{4\pi a^3\operatorname{cosec}^2\theta} \times (a\hat{j} - a\cot\theta\hat{j})$$

$$= \frac{\mu_0 I}{4\pi a}\frac{\operatorname{cosec}\theta}{\operatorname{cosec}^3\theta}d\theta(-\hat{k}) \Rightarrow \overrightarrow{dB} = \frac{\mu_0 I}{4\pi a}\sin\theta d\theta\,(-\hat{k})$$

$$\vec{B} = \frac{\mu_0 I}{4\pi a}[-\cos\theta]_{\pi/2}^{\pi}(-\hat{k}) = \left(\frac{\mu_0 I}{4\pi a} - 0\right)(-\hat{k})$$

$$\Rightarrow \vec{B} = \frac{\mu_0 I}{4\pi a}(-\hat{k})$$

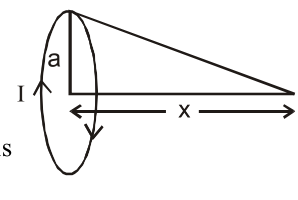
Magnetic field due to a current carrying coil :

(i) *Magnetic field at a point on the axis of symmetry of a circular coil, at a distance "x" from its centre* :

$B = \mu_0 NI\, a^2/2(a^2 + x^2)^{3/2}$

or, $B = \dfrac{\mu_o}{4\pi}\dfrac{2\pi NIa^2}{(a^2 + x^2)^{3/2}}$

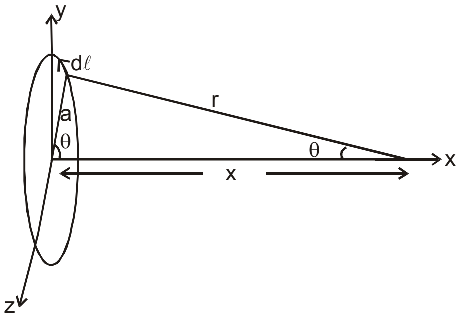
N = total number of turns
a = coil radius



The direction of $\vec{B}$ is given by Right hand screw rule.

Right hand screw rule : *If direction of rotation of right handed screw-head is the directon of current in a circular conductor then the direction of its advance is the direction of magnetic field*. This is applicable even if the current, magnetic field are interchanged, as in case of current flowing through a straight conductor.

Elucidation



Let for a particular angle, position of small length element dl is given by its coordinates as

$z = -a\cos\theta,\ y = a\sin\theta$.

Now, $\vec{a} = -a\cos\theta\hat{k} + a\sin\theta\hat{j}$,

$\vec{r} = -\vec{a} + x\hat{i} = x\hat{i} - a\sin\theta\hat{j} + a\cos\theta\hat{k}$

Also we have $\ell = r\theta \Rightarrow d\ell = rd\theta$.

Now $d\vec{\ell} \perp \vec{a}$ at any instant

$\therefore d\vec{\ell} = d\ell(\sin\theta\hat{k} + \cos\theta\hat{j})$, $d\vec{B} = \frac{\mu_0 I}{4\pi r^3}\left(d\vec{\ell} \times \vec{r}\right)$

$$\Rightarrow d\vec{B} = \frac{\mu_0 Ird\theta}{4\pi r^3}(\sin\theta\hat{k} + \cos\theta\hat{j}) \times (x\hat{i} - a\sin\theta\hat{j} + a\cos\theta\hat{k})$$

$$= \frac{\mu_0 Ird\theta}{4\pi(x^2+a^2)^{3/2}}(x\sin\theta\hat{j} + a\sin^2\theta\hat{i} + x\cos\theta\hat{k} + a\cos^2\theta\hat{i})$$

$$= \frac{\mu_0 Ird\theta}{4\pi(x^2+a^2)^{3/2}}[x(\sin\theta\hat{j} + \cos\theta\hat{k}) + a\hat{i}]$$

$$\Rightarrow \vec{B} = \int \vec{dB}$$

$$= \frac{\mu_0 Ia}{4\pi(x^2+a^2)^{3/2}}[x\,|-\cos\theta\hat{j} + \sin\theta\hat{k}\,|_0^{2\pi} + a(2\pi - 0)\hat{i}]$$

$$\vec{B} = \frac{\mu_0 I 2\pi a(\hat{i})}{4\pi(x^2+a^2)^{3/2}}$$

If number of turns of coil are N, then

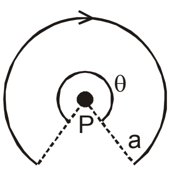
$$|\vec{B}| = \frac{\mu_0 I 2\pi Na(\hat{i})}{4\pi(x^2+a^2)^{3/2}} = \frac{\mu_0 INa(\hat{i})}{2(x^2+a^2)^{3/2}}$$

$$\Rightarrow \quad B = \frac{\mu_0}{4\pi}\frac{2\pi NIa}{(x^2+a^2)^{3/2}}$$

(ii) *At the centre of a circular coil,* $B = \mu_0 NI/2a = \frac{\mu_0}{4\pi}\frac{2\pi NI}{a}$

(iii) *Magnetic field at the centre of a circular arc carrying current*

$$\underset{(at\ P)}{\vec{B}} = \frac{\mu_0 I}{2a} \times \frac{\theta}{360}(-\hat{k}) \Rightarrow B = \frac{\mu_0}{4\pi}\frac{I\theta}{a}$$



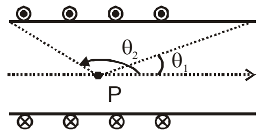
where θ is in radian.

In this case the direction of magnetic field $\vec{B}$ is into the page.

Magnetic field inside a current carrying solenoid

(i) *Finite size solenoid*

$$\underset{(at\ P)}{B} = \frac{\mu_0 nI}{2}(\cos\theta_1 - \cos\theta_2)$$



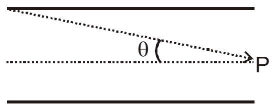
(ii) *Near the end of a finite solenoid*

$$B = \frac{\mu_0 nI}{2}\cos\theta;\ (\theta_1 = \theta\ \&\ \theta_2 = \pi/2)$$

(iii) *In the middle of a very long solenoid,* $B = \mu_0 n I$

(iv) *Near the end of a very long solenoid*

$$B = \frac{\mu_0 n I}{2}$$



n is the number of turns per unit length of solenoid.

(v) *Magnetic field in the endless solenoid (toroid) is same throughout and is* $\mu_0 nI$.

(vi) *Magnetic field outside a solenoid or toroid is zero.*

AMPERE'S CIRCUITAL LAW

The line integral of magnetic field across a closed loop is equal to 40 times the net correct inside the loop

i.e, $\oint \vec{B}.\vec{dl} = \mu_0 I$

where I is the net current inside the loop.

(1) The direction of the magnetic field at a point on one side of a conductor of any shape is equal in magnitude but opposite in direction of the field at an equidistant point on the other side of the conductor.

(2) If the magnetic field at a point due to a conductor of any shape is B_0 if it is placed in vacuum then the magnetic field at the same point in a medium of relative permeability μ_r is given by $B = \mu_r.B_o$.

(3) If the distance between the point and an infinitely long conductor is decreased (or increased) by K-times then the magnetic field at the point increases (or decreases) by K-times.

(4) The magnetic field at the centre of a circular coil of radius smaller than other similar coil with greater radius is more than that of the latter.

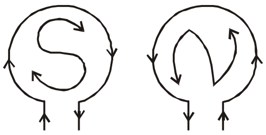
(5) For two circular coils of radii R_1 and R_2 having same current and same number of turns, we have

$\frac{B_1}{B_2} = \frac{R_2}{R_1}$, where B_1 and B_2 are the magnetic fields at their centres.

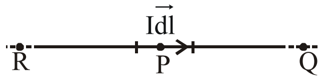
(6) The magnetic field at a point outside a thick straight wire carrying current is inversely proportional to the distance but magnetic field at a point inside the wire is directly proportional to the distance.

Keep in Memory

1. If in a coil the current is clockwise, it acts as a South-pole. If the current is anticlockwise, it acts as North-pole.



2. No magnetic field occurs at point P, Q and R due to a thin current element $I\vec{dl}$.

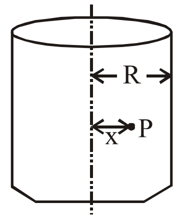


3. Magnetic field intensity in a thick current carrying conductor at any point x is

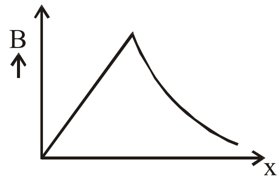
$$B_{inside} = \frac{\mu_0}{4\pi}\frac{2Ix}{R^2} \quad \text{for } x < R$$

$$B_{surface} = \frac{\mu_0}{4\pi}\frac{2I}{R} \quad \text{for } x = R$$

$$B_{outside} = \frac{\mu_0}{4\pi}\frac{2I}{x} \quad \text{for } x > R$$

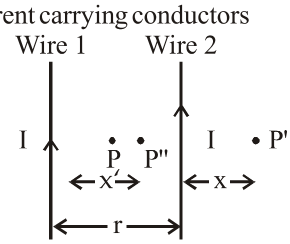
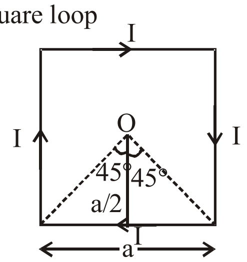
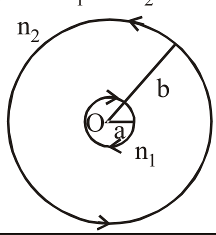
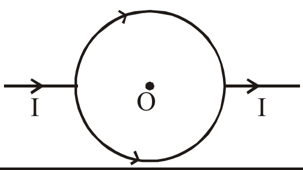


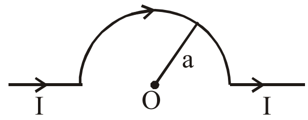
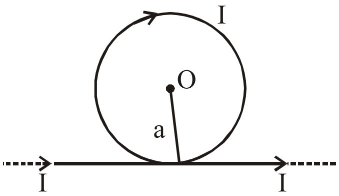
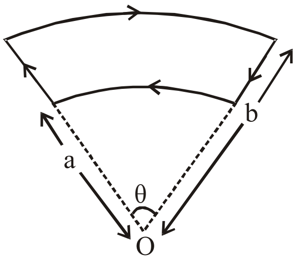
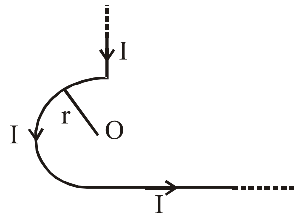
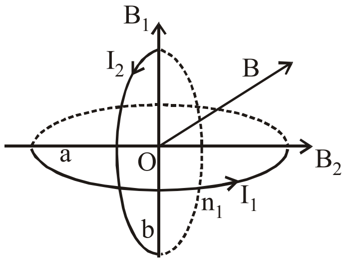
4. Graph of magnetic field $\vec{B}$ versus x



5. Magnetic field is zero at all points inside a current carrying hollow conductor.

Magnitude and direction of magnetic field due to different configuration of current carrying conductor.

S.No.	Configuration of current carrying conductor	Point of observation	Magnetic field: Magnitude	Magnetic field: Direction
1.	Two long linear and parallel current carrying conductors 	At P, the mid point between the two wires. The distance of P from each wire is r/2. At P', distant x from wire 2 as shown. At P'', distant x' from wire 1 as shown.	$B = 0$ $B = \frac{\mu_0}{4\pi}2I\left[\frac{1}{x}+\frac{1}{r+x}\right]$ $B = \frac{\mu_0}{4\pi}2I\left[\frac{1}{r-x'}-\frac{1}{x'}\right]$	Normal to the plane of paper, inwards. Normal to the plane of paper, outwards.
2.	Square loop 	At the centre.	$B = 4\left[\frac{\mu_0}{4\pi}\frac{I}{a/2}\left(\sin 45° + \sin 45°\right)\right]$	Normal to the plane of paper, inwards.
3.	Two concentric circular coils having turns n_1 and n_2 	At the centre.	$B = \frac{\mu_0}{4\pi}2\pi I\left[\frac{n_1}{a}-\frac{n_2}{b}\right]$	If $\frac{n_1}{a} > \frac{n_2}{b}$ Perpendicular to the plane of paper inwards.
4.	Straight wire and loop 	At the centre.	$B = 0$	

5.	Straight wire & semi-circular loop 	At the centre.	$B = \frac{\mu_0}{4\pi}\frac{\pi I}{a}$	Normal to the plane of paper, inwards.
6.	Circular loop 	At the centre of loop.	$B = \frac{\mu_0}{4\pi}\left[\frac{2\pi I}{a} - \frac{2I}{a}\right]$	Normal to the plane of paper, inwards.
7.	Two concentric circular arcs 	At the common centre.	$B = \frac{\mu_0}{4\pi} I\theta\left[\frac{1}{a} - \frac{1}{b}\right]$	Normal to the plane of paper, outwards.
8.	Semi-circular area and straight conductors 	At the centre of the semi-circle.	$B = \frac{\mu_0}{4\pi}\frac{\pi I}{r} + \frac{\mu_0}{4\pi}\frac{I}{r}$	Normal to the plane of paper, outwards.
9.	Two concentric coils mutually normal to each other. 	At the common centre.	$B = \sqrt{B_1^2 + B_2^2}$ where $B_1 = \frac{\mu_0}{4\pi}\frac{2\pi n_1 I}{a}$ $B_2 = \frac{\mu_0}{4\pi}\frac{2\pi n_2 I}{b}$	According to law of vectors addition.

FORCE ON A CONDUCTOR

The force on a conductor is given by

$$F = BI\ell \sin\alpha$$

where ℓ is the length of the conductor in meter; B is the flux density of field in tesla (Wb/m^2); I is the current in ampere and α is the angle which the conductor makes with the direction of the field.

Special case :

If $\alpha = 90°$, then $F = BI\ell$

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

TORQUE ON A COIL

The torque acting on a rectangular coil placed with its plane parallel to a uniform magnetic field of flux density B is given by

$$\tau = BINA$$

where N is the number of turns in the coil, A is the area and I is the current.

If the plane of the coil makes an angle α with the direction of the field, then

$$\tau = BINA\cos\alpha.$$

Example 1.

The field normal to the plane of a wire of n turns and radius r which carries a current i is measured on the axis of the coil at a small distance h from the centre of the coil. By what fraction this is smaller than the field at the centre?

Solution :

The magnetic field on the axis of a current i carrying coil of turns n, radius r and at a distance h from the centre of the coil

$$B = \frac{\mu_0}{4\pi} \times \frac{2\pi n i r^2}{(r^2 + h^2)^{3/2}} \qquad .....(1)$$

The field at the centre is given by

$$B_{centre} = \frac{\mu_0}{4\pi} \times \frac{2\pi i \times n}{r} \qquad ....(2) \quad (\because \text{ at centre } h = 0)$$

$$\frac{B}{B_{centre}} = \frac{r^3}{(r^2 + h^2)^{3/2}}$$

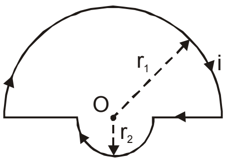
$$= \frac{r^3}{r^3\left[1 + \frac{h^2}{r^2}\right]^{3/2}} = \frac{1}{\left(1 + \frac{3}{2}\frac{h^2}{r^2}\right)}$$

or $\quad B\left(1 + \frac{3}{2}\frac{h^2}{r^2}\right) = B_{centre}$

$\therefore \quad (B_{centre} - B)/B = \frac{3}{2}\frac{h^2}{r^2}$

Example 2.

In fig., there are two semi-circles of radii r_1 and r_2 in which a current i is flowing. Find the magnetic induction at centre O.



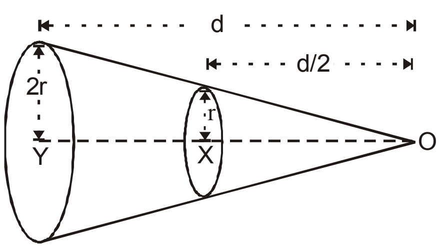
Solution :

$$B = B_1 + B_2 = \frac{\mu_0}{4\pi} \times \frac{\pi i}{r_1} + \frac{\mu_0}{4\pi} \times \frac{\pi i}{r_2}$$

$$= \frac{\mu_0 i}{4}\left[\frac{1}{r_1} + \frac{1}{r_2}\right] = \frac{\mu_0 i}{4}\left[\frac{r_1 + r_2}{r_1 r_2}\right]$$

Example 3.

Two circular coils X and Y having equal number of turns and carry equal currents in the same sense and subtend same solid angle at point O. If the smaller coil X is midway between O and Y, then if we represent the magnetic induction due to bigger coil Y at O as B_Y and due to smaller coil X at O as B_X then find $\frac{B_Y}{B_X}$.



Solution :

Magnetic induction at O due to coil Y is given by

$$B_Y = \frac{\mu_0}{4\pi} \times \frac{2\pi I (2r)^2}{[(2r)^2 + (d)^2]^{3/2}} \qquad ...(1)$$

Similarly, the magnetic induction at O due to coil X is given by

$$B_X = \frac{\mu_0}{4\pi} \times \frac{2\pi I (r)^2}{[(r)^2 + (d/2)^2]^{3/2}} \qquad ...(2)$$

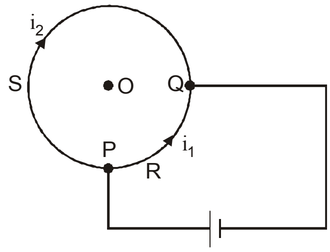
From eqs. (1) and (2), $\frac{B_Y}{B_X} = \frac{1}{2}$

Example 4.

A cell is connected between two points of a uniformly thick circular conductor. i_1 and i_2 are the currents flowing in two parts of the circular conductor of radius a. What will be the magnetic field at the centre of the loop?

Solution :

Let ℓ_1, ℓ_2 be the lengths of the two parts PRQ and PSQ of the conductor and ρ be the resistance per unit length of the conductor. The resistance of the portion PRQ will be $R_1 = \ell_1\rho$



The resistance of the portion PSQ will be $R_2 = \ell_2\rho$

Pot. diff. across P and Q $= i_1R_1 = i_2R_2$

or $i_1\ell_1\rho = i_2\ell_2\rho$ or $i_1\ell_1 = i_2\ell_2$ ......(i)

Magnetic field induction at the centre O due to currents through circular conductors PRQ and PSQ will be

$$B_1 - B_2 = \frac{\mu_0}{4\pi}\frac{i_1\ell_1 \sin 90^o}{r^2} - \frac{\mu_0}{4\pi}\frac{i_2\ell_2 \sin 90^o}{r^2} = 0$$

Example 5.

A current passing through a circular coil of two turns produces magnetic field B at its centre. The coil is then rewound so as to have four turns and the same current is passed through it.The magnetic field at its centre now is

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

Solution : **(d)**

$B = \frac{\mu_0}{4\pi}\frac{2\pi n I}{r}$ i.e. $B \propto \frac{n}{r}$;

Given, $L = 2\pi r_1 \times 2 = 2\pi r_2 \times 4$; $r_1/r_2 = 4/2 = 2$

$\frac{B_2}{B_1} = \frac{n_2}{n_1} \times \frac{r_1}{r_2} = \frac{4}{2} \times 2 = 4$ or $B_2 = 4B_1 = 4B$.

Example 6.

Compute the flux density in air at a point of 9 cm from the long straight wire carrying a current of 6A.

Solution :

Given : $a = 9$ cm $= 9 \times 10^{-2}$ m, $I = 6$A

$$B = \frac{\mu_o I}{2\pi a} = \frac{4\pi \times 10^{-7} \times 6}{2\pi \times 9 \times 10^{-2}} = 1.33 \times 10^{-5}\text{ T}$$

Example 7.

Calculate the flux density at a distance of 1 cm from a very long straight wire carrying a current of 5A. At what distance from the wire will the field flux density neutralize that due to the earth's horizontal component flux density 2×10^{-5} T ? ($\mu_0 = 4\pi \times 10^{-7}$ Hm^{-1})

Solution :

$$B = \frac{\mu_o I}{2\pi a} = \frac{4\pi \times 10^{-7} \times 5}{2\pi \times 1 \times 10^{-2}} = 10^{-4}\text{T}$$

For the second part,

$$a = \frac{\mu_o I}{2\pi B} = \frac{4\pi \times 10^{-7} \times 5}{2\pi \times 2 \times 10^{-5}} = 5 \times 10^{-2} = 5\text{ cm}$$

Example 8.

A wire 28m long is bent into N turns of circular coil of diameter 14 cm forming a solenoid of length 60 cm. Calculate the flux density inside it when a current of 5 amp passed through it. ($\mu_0 = 12.57 \times 10^{-7}$ m^{-1})

Solution :

Given : $d = 14$cm $= 0.14$m $\ell = 60$cm $= 0.6$ m

By the question, $N \times \pi d = 28$ m.

$$N \times \pi \times 0.14 = 28$$

$$\therefore\ N = \frac{28}{0.14 \times \pi} = 63.66\text{ turns.}$$

$$B = \mu_o nI = \mu_o \frac{N}{\ell} I = 12.57 \times 10^{-7} \times \frac{63.66}{0.6} \times 5$$

$$= 6.67 \times 10^{-4}\text{T}$$

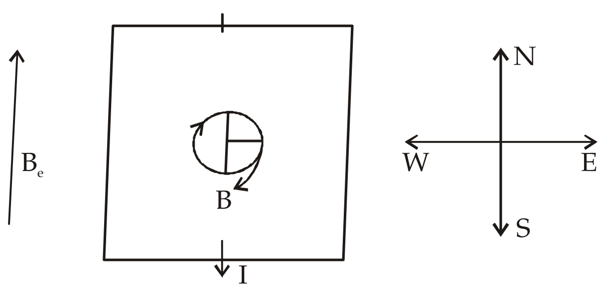
Example 9.

A vertical conductor X carries a downward current of 5A.

(a) What is the flux density due to the current alone at a point P 10 cm due east of X?

(b) If the earth's horizontal magnetic flux density has a value 4×10^{-5} T, calculate the resultant flux density at P.

Is the resultant flux density at a point 10cm due north of X greater or less than at P? Explain your answer.



Solution :

(*a*) $I = 5$A, $a = 10$cm $= 0.1$ m

$$B = \frac{\mu_o I}{2\pi a} = \frac{4\pi \times 10^{-7} \times 5}{2\pi \times 0.1} = 1 \times 10^{-5}\text{T}$$

At P, the earth's horizontal magnetic flux density, $B_e = 4 \times 10^{-5}$T (from South to North)

The direction of B is from north to south.

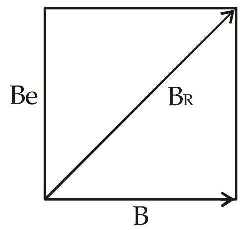
$\therefore$ Resultant intensity at

$P = 4 \times 10^{-5} - 1 \times 10^{-5}$ T

$= 3 \times 10^{-5}$ T (From south to north)

For a point 10 cm , north of X the flux density due to the current in X $= 1 \times 10^{-5}$T (due east)

(*b*) The flux density due to the horizontal component of the earth's field $= 4 \times 10^{-3}$T (due north)



$\therefore$ Resultant Intensity

$$B_R = \sqrt{B_e^2 + B^2}. = \sqrt{(4 \times 10^{-5})^2 + (1 \times 10^{-5})^2}$$

$$= \sqrt{17 \times 10^{-5}} = 4.1 \times 10^{-5}\text{ T}$$

which is greater than the flux density at P.

Example 10.

A horizontal wire, of lenth 5 cm and carrying a current of 2A placed in the middle of a long solenoid and right angles to its axis. The solenoid has 1000 turns per metre and carries a steady current I. Calculate I if the force on the wire is vertically downwards and equal to 10^{-4} N.

Solution :

$1 = 5$cm $= 5 \times 10^{-2}$m, $I_{wire} = 2$A, $n = 1000$ m^{-1}, $F = 10^{-4}$ N

If I be the current through the solenoid, then

$$B = \mu_0 nI$$

Force $= BI_{wire} \times \ell$ or $10^{-4} = \mu_0 NI \times I_{wire} \times 1$

$$\text{or } 10^{-4} = 4\pi \times 10^{-7} \times 1000 \times I \times 2 \times 5 \times 10^{-2} = 4\pi \times 10^{-5} I$$

$$\therefore\ I = \frac{10^{-4}}{4\pi \times 10^{-5}} = \frac{10}{4\pi} = 0.8\text{A}$$

Example 11.

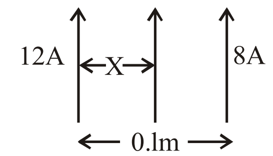
Two long parallel conductors carry currents of 12A and 8A respectively in the same direction. If the wires are 10cm apart, find where the third parallel wire also carrying a current must be placed so that the force experienced by it shall be zero.

Solution :

For the force on the third conductor to be zero, the direction of the flux density due to the current flowing in the two wires must be opposite in the position of the wire.

$\therefore$ Third wire must be placed between the wire. Let the third wire placed at a distance x m from the wire carrying 12A,

then, $B_1 = B_2$



$$\frac{\mu_o I_1}{2\pi x} = \frac{\mu_o I_2}{2\pi(0.1-x)}.$$

or $\frac{12}{x} = \frac{8}{0.1-x}$ or $\frac{3}{x} = \frac{2}{0.1-x}$

or $0.3 = 5x = \frac{0.3}{5} = 0.06\,m$

FORCE ACTING ON A CHARGED PARTICLE MOVING IN A UNIFORM MAGNETIC FIELD

The force acting on a particle having a charge q and moving with velocity $\vec{v}$ in a uniform magnetic field $\vec{B}$ is given by

$\vec{F} = q(\vec{v} \times \vec{B}) \Rightarrow F = qvB\sin\theta$,

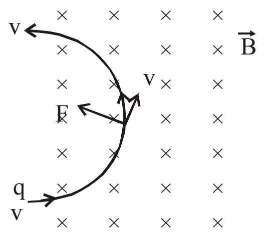
where θ is the angle between $\vec{v}$ and $\vec{B}$

Case (i) If $\theta = 0$, F = 0. Also if $\theta = 180°$, F = 0

If a charged particle enters a uniform magnetic field in the direction of magnetic field or in the opposite direction of magnetic field, the force acting on the charged particle is zero.

Case (ii) If $\theta = 90°$, F = qvB

In this case the force acting on the particle is maximum and this force acts as centripetal force which makes the charged particle move in a circular path.



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

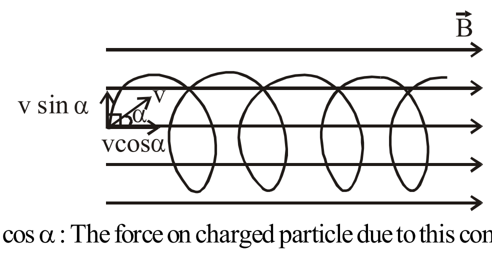
$\Rightarrow \quad r = \frac{mv}{qB}$

where r is the radius of the circular path.

It is important to note that this force cannot change the speed of the charged particle and hence its kinetic energy. But it changes the velocity of charged particle (due to change in direction) and hence also causes a change in momentum.

Also the work done by the force is zero as the force is acting perpendicular to the direction of motion.

Case (iii) If $\theta = \alpha$ is any other angle then the path taken is helical. The velocity of the charged particle can be split into two parts for better understnading.



(a) v cos α : The force on charged particle due to this component is zero. This component is responsible in moving the charged particle uniformly in the direction of $\vec{B}$.

(b) v sin α : The force acting on charged particle due to this component is $q(v\sin\alpha)B\sin 90° = qvB\sin\alpha$. This acts as the centripetal force and moves the particle in a circular path.

The combined effect of these two is a helical path.

A charged particle entering a uniform magnetic field at an angle executes helical path.

Radius of the helix, $R = \frac{mv\sin\alpha}{qB}$

Angular frequency of rotation, $\omega = (2\pi / T) = qB / m$

Pitch of the helix $= (v\cos\alpha)T = \frac{2\pi mv\cos\alpha}{qB}$.

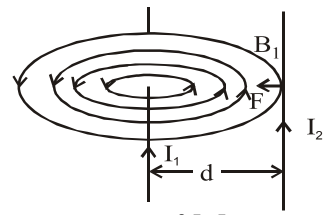
Direction of force $\vec{F}$: We can use the rule of cross product. The direction of $\vec{F}$ is perpendicular to the plane containing $\vec{v}$ and $\vec{B}$ and can be found by right hand thumb rule. It is important to note that if q is positive, we will get the correct direction of $\vec{F}$ by right hand thumb rule. But if q is negative, we have to reverse the direction of force.

Flemings left hand rule : *It states that if the fore finger, the central finger and the thumb of the left hand are stretched at right angles to each other then if the central finger represents the direction of current and fore finger represents field, the thumb will represent the direction of motion or force experienced by the current carrying conductor.*

FORCE BETWEEN TWO PARALLEL CURRENTS

When a current flows in a conductor, the free charges (electrons in case of a metal wire) move. Each free charge movement generates a force which adds up to give the force on the conductor.

Force between infinitely long conductors placed parallel to each other at distance d.



Force per unit length $= \frac{F}{\ell} = \frac{\mu_0}{4\pi}\frac{2I_1 I_2}{d}$

where ℓ is the length of wire.

If currents are pointing in same direction, the force is of attractive nature and if currents are oppositely directed the force is of repulsive nature.

Lorentz Force Equation

For a charged particle q moving in a region of simultaneously applied electric field $\vec{E}$ and magnetic field $\vec{B}$, the force experienced by it is given by

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

Torque on a current loop in uniform magnetic field $\vec{B}$ is given by $\vec{\tau} = (\vec{M} \times \vec{B})$ where $\vec{M}$ is the magnetic moment of coil.

$\vec{M} = N\,I\,A\hat{n}$ where $\vec{n}$ is the unit vector normal to the plane of the loop.

Keep in Memory

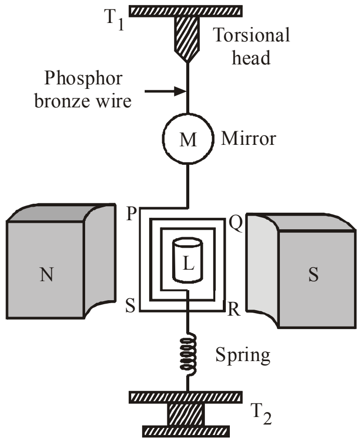
1. No force acts on a charged particle if it enters a magnetic field in a direction parallel or antiparallel to the field.
2. A finite force acts on a charged particle if it enters a uniform magnetic field in a direction with finite angle with the field.
3. If two charged particles of masses m_1 and m_2 and charges q_1 and q_2 are projected in a uniform magnetic field with same constant velocity in a direction perpendicular to the field then the ratio of their radii ($R_1 : R_2$) is given by
$$\frac{R_1}{R_2} = \frac{m_1}{m_2} \times \frac{q_2}{q_1}$$
4. The force on a conductor carrying current in a magnetic field is directly proportional to the current, the length of conductor and the magnetic field.
5. If the distance between the two parallel conductors is decreased (or increased) by k-times then the force between them increases (or decreases) k-times.
6. The momentum of the charged particle moving along the direction of magnetic field does not change, since the force acting on it due to magnetic field is zero.
7. Lorentz force between two charges q_1 and q_2 moving with velocity v_1, v_2 separated by distance r is given by:
$$F_m = \frac{\mu_0}{4\pi} . \frac{(q_1 v_1)(q_2 v_2)}{r^2}$$
8. If the charges move, the electric as well as magnetic fields are produced. In case the charges move with speeds comparable to the speed of light, magnetic and electric force between them would become comparable.
9. A current carrying coil is in stable equilibrium if the magnetic dipole moment $\vec{M}$, is parallel to $\vec{B}$ and is in unstable equilibrium when $\vec{M}$ is antiparallel to $\vec{B}$.
10. Magnetic moment is independent of the shape of the loop. It depends on the area of the loop.
11. A straight conductor and a conductor of any shape in the same plane and between the same two end points carrying equal current in the same direction, when placed in the same magnetic field experience the same force.
12. There is net repulsion between two similar charges moving parallel to each other inspite of attractive magnetic force between them. This is because of electric force of repulsion which is much more stronger than the magnetic force.
13. The speed of the charged particle can only be changed by an electric force.

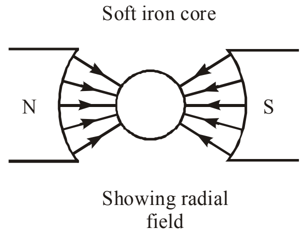
MOVING COIL GALVANOMETER

The moving coil galvanometer was first devised by Kelvin and later on modified by D'Arsonaval. This is used for detection and measurement of small electric current.

The **principle of a moving coil galvanometer** is based on the fact that when a current carrying coil is placed in a magnetic field, it experiences a torque.

Construction: A moving coil ballistic galvanometer is shown in figure.





It essentially consists of a rectangular coil PQRS or a cylindrical coil of large number of turns of fine insulated wire wound over a non-conducting frame of ivory or bamboo. This coil is suspended by means of phosphor bronze wire between the pole pieces of a powerful horse shoe magnet NS. The poles of the magnet are curved to make the field radial. The lower end of the coil, is attached to a spring of phosphor-bronze wire. The spring and the free ends of phosphor bronze wire are joined to two terminals T_2 and T_1 respectively on the top of the case of the instrument. L is a soft iron core. A small mirror M is attached on the suspension wire. Using lamp and scale arrangement, the deflection of the coil can be recorded. The whole arrangement is enclosed in a non-metallic case.

Theory : Let the coil be suspended freely in the magnetic field.

Suppose, n = number of turns in the coil

A = area of the coil

B = magnetic field induction of radial magnetic field in which the coil is suspended.

Here, the magnetic field is radial, i.e., the plane of the coil always remains parallel to the direction of magnetic field, and hence the torque acting on the coil

$$\tau = niAB \qquad \ldots(1)$$

Due to this torque, the coil rotates. As a result, the suspension wire gets twisted. Now a restoring torque is developed in the suspension wire. The coil will rotate till the deflecting torque acting on the coil due to flow of current through it is balanced by the restoring torque developed in the suspension wire due to twisting. Let C be the restoring couple for unit twist in the suspension wire and θ be the angle through which the coil has turned. The couple for this twist θ is Cθ.

In equilibrium, deflecting couple = restoring couple

$\therefore$ $niAB = C\theta$ or $i = C\theta/(nAB)$

or $i = K\theta$ (where $C/nAB = K$) $\ldots(2)$

K is a constant for galvanometer and is known as galvanometer constant.

Hence $i \propto \theta$

Therefore, the deflection produced in the galvanometer is directly proportional to the current flowing through it.

Current sensitivity of the galvanometer : *The current sensitivity of a galvanometer is defined as the deflection produced in the galvanometer when a unit current is passed through it.*

We know that, niAB = Cθ

∴ Current sensitivity, $i_s = \frac{\theta}{i} = \frac{nAB}{C}$

where C = restoring couple per unit twist

The **SI unit** of current sensitivity is radian per ampere or deflection per ampere.

Voltage sensitivity of the galvanometer : *The voltage sensitivity of the galvanometer is defined as the deflection produced in the galvanometer when a unit voltage is applied across the terminals of the galvanometer.*

∴ Voltage sensitivity, $V_s = \frac{\theta}{V}$

If R be the resistance of the galvanometer and a current is passed through it, then

$$V = iR$$

∴ Voltage sensitivity, $V_s = \frac{\theta}{iR} = \frac{nAB}{CR}$

The **SI. unit** of voltage sensitivity is radian per ampere or deflection per ampere.

Conditions for sensitivity : A galvanometer is said to be more sensitive if it shows a large deflection even for a small value of current.

We know that, $\theta = \frac{nAB}{C} i$

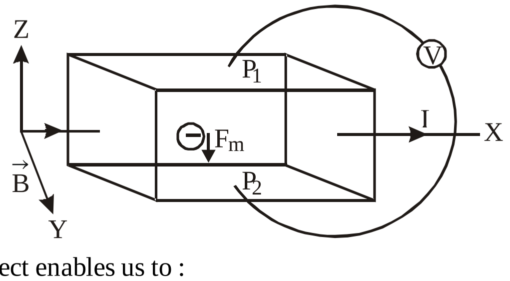
For a given value of *i*, θ will be large if (i) n is large, (ii) A is large, (iii) B is large, and (iv) C is small.

Regarding above factors, n and A cannot be increased beyond a certain limit. By increasing n, the resistance of the galvanometer will increase and by increasing A, the size of the galvanometer will increase. So, the sensitivity will decrease. Therefore, B is increased. The value of B can be increased by using strong horse shoe magnet. Further, the value of C can be decreased. The value of C for quartz and phosphor-bronze is very small. So, the suspension wire of quartz or phosphor-bronze is used. The value of C is further decreased if the wire is hammered into a flat strip.

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 directio ı. Tˈıe ıagnetic 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:

Case 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.

Case II : If the charged particles 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 B,

$$F_m = Bev_d$$

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, $v_d = \frac{j}{ne}$

where n is the number of current carries per unit volume of the strip.

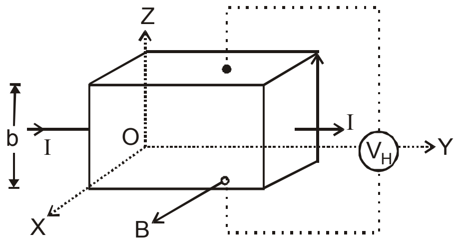
Hall resistance, $R_H = \frac{V_H}{I} = \left(\frac{Bwj}{ne}\right)\frac{1}{I}$

∴ *Hall voltage* $V_H = \frac{Bwj}{ne}$

Keep in Memory

1. Hall effect can determine nature of current (charge) carriers in the material. i.e. whether the charge is +ve or –ve.
2. Hall voltage $V_H = \frac{bBI}{neA}$

   where n is the density of charge carriers



b = thickness of plate, B = magnetic field, I = current flowing through plate, A = area of cross-section of plates

Example 12.

Two particles X and Y having equal charges, after being accelerated throught the same potential difference, enter a region of uniform magnetic field and describe circular paths of radii R_1 and R_2 respectively. Find the ratio of mass of X to that of Y.

Solution :

$$\frac{1}{2}mv^2 = qV$$

$$\therefore v = (2qV/m)^{1/2}$$

(where V is the potential difference)

Centripetal force $\frac{mv^2}{R} = qvB$

$$\therefore v = \left(\frac{qB}{m}\right)R$$

Hence $\left(\frac{2qV}{m}\right)^{1/2} = \left(\frac{qB}{m}\right)R$ or $R = \left(\frac{2mV}{q}\right)^{1/2} \times \frac{1}{B}$

Here V, q and B are constant. Hence $R \propto \sqrt{m}$

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

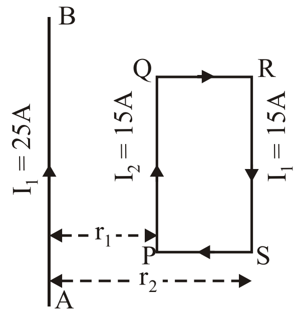
Example 13.

A rectangular loop of sides 25 cm and 10 cm carrying a current of 15 A is placed with its longer side parallel to a long straight conductor 2.0 cm apart carrying a current of 25 A. What is the net force on the loop?

Solution :

Consider a rectangular loop PQRS placed near a long straight conductor AB as shown in Fig. Due to the interaction of currents, the arm PQ of the loop will get attracted while arm RS will get repelled. Forces on the arms QR and SP will be equal and opposite and hence cancel out.

Here, PQ = 25 cm = 25×10^{-2} m,



PS = 10 cm = 10×10^{-2} m

Distance of PQ from AB,

$r_1 = 2.0$ cm $= 2.0 \times 10^{-2}$ m

Distance of RS from AB,

$r_2 = 2.0 + 10 = 12.0$ cm $= 12.0 \times 10^{-2}$ m

Current through long wire AB, $I_1 = 25$ A

Current through rectangular loop, $I_2 = 15$ A

$\therefore$ Force on the arm PQ, $F_1 = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r_1} \times \text{length PQ}$

$$F_1 = \frac{10^{-1} \times 2 \times 25 \times 15 \times 25 \times 10^{-2}}{2.0 \times 10^{-2}}$$

$= 9.375 \times 10^{-4}$ (towards AB)

Force on the arm RS,

$$F_2 = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r_2} \times \text{length RS}$$

$$= \frac{10^{-7} \times 2 \times 25 \times 15 \times 25 \times 10^{-2}}{12 \times 10^{-2}}$$

$= 1.563 \times 10^{-4}$ (away from AB)

$\therefore$ Effective force on the loop,

$F = F_1 - F_2 = 9.375 \times 10^{-4} - 1.563 \times 10^{-4} = 7.812 \times 10^{4}$ N (towards AB)

Example 14.

An electron beam moving with a velocity of 10^6 ms^{-1} through a uniform magnetic field of 0.1T, which is perpendicular to the direction of the beam. Calculate the force on an electron if the electron charge is 1.6×10^{-19}C.

Solution :

$v = 10^{-6} ms^{-1}$, B = 0.IT, q = 1.6×10^{-19}C

$F = Bqv = 0.1 \times 10^6 \times 10^{19} = 1.6 \times 10^{-14}$ N

Example 15.

A narrow vertical rectangular coil is suspended from the middle of its upper side with its plane parallel to a uniform horizontal magnetic field of 0.02 T. The coil has 10 turns and the lengths of its vertical and horizontal sides are 0.1 m and 0.05 m respectively. Calculate the torque on the coil when a current of 5A is passed into it.

What would be the new value of the torque if the plane of the vertical coil was initially at 60° to the magnetic field and a current of 5A was passed into the coil.

Solution :

B = 0.02 T, N = 10 turns

A = 1 × b = 0.1 × 0.05 = 0.005 m^2

I = 5A

Torque = BINA = 0.02 × 5 × 10 × 0.005

= 0.005 Nm = 5 × 10^{-3}Nm

New value of the torque when the plane of the vertical coil was at 60° to the magnetic field.

= BINA cos θ = 5 × 10^{-3} cos 60°

$$= 5\times 10^{-3} \times \frac{1}{2} = 2.5 \times 10^{-3}\ \text{Nm.}$$

Example 16.

A rectangular coil of 50 turns hungs vertically in a uniform magnetic field of magnitude 10^{-2} T, so that the plane of the coil is parallel to the field, the mean height of the coil is 5cm and its mean width is 2cm. Calculate the strength of the current the must pass through the coil in order to deflect it 30° if the torsional constant of the suspension is 10^{-9} Nm per degree.

Solution :

N = 50 turns, B = 10^{-2}T, θ = 30°

C = 10^{-9} Nm per degree,

A = 5 × 2 cm^2 = 10 × 10^{-4} m^2 = 10^{-3} m^2

Torque = BINA cos θ = Cθ

$$\therefore\ I = \frac{C\theta}{BNA\cos\theta} = \frac{10^{-9}\times 30}{10^{-2}\times 50\times 10^{-3}\cos 30^{\circ}} = 6.9 \times 10^{-5}$$

A = 69μA

Example 17.

A copper wire has 1.0 × 10^{29} free electrons per cubic metre, a cross sectional area of 2.0 mm^2 and carries a current of 5.0A. Calculate the force acting on each electron if the wire is now placed in a magnetic field of flux density 0.15 T which is perpendicular to the wire (e=1.6 × 10^{19}C)

Solution :

n = 10 × 10^{29} m^{-3}, A = 2.0 mm^2 = 2 × 10^{-6} m^2

I = 5.0A, B = 0.15 T, F = ?.

$$I = nevA \text{ or } v = \frac{I}{nev}$$

$$F = Bev = \frac{Be\times I}{neA} = \frac{BI}{nA} = \frac{0.15\times 5}{1.0\times 10^{29}\times 2\times 10^{-6}}$$

= 3.75×10^{-24} N

Example 18.

If the coil of a moving coil galvanometer having 10 turns and of resistance 4Ω is removed and is replaced by a second coil having 100 turns and of resistance 160Ω. Calculate (a) the factor by which the current sensitivity changes and (b) the factor by which the voltage sensitivity changes.

Solution :

Given : N_1 = 10 turns, R = 4Ω

N_2 = 100 turns, R_2 = 160Ω

(a) Current sensitivity with the Ist coil, $\left(\frac{\theta}{I}\right)_1 = \frac{N_1AB}{C}$

Current sensitivity with the 2nd coil $\left(\frac{\theta}{I}\right)_2 = \frac{N_2AB}{C}$

$$\therefore\ \frac{\left(\frac{\theta}{I}\right)_2}{\left(\frac{\theta}{I}\right)_1} = \frac{N_2}{N_1} = \frac{100}{10} = 10$$

(b) Voltage sensitivity with the Ist coil $\left(\frac{\theta}{V}\right)_1 = \frac{N_1AB}{CR_1}$

Voltage sensitivity with the 2nd coil $\left(\frac{\theta}{V}\right)_2 = \frac{N_2AB}{CR_2}$

$$\therefore\ \frac{\left(\frac{\theta}{v}\right)_2}{\left(\frac{\theta}{v}\right)_1} = \frac{N_2}{N_1}\frac{R_1}{R_2} = \frac{100}{10}\times\frac{4}{160} = \frac{1}{4}$$

CONCEPT MAP

MOVING CHARGES AND MAGNETISM

Magnetic field Space in the surrounding of a magnet or any current carrying conductor in which its magnetic influence can be experienced

- Direction of magnetic field-Depends upon the direction of current. Right hand thumb rule-Thumb points in the direction of current, curling of fingers represents direction of magnetic field .
- Ampere's circuital law $\oint B dl = \mu_0 I$
  - Magnetic field due to a solenoid. Inside a long solenoid $B = \mu_0 nI$. At a point on one end $B = \frac{\mu_0 nI}{2}$
  - Magnetic field due to a toroid inside the turns $B = \mu_0 nI$
- Biot-savart's law magnetic field due to current carrying element, $dB = \frac{\mu_0}{4\pi}\frac{Idl \sin\theta}{r^2}$
  - Magnetic field due to a straight current carrying conductor of infinite lenght $B = \frac{\mu_0 I}{2\pi R}$
  - **Magnetic field due to a current carrying circular loop**
    - At the centre of circular loop $B = \frac{\mu NI}{2R}$
    - On the axis of circular loop $B = \frac{\mu_0 NIa^2}{2(r^2+a^2)^{3/2}}$

Motion of a charged particle in a uniform magnetic field follows a circular path, radius $r = \frac{MV \sin\theta}{Bq}$

- Force acting on a charged particle moving in a uniform magnetic field $F = qVB \sin\theta = q(V \times B)$
  - Lorentz force $F = q (E \times V \times B)$
- Force on a conductor carrying current in a uniform magnetic field, $F = I Bl \sin\theta$, $F = I (B \times l)$
  - Force between two parallel current carrying conductors $F = \frac{\mu_0}{4\pi}.\frac{2I_1I_2}{r}$
    - Torque experienced by a current carrying loop in a uniform magnetic field $T = MB \sin\theta\,\hat{n} = M \times B$

Galvanometer to ammeter conversion : Low resistance or shunt connected in parallel $S = \left(\frac{I_g}{I - I_g}\right)G$

- Galvanometer to voltmeter conversion : High resistance in series $R = \frac{V}{I_g} - G$

EXERCISE - 1
Conceptual Questions

1. A current carrying coil is subjected to a uniform magnetic field. The coil will orient so that its plane becomes
(a) inclined at 45° to the magnetic field
(b) inclined at any arbitrary angle to the magnetic field
(c) parallel to the magnetic field
(d) perpendicular to the magnetic field

2. An electron enters a region where magnetic field (B) and electric field (E) are mutually perpendicular, then
(a) it will always move in the direction of B
(b) it will always move in the direction of E
(c) it always possesses circular motion
(d) it can go undeflected also

3. A current carrying conductor placed in a magnetic field experiences maximum force when angle between current and magnetic field is
(a) $3\pi/4$ (b) $\pi/2$ (c) $\pi/4$ (d) zero

4. Two concentric circular coils of ten turns each are situated in the same plane. Their radii are 20 and 40 cm and they carry respectively 0.2 and 0.4 ampere current in opposite direction. The magnetic field in weber/m^2 at the centre is
(a) $\mu_0/80$ (b) $7\mu_0/80$ (c) $(5/4)\mu_0$ (d) zero

5. A wire of length L metre carrying a current I ampere is bent in the form of a circle. Its magnitude of magnetic moment will be
(a) $IL/4\pi$ (b) $I^2L^2/4\pi$ (c) $IL^2/4\pi$ (d) $IL^2/8\pi$

6. Two straight long conductors AOB and COD are perpendicular to each other and carry currents I_1 and I_2. The magnitude of the magnetic induction at a point P at a distance a from the point O in a direction perpendicular to the plane ABCD is
(a) $\frac{\mu_0}{2\pi a}(I_1+I_2)$ (b) $\frac{\mu_0}{2\pi a}(I_1-I_2)$
(c) $\frac{\mu_0}{2\pi a}(I_1^2+I_2^2)^{\frac{1}{2}}$ (d) $\frac{\mu_0}{2\pi a}\frac{I_1 I_2}{I_1+I_2}$

7. A proton, deutron and an α-particle enter a magnetic field perpendicular to field with same velocity. What is the ratio of the radii of circular paths?
(a) 1 : 2 : 2 (b) 2 : 1 : 1
(c) 1 : 1 : 2 (d) 1 : 2 : 1

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

9. In cyclotron the gyro radius is
(a) proportional to momentum
(b) proportional to energy
(c) inversely proportional to momentum
(d) inversely proportional to energy

10. The current sensitivity of a moving coil galvanometer depends on
(a) the number of turns in the coil
(b) moment of inertia of the coil
(c) current sent through galvanometer
(d) eddy current in Al frame

11. Current i is flowing in a coil of area A & number of turns N, then magnetic moment of the coil is M is equal to
(a) NiA (b) Ni/A (c) $Ni/\sqrt{A}$ (d) N^2Ai

12. 1 Wbm^{-2} is equal to
(a) 10^4 G (b) 10^2 G (c) 10^{-2} G (d) 10^{-4} G

13. The radius of motion of a charged particle oscillating in a magnetic field is
(a) $\frac{mB}{qv}$ (b) $\frac{mv}{qB}$
(c) $\frac{mq}{vB}$ (d) $\frac{qv}{mB}$

14. Magnetic effect of current was discovered by
(a) Faraday (b) Oersted
(c) Kirchhoff (d) Joule

15. In cyclotron the charged particle may be accelerated upto energies
(a) Several eV (b) MeV
(c) BeV (d) Kev

16. In cyclotron the resonance condition is
(a) the frequency of revolution of charged particle is equal to the frequency of A.C. voltage sources
(b) the frequency of revolution of charged particle is equal to the frequency of applied magnetic field
(c) the frequency of revolution of charged particle is equal to the frequency of rotation of earth
(d) the frequency of revolution of charged particle, frequency of A.C. source and frequency of magnetic field are equal

17. Two parallel wires carrying currents in the same direction attract each other because of
(a) mutual inductance between them
(b) potential difference between them
(c) electric forces between them
(d) magnetic forces between them

18. If we double the radius of a coil keeping the current through it unchanged, then the magnetic field at any point at a large distance from the centre becomes approximately

(a) double (b) three times
(c) four times (d) one-fourth

19. To convert a galvanometer into an ammeter, one needs to connect a

(a) low resistance in parallel
(b) high resistance in parallel
(c) low resistance in series
(d) high resistance in series.

20. If a current is passed through a spring then the spring will

(a) expand (b) compress
(c) remains same (d) None of these.

21. A charged particle moves through a magnetic field in a direction perpendicular to it. Then the

(a) velocity remains unchanged
(b) speed of the particle remains unchanged
(c) direction of the particle remains unchanged
(d) acceleration remains unchanged

22. A long solenoid carrying a current produces a magnetic field B along its axis. If the current is double and the number of turns per cm is halved, the new value of the magnetic field is

(a) 4 B (b) B/2
(c) B (d) 2 B

23. The total charge induced in a conducting loop when it is moved in a magnetic field depends on

(a) the rate of change of magnetic flux
(b) initial magnetic flux only
(c) the total change in magnetic flux
(d) final magnetic flux only

24. Energy in a current carrying coil is stored in the form of

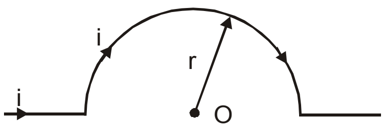
(a) electric field (b) magnetic field
(c) dielectric strength (d) heat

25. Tesla is the unit of

(a) magnetic flux (b) magnetic field
(c) magnetic induction (d) magnetic moment

EXERCISE - 2
Applied Questions

1. A portion of a conductive wire is bent in the form of a semicircle of radius r as shown below in fig. At the centre of semicircle, the magnetic induction will be



(a) zero (b) infinite
(c) $\frac{\mu_0}{4\pi}.\frac{\pi i}{r}$ gauss (d) $\frac{\mu_0}{4\pi}.\frac{\pi i}{r}$ tesla

2. A helium nucleus makes a full rotation in a circle of radius 0.8 meter in 2 sec. The value of the magnetic field induction B in tesla at the centre of circle will be

(a) $2\times10^{-19}\,\mu_0$ (b) $10^{-19}/\mu_0$
(c) $10^{-19}\,\mu_0$ (d) $2\times10^{-20}/\mu_0$

3. A solenoid of length 1.5 m and 4 cm diameter possesses 10 turns per cm. A current of 5A is flowing through it, the magnetic induction at axis inside the solenoid is

$(\mu_0 = 4\pi\times10^{-7}$ weber amp^{-1} m$^{-1})$

(a) $4\pi\times10^{-5}$ gauss (b) $2\pi\times10^{-5}$ gauss
(c) $4\pi\times10^{-5}$ tesla (d) $2\pi\times10^{-5}$ tesla

4. An electron (mass = 9×10^{-31} kg, charge = 1.6×10^{-19} C) moving with a velocity of 10^6 m/s enters a magnetic field. If it describes a circle of radius 0.1m, then strength of magnetic field must be

(a) 4.5×10^{-5} T (b) 1.4×10^{-5} T
(c) 5.5×10^{-5} T (d) 2.6×10^{-5} T

5. An electron moving with kinetic energy 6×10^{-16} joules enters a field of magnetic induction 6×10^{-3} weber/m^2 at right angle to its motion. The radius of its path is

(a) 3.42 cm (b) 4.23 cm
(c) 5.17 cm (d) 7.7 cm

6. An electron moves in a circular arc of radius 10 m at a contant speed of 2×10^7 ms^{-1} with its plane of motion normal to a magnetic flux density of 10^{-5} T. What will be the value of specific charge of the electron?

(a) 2×10^4 C kg^{-1} (b) 2×10^5 C kg^{-1}
(c) 5×10^6 C kg^{-1} (d) 2×10^{11} C kg^{-1}

7. A current of 3 A is flowing in a linear conductor having a length of 40 cm. The conductor is placed in a magnetic field of strength 500 gauss and makes an angle of 30º with the direction of the field. It experiences a force of magnitude

(a) 3×10^{-4} N (b) 3×10^{-2} N
(c) 3×10^2 N (d) 3×10^4 N

8. A cathode ray beam is bent in a circle of radius 2 cm by a magnetic induction 4.5×10^{-3} weber/m^2. The velocity of electron is

(a) 3.43×10^7 m/s (b) 5.37×10^7 m/s
(c) 1.23×10^7 m/s (d) 1.58×10^7 m/s

9. Two long parallel wires P and Q are held perpendicular to the plane of paper with distance of 5 m between them. If P and Q carry current of 2.5 amp. and 5 amp. respectively in the same direction, then the magnetic field at a point half-way between the wires is

(a) $\mu_0/17$ (b) $\sqrt{3}\mu_0/2\pi$

(c) $\mu_0/2\pi$ (d) $3\mu_0/2\pi$

10. A charged particle with velocity 2×10^3 m/s passes undeflected through electric and magnetic field. Magnetic field is 1.5 tesla. The electric field intensity would be

(a) 2×10^3 N/C (b) 1.5×10^3 N/C

(c) 3×10^3 N/C (d) $4/3 \times 10^{-3}$ N/C

11. If in a circular coil A of radius R, current I is flowing and in another coil B of radius 2R a current 2I is flowing, then the ratio of the magnetic fields B_A and B_B, produced by them will be

(a) 1 (b) 2 (c) 1/2 (d) 4

12. A circular loop of area 0.02 m^2 carrying a current of 10A, is held with its plane perpendicular to a magnetic field induction 0.2 T. The torque acting on the loop is

(a) 0.01 Nm (b) 0.001 Nm

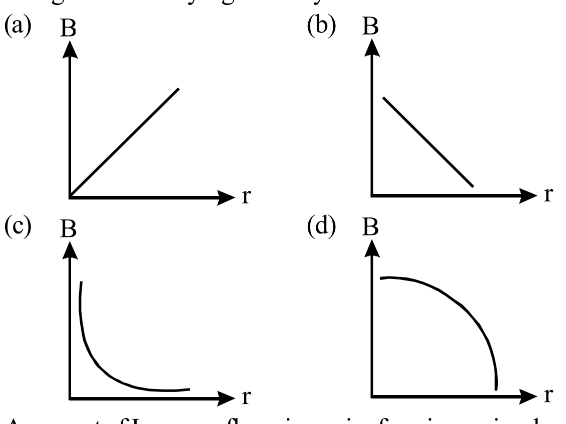
(c) zero (d) 0.8 Nm

13. Through two parallel wires A and B, 10A and 2A of currents are passed respectively in opposite directions. If the wire A is infinitely long and the length of the wire B is 2m, then force on the conductor B, which is situated at 10 cm distance from A, will be

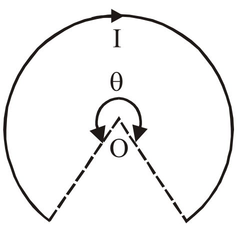
(a) 8×10^{-7} N (b) 8×10^{-5} N

(c) 4×10^{-7} N (d) 4×10^{-5} N

14. The magnetic flux density B at a distance r from a long straight wire carrying a steady current varies with r as



15. A current of I ampere flows in a wire forming a circular arc of radius r metres subtending an angle θ at the centre as shown. The magnetic field at the centre O in tesla is



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

16. A uniform electric field and a uniform magnetic field exist in a region in the same direction. An electron is projected with velocity pointed in the same direction. The electron will

(a) turn to its right

(b) turn to its left

(c) keep moving in the same direction but its speed will increase

(d) keep moving in the same direction but its speed will decrease

17. A current of I ampere flows along an infinitely long straight thin walled hollow metallic cylinder of radius r. The magnetic field at any point inside the cylinder at a distance x from the axis of the cylinder is

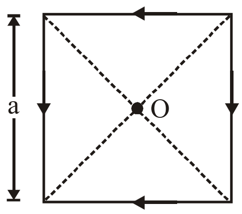
(a) ∞ (b) $\frac{\mu_0 I}{2\pi r}$ (c) $\frac{\mu_0 I}{2\pi x}$ (d) zero

18. Two particles X and Y having equal charge, after being accelerated through the same potential difference enter a region of uniform magnetic field and describe circular paths of radii R_1 and R_2 respectively. The ratio of the mass of X to that of Y is

(a) $\sqrt{\frac{R_1}{R_2}}$ (b) $\left(\frac{R_2}{R_1}\right)^2$

(c) $\left(\frac{R_1}{R_2}\right)^2$ (d) $\sqrt{\frac{R_2}{R_1}}$

19. A square coil of side a carries a current I. The magnetic field at the centre of the coil is



(a) $\frac{\mu_0 I}{a\pi}$ (b) $\frac{\sqrt{2}\mu_0 1}{a\pi}$

(c) $\frac{\mu_0 1}{\sqrt{2}\, a\pi}$ (d) $\frac{2\sqrt{2}\,\mu_0 I}{a\pi}$

20. Protons and α-particles of equal momenta enter a uniform magnetic field normally. The radii of their orbits will have the ratio.

(a) 1 (b) 2 (c) 0.5 (d) 4

21. 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

(a) depends on both R and v

(b) is independent of both R and v

(c) depends on R and not v

(d) depends on v and not on R

22. What is cyclotron frequency of an electron with an energy of 100 e V in the earth's magnetic field of 1×10^{-4} weber / m^2 if its velocity is perpendicular to magnetic field?
(a) 0.7 MHz (b) 2.8 MHz
(c) 1.4 MHz (d) 2.1 MHz

23. A circular loop of area 0.02 m^2 carrying a current of 10A, is held with its plane perpendicular to a magnetic field induction 0.2 T. The torque acting on the loop is
(a) 0.01 Nm (b) 0.001 Nm
(c) zero (d) 0.8Nm

24. Two thin, long, parallel wires, separated by a distance 'd' carry a current of 'i' A in the same direction. They will
(a) repel each other with a force of $\mu_0 i^2/(2\pi d)$
(b) attract each other with a force of $\mu_0 i^2/(2\pi d)$
(c) repel each other with a force of $\mu_0 i^2/(2\pi d^2)$
(d) attract each other with a force of $\mu_0 i^2/(2\pi d^2)$

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

26. If an electron describes half a revolution in a circle of radius r in a magnetic field B, the energy acquired by it is
(a) zero (b) $\frac{1}{2}mv^2$
(c) $\frac{1}{4}mv^2$ (d) $\pi r \times Bev$

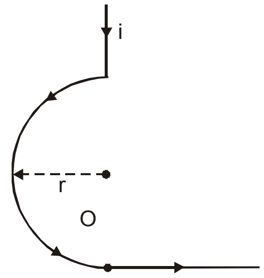
27. The orbital speed of electron orbiting around a nucleus in a circular orbit of radius 50 pm is 2.2×10^6 ms^{-1}. Then the magnetic dipole moment of an electron is
(a) 1.6×10^{-19} Am^2 (b) 5.3×10^{-21} Am^2
(c) 8.8×10^{-24} Am^2 (d) 8.8×10^{-26} Am^2

28. A deutron of kinetic energy 50 keV is describing a circular orbit of radius 0.5m, in a plane perpendicular to magnetic field $\vec{B}$. The kinetic energy of a proton that discribes a circular orbit of radius 0.5m in the same plane with the same magnetic field $\vec{B}$ is
(a) 200keV (b) 50keV (c) 100keV (d) 25keV

29. A proton and an α-particle enter a uniform magnetic field perpendicularly with the same speed. If proton takes 25 μ second to make 5 revolutions, then the time period for the α-particle would be
(a) 50 μ sec (b) 25 μ sec
(c) 10 μ sec (d) 5 μ sec

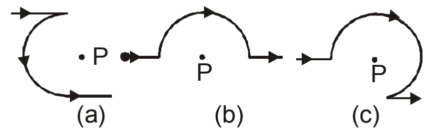
30. A cell is connected between two points of a uniformly thick circular conductor and i_1 and i_2 are the currents flowing in two parts of the circular conductor of radius a. The magnetic field at the centre of the loop will be
(a) zero (b) $\frac{\mu_0}{4\pi}(I_1 - I_2)$
(c) $\frac{\mu_0}{2a}(I_1 + I_2)$ (d) $\frac{\mu_0}{a}(I_1 + I_2)$

31. In fig, what is the magnetic field induction at point O



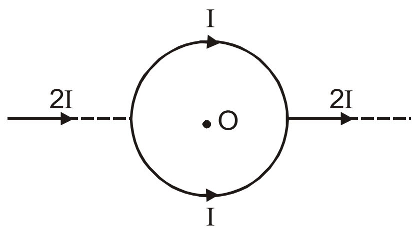
(a) $\frac{\mu_0 i}{4\pi r}$
(b) $\frac{\mu_0 i}{4r} + \frac{\mu_0 i}{2\pi r}$
(c) $\frac{\mu_0 i}{4r} + \frac{\mu_0 i}{4\pi r}$
(d) $\frac{\mu_0 i}{4r} - \frac{\mu_0 i}{4\pi r}$

32. The field B at the centre of a circular coil of radius r is π times that due to a long straight wire at a distance r from it, for equal currents. Fig. shows three cases:



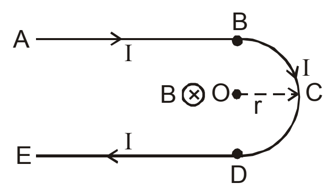
in all cases the circular part has radius r and straight ones are infinitely long. For same current the field B at the centre P in cases 1, 2, 3 has the ratio
(a) $\left(-\frac{\pi}{2}\right):\frac{\pi}{2}:\left(\frac{3\pi}{4}-\frac{1}{2}\right)$
(b) $\left(-\frac{\pi}{2}+1\right):\left(\frac{\pi}{2}+1\right):\left(\frac{3\pi}{4}+\frac{1}{2}\right)$
(c) $-\frac{\pi}{2}:\frac{\pi}{2}:\frac{3\pi}{4}$
(d) $\left(-\frac{\pi}{2}-1\right):\left(\frac{\pi}{4}+\frac{1}{4}\right):\left(\frac{3\pi}{4}+\frac{1}{2}\right)$

33. An infinite straight conductor carrying current 2 I is split into a loop of radius r as shown in fig. The magnetic field at the centre of the coil is



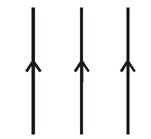
(a) $\frac{\mu_0}{4\pi}\frac{2(\pi+1)}{r}$
(b) $\frac{\mu_0}{4\pi}\frac{2(\pi-1)}{r}$
(c) $\frac{\mu_0}{4\pi}\frac{(\pi+1)}{r}$
(d) zero

34. A long wire is bent into shape ABCDE as shown in fig., with BCD being a semicircle with centre O and radius r metre. A current of I amp. flows through it in the direction $A \to B \to C \to D \to E$. Then the magnetic induction at the point O of the figure in vacuum is



(a) $\mu_0\left[\frac{I}{2\pi r}+\frac{I}{4r}\right]$
(b) $\mu_0\left[\frac{I}{2\pi r}-\frac{I}{4r}\right]$
(c) $\mu_0 I / 4r$
(d) $\mu_0 I / \pi r$

35. Three wires are situated at the same distance. A current of 1A, 2A, 3A flows through these wires in the same direction. What is ratio of F_1/F_2, where F_1 is force on 1 and F_2 on 2?

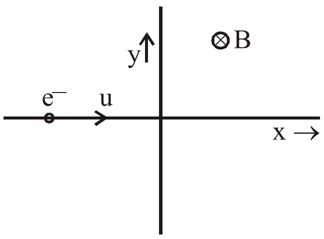


(a) 7/8
(b) 1
(c) 9/8
(d) None of these

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

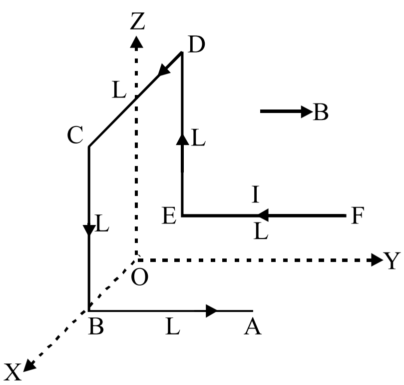
(a) irB_0 (b) $2\pi irB_0$
(c) zero (d) πirB_0

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



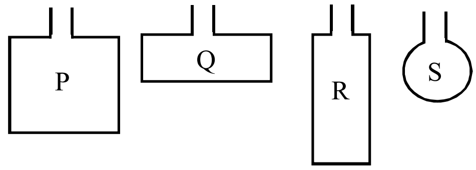
(a) v = u at y > 0 (b) v = u at y < 0
(c) v > u at y > 0 (d) v > u at y < 0

38. A wire ABCDEF is bent in the form as shown in figure. The wire carries a current I and is placed in a uniform magnetic field of induction B parallel to positive Y-axis. If each side is of length L, the force experienced by the wire will be



(a) IBL along the positive Z-direction
(b) IBL along the negative Z-direction
(c) 2IBL along the positive Z-direction
(d) 2IBL along the negative Z-direction

39. Four wires, each of length 2.0 m, are bent into four loops P, Q, R and S and then suspended in a uniform magnetic field. If the same current is passed in each, then the torque will be maximum on the loop



(a) P (b) Q
(c) R (d) S

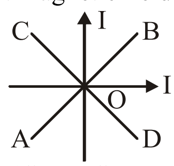
40. A charged particle (charge q) is moving in a circle of radius R with uniform speed v. The associated magnetic moment μ is given by

(a) qvR^2 (b) $qvR^2/2$ (c) qvR (d) qvR/2

41. A straight wire of diameter 0.5 mm, carrying a current of 1A is replaced by another wire of 1mm diameter carrying the same current. The strength of magnetic field far away is

(a) unchanged
(b) quarter of its earlier value
(c) half of the earlier value
(d) twice the earlier value

42. Two equal electric currents are flowing perpendicular to each other as shown in figure. AB and CD are perpendicular to each other and symmetrically placed with respect to the currents. Where do we expect the resultant magnetic field to be zero?



(a) on AB
(b) on CD
(c) on both AB & CD
(d) on both OD & BO

43. The magnetic field (dB) due to small element (dl) at a distance $(\vec{r})$ from element carrying current i, is

(a) $dB = \frac{\mu_0}{4\pi} i \left(\frac{\vec{dl} \times \vec{r}}{r}\right)$ (b) $dB = \frac{\mu_0}{4\pi} i^2 \left(\frac{\vec{dl} \times \vec{r}}{r^2}\right)$

(c) $dB = \frac{\mu_0}{4\pi} i^2 \left(\frac{\vec{dl} \times \vec{r}}{r^2}\right)$ (d) $dB = \frac{\mu_0}{4\pi} i \left(\frac{\vec{dl} \times \vec{r}}{r^3}\right)$

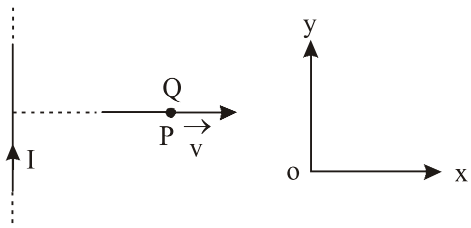
44. A 10eV electron is circulating in a plane at right angles to a uniform field at a magnetic induction 10^{-4} Wb/m^2 (= 1.0 gauss). The orbital radius of the electron is

(a) 12 cm (b) 16 cm (c) 11 cm (d) 18 cm

45. A coil of one turn is made of a wire of certain length and then from the same length a coil of two turns is made. If the same current is passed in both the cases, then the ratio of the magnetic inductions at their centres will be

(a) 2 : 1 (b) 1 : 4 (c) 4 : 1 (d) 1 : 2

46. A very long straight wire carries a current I. At the instant when a charge + Q at point P has velocity $\vec{v}$, as shown, the force on the charge is



(a) along oy (b) opposite to oy
(c) along ox (d) opposite to ox

47. 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

(a) $3\vec{F}$ (b) $-\vec{F}$

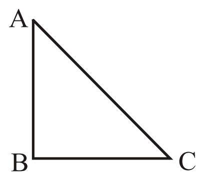
(c) $-3\vec{F}$ (d) $\vec{F}$

48. 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

(a) $\frac{\mu_0 i}{\sqrt{2}R}$ (b) $\frac{\mu_0 i}{2\sqrt{2}R}$

(c) $\frac{\mu_0 i}{2R}$ (d) $\frac{\mu_0 i}{4R}$

49. A current carrying 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 F, what is the force on the arm AC?



(a) $-\sqrt{2}\,\vec{F}$

(b) $-\vec{F}$

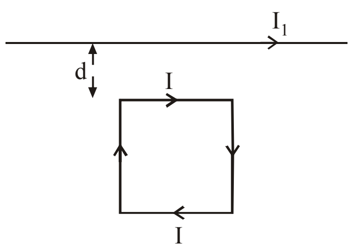
(c) $\vec{F}$

(d) $\sqrt{2}\,\vec{F}$

50. A uniform electric field and uniform magnetic field are acting along the same direction in a certain region. If an electron is projected in the region such that its velocity is pointed along the direction of fields, then the electron

(a) will turn towards right of direction of motion
(b) speed will decrease
(c) speed will increase
(d) will turn towards left direction of motion

51. 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

52. Charge q is uniformly spread on a thin ring of radius R. The ring rotates about its axis with a uniform frequency f Hz. The magnitude of magnetic induction at the centre of the ring is

(a) $\frac{\mu_0 qf}{2R}$ (b) $\frac{\mu_0 q}{2fR}$ (c) $\frac{\mu_0 q}{2\pi fR}$ (d) $\frac{\mu_0 qf}{2\pi R}$

53. 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

(a) $\frac{\sqrt{5}\mu_0 I}{2R}$ (b) $\frac{3\mu_0 I}{2R}$ (c) $\frac{\mu_0 I}{2R}$ (d) $\frac{\mu_0 I}{R}$

54. An alternating electric field, of frequency v, 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 and the kinetic energy (K) of the proton beam, produced by it, are given by

(a) $B = \frac{m\nu}{e}$ and $K = 2m\pi^2\nu^2R^2$

(b) $B = \frac{2\pi m\nu}{e}$ and $K = m^2\pi\nu R^2$

(c) $B = \frac{2\pi m\nu}{e}$ and $K = 2m\pi^2\nu^2R^2$

(d) $B = \frac{m\nu}{e}$ and $K = m^2\pi\nu R^2$

55. 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?

(a) 2 MeV (b) 1 MeV

(c) 0.5 MeV (d) 4 MeV

56. 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

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

57. A current loop in a magnetic field

(a) can be in equilibrium in one orientation
(b) can be in equilibrium in two orientations, both the equilibrium states are unstable
(c) can be in equilibrium in two orientations, one stable while the other is unstable
(d) experiences a torque whether the field is uniform or non-uniform in all orientations

58. A charged particle moves through a magnetic field in a direction perpendicular to it. Then the

(a) velocity remains unchanged

(b) speed of the particle remains unchanged

(c) direction of the particle remains unchanged

(d) acceleration remains unchanged

59. Electron move at right angle to a magnetic field of 1.5×10^{-2} tesla with speed of 6×10^7 m/s. If the specific charge of the electron is 1.7×10^{11} C/kg. The radius of circular path will be

(a) 3.31 cm (b) 4.31cm

(c) 1.31 cm (d) 2.35 cm

60. A conducting circular loop of radius r carries a constant current *i*. It is placed in a uniform magnetic field B such that B is perpendicular to the plane of the loop. The magnetic force acting on the loop is :

(a) irB (b) $2\pi riB$

(c) zero (d) πriB

61. An infinitely long straight wire contains a uniformly continuous current of 10A. The radius of the wire is 4×10^{-2} m. The magnetic field at 2×10^{-2} m from the centre of the wire will be:

(a) 0 (b) 2.5×10^{-5} T

(c) 5.0×10^{-5} T (d) none of these.

62. A proton moving vertically downward enters a magnetic field pointing towards north. In which direction proton will deflect?

(a) East (b) West

(c) North (d) South

63. 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

(a) angle between $\vec{v}$ and $\vec{B}$ is necessarily 90°

(b) angle between $\vec{v}$ and $\vec{B}$ can have any value other than 90°

(c) angle between $\vec{v}$ and $\vec{B}$ can have any value other than zero and 180°

(d) angle between $\vec{v}$ and $\vec{B}$ is either zero or 180°

64. A coil carrying electric current is placed in uniform magnetic field, then

(a) torque is formed

(b) e.m.f is induced

(c) both (a) and (b) are correct

(d) none of the above

65. A charge moving with velocity v in *X*-direction is subjected to a field of magnetic induction in negative *X*-direction. As a result, the charge will

(a) remain unaffected

(b) start moving in a circular path *Y–Z* plane

(c) retard along *X*-axis

(d) move along a helical path around *X*-axis

66. The magnetic field at a distance r from a long wire carrying current i is 0.4 tesla. The magnetic field at a distance 2r is

(a) 0.2 tesla (b) 0.8 tesla

(c) 0.1 tesla (d) 1.6 tesla

67. A straight wire of length 0.5 metre and carrying a current of 1.2 ampere is placed in uniform magnetic field of induction 2 tesla. The magnetic field is perpendicular to the length of the wire. The force on the wire is

(a) 2.4 N (b) 1.2 N

(c) 3.0 N (d) 2.0 N

68. A moving coil galvanometer has a resistance of 900 Ω. In order to send only 10% of the main current through this galvanometer, the resistance of the required shunt is

(a) 0.9 Ω (b) 100 Ω (c) 405 Ω (d) 90 Ω

69. A uniform magnetic field acts at right angles to the direction of motion of electron. As a result, the electron moves in a circular path of radius 2cm. If the speed of electron 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

70. 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

(a) $\sqrt{\dfrac{B}{v}}$ (b) $\dfrac{B}{v}$

(c) $\sqrt{\dfrac{v}{B}}$ (d) $\dfrac{v}{B}$

71. The magnetic induction at a point P which is at a distance of 4 cm from a long current carrying wire is 10^{-3} T. The field of induction at a distance 12 cm from the current will be

(a) 3.33×10^{-4} T (b) 1.11×10^{-4} T

(c) 3×10^{-3} T (d) 9×10^{-3} T

Directions for Qs. (72 to 75) : Each question contains STATEMENT-1 and STATEMENT-2. Choose the correct answer (ONLY ONE option is correct) from the following.

(a) Statement -1 is false, Statement-2 is true

(b) Statement -1 is true, Statement-2 is true; Statement -2 is a correct explanation for Statement-1

(c) Statement -1 is true, Statement-2 is true; Statement -2 is not a correct explanation for Statement-1

(d) Statement -1 is true, Statement-2 is false

72. **Statement 1 :** If the current in a solenoid is reversed in direction while keeping the same magnitude, the magnetic field energy stored in the solenoid decreases.

Statement 2 : Magnetic field energy density is proportional to square of current.

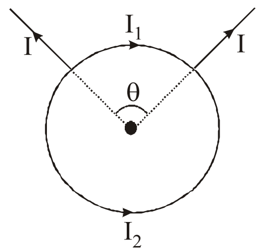
73. **Statement 1 :** If a charged particle is released from rest in a region of uniform electric and magnetic fields parallel to each other, it will move in a straight line.

Statement 2 : The electric field exerts no force on the particle but the magnetic field does.

74. **Statement 1 :** A cyclotron cannot accelerate neutrons.

Statement 2 : Neutrons are neutral.

75. **Statement 1 :** The magnetic field at the centre of the circular coil in the following figure due to the currents I_1 and I_2 is zero.



Statement 2 : $I_1 = I_2$ implies that the fields due to the current I_1 and I_2 will be balanced.

EXERCISE - 3
Exemplar & Past Years NEET/AIPMT Questions

Exemplar Questions

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

(a) They have equal z-components of momenta

(b) They must have equal charges

(c) They necessarily represent a particle, anti-particle pair

(d) The charge to mass ratio satisfy

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

2. Biot-Savart law indicates that the moving electrons (velocity v) produce a magnetic field **B** such that

(a) B is perpendicular of

(b) B is parallel to v

(c) it obeys inverse cube law

(d) it is along the line joining the electron and point of observationt.

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

(a) The magnitude of magnetic moment now diminishes

(b) The magnetic moment does not change

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

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

4. An electron is projected with uniform velocity along the axis of a current carrying long solenoid. Which of the following is true?

(a) The electron will be accelerated along the axis

(b) The electron path will be circular about the axis

(c) The electron will experience a force at 45° to the axis and hence execute a helical path

(d) The electron will continue to move with uniform velocity along the axis of the solenoid

5. 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 dees

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

NEET/AIPMT (2013-2017) Questions

6. A current loop in a magnetic field ***[2013]***

(a) can be in equilibrium in one orientation

(b) can be in equilibrium in two orientations, both the equilibrium states are unstable

(c) can be in equilibrium in two orientations, one stable while the other is unstable

(d) experiences a torque whether the field is uniform or non-uniform in all orientations

7. 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 respectively ***[2013]***

(a) $\frac{ma_0}{e}$ west, $\frac{2ma_0}{ev_0}$ down

(b) $\frac{ma_0}{e}$ east, $\frac{3ma_0}{ev_0}$ up

(c) $\frac{ma_0}{e}$ east, $\frac{3ma_0}{ev_0}$ down

(d) $\frac{ma_0}{e}$ west, $\frac{2ma_0}{ev_0}$ up

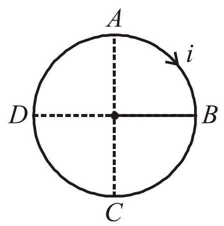
8. A long straight wire carries a certain current and produces a magnetic field of $2 \times 10^{-4}\ \frac{\text{weber}}{\text{m}^2}$ at a perpendicular distance of 5 cm from the wire. An electron situated at 5 cm from the wire moves with a velocity 10^7 m/s towards the wire along perpendicular to it. The force experienced by the electron will be ***[NEET Kar. 2013]***

(charge on electron $= 1.6 \times 10^{-19}$ C)

(a) Zero (b) 3.2 N

(c) 3.2×10^{-16} N (d) 1.6×10^{-16} N

9. A circular coil *ABCD* carrying a current *i* is placed in a uniform magnetic field. If the magnetic force on the segment *AB* is $\vec{F}$, the force on the remaining segment *BCDA* is ***[NEET Kar. 2013]***



(a) $\vec{F}$ (b) $-\vec{F}$

(c) $3\vec{F}$ (d) $-3\vec{F}$

10. 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 : ***[2014]***

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

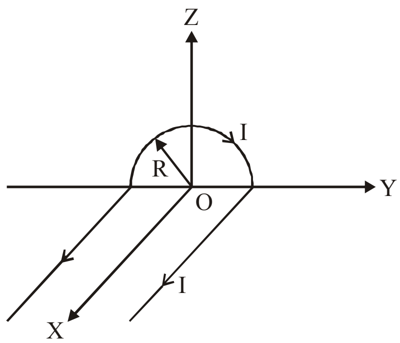
(c) $\frac{\mu_0}{2\pi d}(I_1^2 - I_2^2)$ (d) $\frac{\mu_0}{2\pi d}(I_1^2 \times I_2^2)^{1/2}$

11. An electron moving in a circular orbit of radius r makes n rotations per second. The magnetic field produced at the centre has magnitude: ***[2015]***

(a) Zero (b) $\frac{\mu_0 n^2 e}{r}$

(c) $\frac{\mu_0 ne}{2r}$ (d) $\frac{\mu_0 ne}{2\pi r}$

12. 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 : ***[2015]***



(a) $\vec{B} = -\frac{\mu_0}{4\pi}\frac{I}{R}\left(\mu\hat{i} \times 2\hat{k}\right)$

(b) $\vec{B} = -\frac{\mu_0}{4\pi}\frac{I}{R}\left(\pi\hat{i} + 2\hat{k}\right)$

(c) $\vec{B} = \frac{\mu_0}{4\pi}\frac{I}{R}\left(\pi\hat{i} - 2\hat{k}\right)$

(d) $\vec{B} = \frac{\mu_0}{4\pi}\frac{I}{R}\left(\pi\hat{i} + 2\hat{k}\right)$

13. A proton and an alpha particle both enter a region of uniform magnetic field B, moving at right angles to 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: ***[2015 RS]***

(a) 0.5 MeV (b) 1.5 MeV

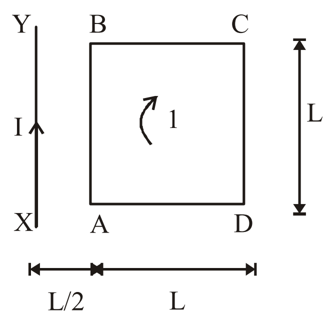
(c) 1 MeV (d) 4 MeV

14. A rectangular coil of length 0.12 m and width 0.1 m 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 2A. 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 : ***[2015 RS]***

(a) 0.20 Nm (b) 0.24 Nm

(c) 0.12 Nm (d) 0.15 Nm

15. 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 force on the loop will be : ***[2016]***



(a) $\frac{2\mu_0 Ii}{3\pi}$ (b) $\frac{\mu_0 Ii}{2\pi}$

(c) $\frac{2\mu_0 IiL}{3\pi}$ (d) $\frac{\mu_0 IiL}{2\pi}$

16. 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 $\frac{a}{2}$ and 2a respectively, from the axis of the wire is :***[2016]***

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

(c) 1 (d) 4

17. A long solenoid has 1000 turns. When a current of 4A flows through it, the magnetic flux linked with each turn of the solenoid is 4×10^{-3} Wb. The self inductance of the solenoid is : ***[2016]***

(a) 4H (b) 3H

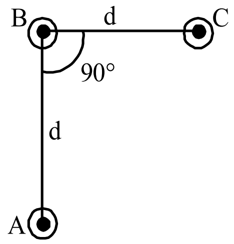
(c) 2H (d) 1H

18. A 250-turn rectangular coil of length 2.1 cm and width 1.25 cm 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 ***[2017]***

(a) 4.55 μJ (b) 2.3 μJ

(c) 1.15 μJ (d) 9.1 μJ

19. 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 ***[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) $\frac{\mu_0 i^2}{2\pi d}$

Hints & Solutions

EXERCISE - 1

1. (d) 2. (d)

3. (b) F = iB l sin θ. This is maximum when sin θ = 1 or θ = π/2.

4. (d) $B = \frac{\mu_0}{4\pi}.\frac{2\pi n i_1}{r_1} - \frac{\mu_0}{4\pi}.\frac{2\pi n i_2}{r_2} = \frac{\mu_0}{2}\left[\frac{n i_1}{r_1} - \frac{n i_2}{r_2}\right]$

5. (c) If r is the radius of the circle,

   then $L = 2\pi r$ or, $r = \frac{L}{2\pi}$

   Area = $\pi r^2 = \pi L^2/4\pi^2 = L^2/4\pi$

6. (c) The point P is lying symmetrically w.r.t. the two long straight current carrying conductors. The magnetic fields at P due to these current carrying conductors are mutually perpendicular.

7. (a) $r = \frac{mv}{Bq}$ or, $r \propto \frac{m}{q}$ for the same value of v and B.

8. (a) r = mv/Bq is same for both.

9. (a) $Bqv = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{Bq}$

10. (a) Current sensitivity = $\frac{nBA}{K}$

    where K is constant of torsional rigidity.

11. (a)

12. (a)

13. (b) 14. (b)

15. (b) In cyclotron, energy with which aceleration takes place is in term of MeV.

16. (a)

17. (d)

18. (c) $B_{axis} = \left(\frac{\mu_0 NI}{2x^3}\right)R^2$

    $B \propto R^2$

    So, when radius is doubled, magnetic field becomes four times.

19. (a) To convert a galvanometer into an ammeter, one needs to connect a low resistance in parallel so that maximum current passes through the shunt wire and ammeter remains protected.

20. (b) It will compress due to the force of attraction between two adjacent coils carrying current in the same direction.

21. (b) Magnetic force acts perpendicular to the velocity. Hence speed remains constant.

22. (c) $B = \mu_0 N_0 i\,;\ B_1 = (\mu_0)\left(\frac{N_0}{2}\right)(2\,i) = \mu_0 N_0 i = B$

    $\Rightarrow B_1 = B$

23. (c) $e = \frac{d\phi}{dt};\ i = \frac{e}{R} = \frac{1}{R}\frac{d\phi}{dt}$

    Total charge induced = $\int i\,dt = \int \frac{1}{R}\frac{d\phi}{dt}.dt$

    $= \frac{1}{R}\int_{\phi_1}^{\phi_2} d\phi = \frac{1}{R}(\phi_2 - \phi_1)$

24. (b) Energy is stored in magnetic field.

25. (b) Tesla is the unit of magnetic field.

EXERCISE - 2

1. (d) The straight part will not contribute magnetic field at the centre of the semicircle because every element of the straight part will be 0º or 180º with the line joining the centre and the element

   Due to circular portion, the field is $\frac{1}{2}\frac{\mu_0 i}{2r} = \frac{\mu_0 i}{4r}$

   Hence total field at $O = \frac{\mu_0 i}{4r}$ tesla

2. (c) $B = \frac{\mu_0}{4\pi}\frac{2\pi i}{r}$ where

   $i = \frac{2e}{t} = \frac{2\times1.6\times10^{-19}}{2} = 1.6\times10^{-19}$ A

   $\therefore\ B = \frac{\mu_0 i}{2r} = \frac{\mu_0\times1.6\times10^{-19}}{2\times0.8} = \mu_0\times10^{-19}$ T

3. (d) $B = \mu_0 nI = 4\pi\times10^{-7}\times10\times5 = 2\pi\times10^{-5}$ T.

4. (c) $Bqv = \frac{m v^2}{r}$ or $B = \frac{m v}{rq} = \frac{(9\times10^{-31})\times10^6}{0.1\times(1.6\times10^{-19})}$

   $= 5.5\times10^{-5}$ T

5. (a) $E_k = \frac{1}{2}mv^2$ or $mv = \sqrt{2E_k m}$ and

   $r = \frac{mv}{Bq} = \frac{\sqrt{2E_k m}}{Bq}$

6. (d) $Bqv = mv^2/r$ or $q/m = v/rB$.

7. (b) $F = I\ell B \sin\theta = 3\times0.40\times(500\times10^{-4})\times\sin 30^\circ = 3\times10^{-2}$ N.

8. (d) $v = \frac{Bqr}{m} = \frac{4.5\times10^{-3}\times1.6\times10^{-19}\times2\times10^{-2}}{9.1\times10^{-31}}$

   $= 1.58\times10^7$ m/s

9. (c) $B = \frac{\mu_0}{4\pi}\frac{2i_2}{(r/2)} - \frac{\mu_0}{4\mu}\frac{2i_1}{(r/2)} = \frac{\mu_0}{4\pi}\frac{4}{r}(i_2 - i_1)$

   $= \frac{\mu_0}{4\pi}\frac{4}{5}(5-2.5) = \frac{\mu_0}{2\pi}.$

10. (c) $E = vB = 2\times10^3\times1.5 = 3\times10^3$ V/m.

11. (a) In coil A, $B = \frac{\mu_0}{4\pi}\frac{2\pi I}{R}.\ \ \therefore B \propto \frac{I}{R};$

Hence, $\frac{B_1}{B_2} = \frac{I_1}{R_1} \cdot \frac{R_2}{I_2} = \frac{2}{2} = 1$

12. (c) Torque on loop $\tau = nIAB\cos\theta$; Here $\theta = 90^\circ$
$\therefore\ \tau = 0.$

13. (b) $F = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r} \times \ell = \frac{10^{-7} \times 2 \times 10 \times 2}{0.1} \times 2 = 8 \times 10^{-5}$ N

14. (c)

15. (a) $B = \frac{\mu_0 I}{2r} \times \frac{\theta}{2\pi} = \frac{\mu_0 I\theta}{4\pi r}$

16. (d) No magnetic force acts on the electron and force due to electric field will act opposite to its initial direction of motion. Hence its velocity decreases in magnitude.

17. (d) Since no current is enclosed inside the hollow conductor. Hence $B_{inside} = 0$.

18. (c) $r = \frac{1}{B}\sqrt{\frac{2mV}{q}}$

$$\frac{R_1}{R_2} = \sqrt{\frac{m_x}{m_y}}$$

$$\Rightarrow \frac{m_x}{m_y} = \left(\frac{R_1}{R_2}\right)^2$$

19. (d) $B_{total} = 4B_{side}$

$$B_{total} = 4\frac{\mu_0 I}{2\pi\left(\frac{a}{2}\right)}\left[\sin\frac{\pi}{4} + \sin\frac{\pi}{4}\right]$$

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

20. (b) $r = \frac{mv}{qB} = \frac{p}{qB} \Rightarrow \frac{r_p}{r_\alpha} = \frac{q_\alpha}{q_p} = \frac{2e}{e} = \frac{2}{1}$

21. (b) In a uniform magnetic field, a charged particle is moving in a circle of radius R with constant speed v.

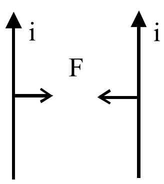
$$\therefore \frac{mv^2}{R} = Bqv \quad \text{or, } R = \frac{mv}{Bq} \qquad .....(1)$$

$$\text{Time period, } T = \frac{2\pi R}{v} = \frac{2\pi mv}{Bqv} = \frac{2\pi m}{Bq} \qquad .....(2)$$

Time period T does not depend on both R and v because when v is changed, R is also changed proportionately and for period, it is R/v that is taken.

22. (b) 23. (c)

24. (b)

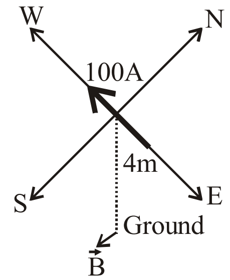


$$\frac{F}{\ell} = \frac{\mu_0 i_1 i_2}{2\pi d} = \frac{\mu_0 i^2}{2\pi d}$$

(attractive as current is in the same direction)

25. (c) The magnetic field is

$$B = \frac{\mu_0}{4\pi}\frac{2I}{r} = 10^{-7} \times \frac{2 \times 100}{4} = 5 \times 10^{-6}\ \text{T}$$



According to right hand palm rule, the magnetic field is directed towards south.

26. (a) Since magnetic force is always perpendicular to the velocity of electron, so it can only change the direction of velocity of electron, but it (the magnetic force) cannot accelerate or deaccelerate the electron.

27. (c) Magnetic dipole moment

$$m = iA = \frac{e}{T} \times \pi r^2 = \frac{e}{(2\pi r / v)} \times \pi r^2 = \frac{erv}{2}.$$

$$= \frac{1.6 \times 10^{-19} \times 50 \times 10^{-12} \times 2.2 \times 10^6}{2}$$

$$= 8.8 \times 10^{-24}\ \text{Am}^2.$$

28. (c) So $r_{deutron} = \frac{\sqrt{2m_dE_d}}{Bq}$; $r_{proton} = \frac{\sqrt{2m_pE_p}}{Bq}$

For same radius, B and q

$$m_pE_p = m_dE_d \Rightarrow E_p = \frac{m_d}{m_p}E_d = \frac{2}{1} \times 50 = 100\text{keV}$$

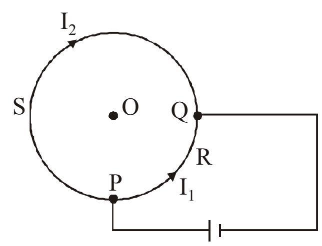
29. (c) Time taken by proton to make one revolution

$$= \frac{25}{5} = 5\mu\ \text{sec}.$$

As $T = \frac{2\pi m}{qB}$; so $\frac{T_2}{T_1} = \frac{m_2}{m_1} \times \frac{q_1}{q_2}$

or $T_2 = T_1\frac{m_2 q_1}{m_1 q_2} = \frac{5 \times 4m_1}{m_1} \times \frac{q}{2q} = 10\ \mu$ sec.

30. (a) Let ℓ_1, ℓ_2 be the lengths of the two parts PRQ and PSQ of the conductor and ρ be the resistance per unit length of the conductor. The resistance of the portion PRQ will be $R_1 = \ell_1\rho$



The resistance of the portion PSQ will be $R_2 = \ell_2 \rho$
Pot. diff. across P and Q = $I_1 R_1 = I_2 R_2$
or $I_1 \ell_1 \rho = I_2 \ell_2 \rho$ or $I_1 \ell_1 = I_2 \ell_2$ ...(1)
Magnetic field induction at the centre O due to currents through circular conductors PRQ and PSQ will be

$$= B_1 - B_2 = \frac{\mu_0}{4\pi}\frac{I_1\ell_1 \sin 90^o}{r^2} - \frac{\mu_0}{4\pi}\frac{I_2\ell_2 \sin 90^o}{r^2} = 0.$$

31. (c) B at O will be due to the following portions
(i) Vertical straight portion. This is zero.
(ii) Circular portion. This is given by

$$B_{circular} = \frac{1}{2}\frac{\mu_0 i}{2r} = \frac{\mu_0 i}{4r}$$

(iii) Straight horizontal portion. This is given by

$$B_{straight} = \frac{\mu_0 i}{4\pi r}$$

$$\therefore \ B_{Total} = \frac{\mu_0 i}{4r} + \frac{\mu_0 i}{4\pi r}$$

32. (a) **For case (a)** magnetic field due to straight portions is cancelled & the magnetic field due to semi circular arc of radius r at P is

$$B_a = \frac{\mu_o}{4\pi}\frac{i\times\pi}{r} = \left(\frac{\mu_o i}{4\pi r}\right)\times\pi$$

It is in upward direction & we take upward direction negative, So $\vec{B}_a = -\left(\frac{\mu_o i}{4\pi r}\right).\pi$

For case (b) Due to straight portion the magnetic field is zero so the magnetic field due to semi circular arc is

$\vec{B}_b = \left(\frac{\mu_o i}{4\pi r}\right)\times\pi$ (in down wards direction so +ive sign)

For case (c) Magnetic field due to straight portion is

$= -\frac{\mu_o}{4\pi}\frac{i}{r}$ (upward direction)

Magnetic field due to circular arc which substand an angle $3\pi/2$ at centre is

$= \left(\frac{\mu_o i}{4\pi r}\right)\times\frac{3\pi}{2}$ (down ward direction)

so $\vec{B}_c = \left(\frac{\mu_o i}{4\pi r}\right)\left(\frac{3\pi}{2} - 1\right)$

so $\vec{B}_a : \vec{B}_b : \vec{B}_c = -\pi : \pi : \left(\frac{3\pi}{2} - 1\right)$

$$= \left(\frac{-\pi}{2}\right) : \frac{\pi}{2} : \left(\frac{3\pi}{4} - \frac{1}{2}\right)$$

33. (d) Here, the wire does not produce any magnetic field at O because the conductor lies on the line of O. Also, the loop does not produce magnetic field at O.

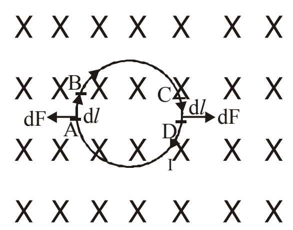
34. (a) $B = \frac{\mu_0}{4\pi}\left[\frac{I}{r} + \frac{\pi I}{r} + \frac{I}{r}\right] \frac{\mu_0}{4\pi}\left[\frac{2I}{r} + \frac{\pi I}{r}\right]$

$$= \mu_0\left[\frac{I}{2\pi r} + \frac{I}{4r}\right]$$

(The direction of $\vec{B}$ is into the page.)

35. (a) Due to flow of current in same direction at adjacent side, an attractive magnetic force will be produced.

36. (c) The magnetic field is perpendicular to the plane of the paper. Let us consider two diametrically opposite elements. By Fleming's Left hand rule on element AB the direction of force will be Leftwards and the magnitude will be
$dF = Idl\,B \sin 90° = IdlB$



On element CD, the direction of force will be towards right on the plane of the papper and the magnitude will be $dF = IdlB$.

37. (b) From Lorentz equation

$F = -eu\,\hat{i}\times B_0(-\hat{k}) = -euB_0\hat{j}$

hence it will complete a semicircular arc and comes out of the region at a position y, such that $y < 0$

38. (a)

39. (d) For a given perimeter the area of circle is maximum. So magnetic moment of (S) is greatest.

40. (d) Magnetic moment $\mu = IA$

Since $T = \frac{2\pi R}{v}$

Also, $I = \frac{q}{T} = \frac{qv}{2\pi R}$

$$\therefore \ \mu = \left(\frac{qv}{2\pi R}\right)\left(\pi R^2\right) = \frac{qvR}{2}.$$

41. (a) [Hint $\Rightarrow B = \frac{\mu_0 i}{2\pi r}$, where r is distance of point from the wire, where we want to calculate the magnetic field. It is clear from expression that B is independent of thickness of wire.]

42. (a) The direction of the magnetic field due to a current is given by right hand curled fingers rule. Therefore at AB axis, the components of magnetic field will cancel each other and the resultant magnetic field will be zero on AB.

43. (d)

44. (b) [Hint $\Rightarrow \frac{mv^2}{r} = qvB$].

45. (b) Let ℓ be length of wire

Ist case : $\ell = 2\pi r \Rightarrow r = \dfrac{\ell}{2\pi}$

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

2nd Case : $\ell = 2(2\pi r') \Rightarrow r' = \dfrac{\ell}{4\pi}$

$$B' = \frac{\mu_0 In}{2\pi \frac{\ell}{4\pi}} = \frac{2\mu_0 I}{\frac{\ell}{2}} \quad \text{(where n = 2)}$$

on putting the value of B $\Rightarrow B' = 4\left(\dfrac{\mu_0 I}{l}\right) = 4B$

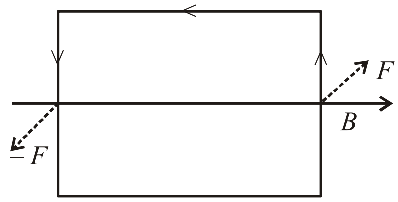
46. (a) The direction of B is along $(-\hat{k})$

$\therefore$ The magnetic force

$\vec{F} = Q(\vec{v} \times \vec{B}) = Q(v\hat{i}) \times B(-\hat{k}) = QvB\hat{j}$

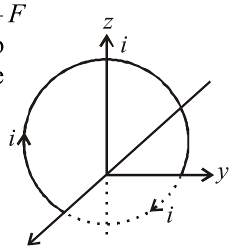
$\Rightarrow$ along OY.

47. (b) The force on the two arms parallel to the field is zero.



$\therefore$ Force on remaining arms = – F

48. (b) Magnetic fields due to the two parts at their common centre are respectively,



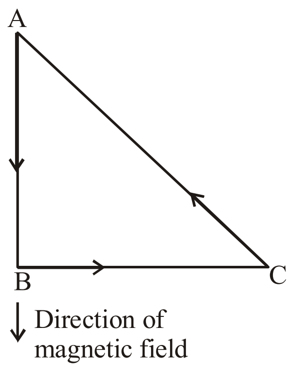
$B_y = \dfrac{\mu_0 i}{4R}$ and $B_z = \dfrac{\mu_0 i}{4R}$

Resultant field = $\sqrt{B_y^2 + B_z^2}$

$$= \sqrt{\left(\frac{\mu_0 i}{4R}\right)^2 + \left(\frac{\mu_0 i}{4R}\right)^2} = \sqrt{2}.\frac{\mu_0 i}{4R} = \frac{\mu_0 i}{2\sqrt{2}R}$$

49. (b) Let a current i be flowing in the loop ABC in the direction shown in the figure. If the length of each of the sides AB and BC be x then

$|\vec{F}| = i\,x\,B$



where B is the magnitude of the magnetic force.

The direction of $\vec{F}$ will be in the direction perpendicular to the plane of the paper and going into it.

By Pythagorus theorem,

$AC = \sqrt{x^2 + x^2} = \sqrt{2}x$

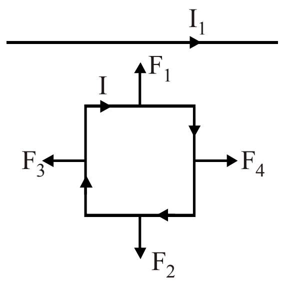
$\therefore$ Magnitude of force on AC = i $\sqrt{2}$ x B sin 45°

$= i\sqrt{2}\,x\,B \times \dfrac{1}{\sqrt{2}} = ixB = |\vec{F}|$

The direction of the force on AC is perpendicular to the plane of the paper and going out of it. Hence, force on AC = $-\vec{F}$

50. (b) $\vec{v}$ and $\vec{B}$ are in same direction so that magnetic force on electron becomes zero, only electric force acts. But force on electron due to electric field is opposite to the direction of velocity.

51. (d)



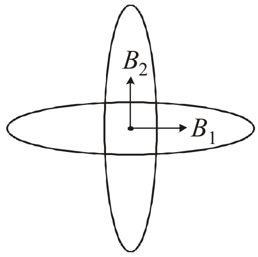
$F_1 > F_2$ as $F \propto \dfrac{1}{d}$, and F_3 and F_4 are equal and opposite.

Hence, the net attraction force will be towards the conductor.

52. (a) Magnetic field at the centre of the ring is

$\dfrac{\mu_0 qf}{2R}$

53. (a)



The magnetic field, due the coil, carrying current I Ampere

$$B_1 = \frac{\mu_0 I}{2R}$$

The magnetic field due to the coil, carrying current 2I Ampere

$$B_2 = \frac{\mu_0 (2I)}{2R}$$

The resultant B

$$B_{net} = \sqrt{B_1^2 + B_2^2 + 2B_1B_2\cos\theta},\ \theta = 90°$$

$$B_{net} = \sqrt{B_1^2 + B_2^2} = \frac{\mu_0(2I)}{2R}\sqrt{1+4} = \frac{\sqrt{5}\mu_0 I}{2R}$$

54. (c) Time period of cyclotron is

$$T = \frac{1}{\upsilon} = \frac{2\pi m}{eB};\ B = \frac{2\pi m}{e}\upsilon;\ R = \frac{m\upsilon}{eB} = \frac{p}{eB}$$

$$\Rightarrow\ P = eBR = e \times \frac{2\pi m\upsilon}{e}R = 2\pi m\upsilon R$$

$$\text{K.E.} = \frac{p^2}{2m} = \frac{(2\pi m\upsilon R)^2}{2m} = 2\pi^2 m\upsilon^2 R^2$$

55. (b) According to the principal of circular motion in a magnetic field

$$F_c = F_m \Rightarrow \frac{mv^2}{R} = qVB$$

$$\Rightarrow R = \frac{mv}{qB} = \frac{P}{qB} = \frac{\sqrt{2m.k}}{qB}$$

$$R_\alpha = \frac{\sqrt{2(4m)K'}}{2qB}$$

$$\frac{R}{R_\alpha} = \sqrt{\frac{K}{K'}}$$

but $R = R_\alpha$ (given)

Thus $K = K' = 1$ MeV

56. (b) According to work energy theorem

$W = U_{final} - U_{initial} = MB(\cos 0 - \cos 60°)$

$$W = \frac{MB}{2} = \sqrt{3}\text{J} \quad \text{...(i)}$$

$$\tau = \vec{M} \times \vec{B} = MB\sin 60° = \left(\frac{MB\sqrt{3}}{2}\right) \quad \text{...(ii)}$$

From equation (i) and (ii)

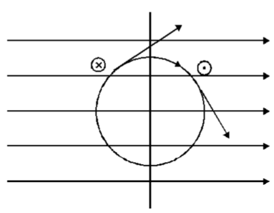
$$\tau = \frac{2\sqrt{3} \times \sqrt{3}}{2} = 3\text{J}$$

57. (c) A current loop in a magnetic field is in equilibrium in two orientations one is stable and another unstable.

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

If $\theta = 0° \Rightarrow \tau = 0$ (stable)

If $\theta = \pi \Rightarrow \tau = 0$ (unstable)



Do not experience a torque in some orientations

Hence option (c) is correct.

58. (b) Magnetic force acts perpendicular to the velocity. Hence speed remains constant.

59. (d) $B = 1.5 \times 10^{-2}$ T, $\theta = 90°$, $\sin\theta = 1$

$v = 6 \times 10^7$ m/s, $\frac{e}{m} = 1.7 \times 10^{11}$ C/kg

$$r = \frac{mv}{Be} = \frac{6 \times 10^7}{1.5 \times 10^{-2} \times 1.7 \times 10^{11}}$$

$= 2.35 \times 10^{-2}$m $= 2.35$ cm

60. (c) The force on each point on loop is radially outward and so net force = 0

61. (b) $B = \frac{\mu_0}{2\pi}.\frac{ir}{R^2} = 2 \times 10^{-7} \times 10 \times \frac{2 \times 10^{-2}}{(4 \times 10 - 2)^2}$

$= 2.5 \times 10^{-5}$ T

62. (a) Proton will represent the direction of current, so the direction of current is vertically downward. By Fleming's left hand rule, force acting on the proton in east direction.

63. (c) As $\vec{F} = q\vec{V}\vec{B}\sin\theta$

F is zero for sin 0° or sin 180° and is non-zero for angle between $\vec{V}$ and $\vec{B}$ any value other than zero and 180°.

64. (a) A current carrying coil has magnetic dipole moment. Hence, a torque $\vec{p}_m \times \vec{B}$ acts on it in magnetic field.

65. (a) The force acting on a charged particle in magnetic field is given by

$\vec{F} = q(\vec{v} \times \vec{B})$ or $F = qvB\sin\theta$,

When angle between v and B is 180°,

$F = 0$

66. (a) $B = \frac{\mu_0 i}{2\pi r}$ or $B \propto \frac{1}{r}$

When r is doubled, the magnetic field becomes half, i.e., now the magnetic field will be 0.2 T.

67. (b) $F = Bi\ell = 2 \times 1.2 \times 0.5 = 1.2$ N

68. (b) $I_g = 0.1I,\ I_s = 0.9I;\ S = I_g R_g / I_s$

$= 0.1 \times 900 / 0.9 = 100\Omega$.

69. (c) $r = \frac{mv}{qB}$ or $r \propto v$

As v is doubled, the radius also becomes double. Hence, radius $= 2 \times 2 = 4$ cm

70. (d) $r = \frac{mv}{qB} \Rightarrow r \propto \frac{v}{B}$

71. (a) $B = \frac{\mu_0 I}{2\pi r} \Rightarrow B \propto \frac{1}{r}$

As the distance is increased to three times, the magnetic induction reduces to one third. Hence,

$$B = \frac{1}{3} \times 10^{-3}\text{ tesla} = 3.33 \times 10^{-4}\text{ tesla}$$

72. (a) Reversing the direction of the current reverses the direction of the magnetic field. However, it has no effect on the magnetic-field energy density, which is proportional to the square of the magnitude of the magnetic field.

73. (c) Due to electric field, the force is $\vec{F} = q\vec{E}$ in the direction of $\vec{E}$. Since $\vec{E}$ is parallel to $\vec{B}$, the particle velocity $\vec{v}$ (acquired due to force $\vec{F}$) is parallel to $\vec{B}$. Hence $\vec{B}$ will not exert any force since $\vec{v} \times \vec{B} = 0$ and the motion of the particle is not affected by $\vec{B}$.

74. (b) Neutrons are neutral.

75. (d) $\frac{I_1}{I_2} = \frac{2\pi - \theta}{\theta} \Rightarrow I_1\theta = I_2(2\pi - \theta)$ ....(1)

$B_1 = \frac{\theta}{2\pi} \cdot \frac{\mu_0 I_1}{2R}$ and $B_2 = \frac{2\pi - \theta}{2\pi} \cdot \frac{\mu_0 I_2}{2R}$

Using (1), we get $B_1 = B_2$.

EXERCISE - 3

Exemplar Questions

1. (d) As we know that the uniqueness of helical path is determined by its pitch

$$P(\text{Pitch}) = \frac{2\pi mv\cos\theta}{Bq}$$

Where θ is angle of velocity of charge particle with x-axis

For the given pitch d correspond to charge particle, we have

$$\frac{q}{m} = \frac{2\pi v\cos\theta}{BP} = \text{constant}$$

If motion is not helical, $(\theta = 0)$

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

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

2. (a) By Biot-Savart law

$$dB = \frac{Idl\sin\theta}{r^2} = \left(\frac{I \times dl}{r}\right)$$

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

$$B \perp V$$

So, the magnetic field is ⊥ to the direction of flow of charge.

3. (a) As the direction of magnetic moment of circular loop of radius R placed in the x-y plane is along z-direction and given by $M = I(\pi r^2)$, when half of the loop with x > 0 is now bent so that it now lies in the y-z plane, the magnitudes of magnetic field moment of each semicircular loop of radius R lie in the x-y plane and the y-z plane is $M' = I(\pi r^2)/4$ and the direction of magnetic field moments are along z-directlon and x-direction respectively.

Then resultant is :

$$M_{net} = \sqrt{M'^2 + M'^2} = \sqrt{2}\,M' = \sqrt{2}\,I(\pi r^2)/4$$

So, $M_{net} < M$ or M diminishes.

Hence, the magnitude of magnetic moment is now diminishes.

4. (d) Magnetic Lorentz force :

$$F = qVB\sin\theta$$

Magnetic Lorentz force electron is projected with uniform velocity along the axis of a current carrying long solenoid $F = -qvB\sin 180° = 0(\theta = 0°)$ as magnetic field and velocity are parallel and electric field is zero (E = 0) due to this magnetic field (B) perpendicular to the direction of motion (V). So it will not affect the velocity of moving charge particle. So the electron will continue to move with uniform velocity along the axis of the solenoid

5. (a) There is crossed electric and magnetic field between dees so the charged particle accelerates by electric field between dees towards other dees.

So, the charged particle undergoes acceleration as

(i) speeds up between the dees because of the oscillating electric field.

(ii) speed remain the same inside the dees because of the magnetic field but direction undergoes change continuously.

Hence, the charge particle accelerates inside and between Dees always.

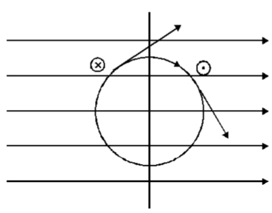
NEET/AIPMT (2013-2017) Questions

6. (c) A current loop in a magnetic field is in equilibrium in two orientations one is stable and another unstable.

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

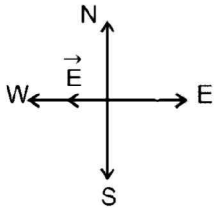
If $\theta = 0° \Rightarrow \tau = 0$ (stable)

If $\theta = \pi \Rightarrow \tau = 0$ (unstable)



Do not experience a torque in some orientations

Hence option (c) is correct.

7. (a) 

When moves with an acceleration a_0 towards west, electric field

$$E = \frac{F}{q} = \frac{ma_0}{e} \text{ (West)}$$

When moves with an acceleration $3a_0$ towards east, magnetic field

$$B = \frac{2ma_0}{ev_0} \text{ (downward)}$$

8. (c) Given:
Magnetic field $B = 2 \times 10^{-4}$ weber/m^2
Velocity of electron, $v = 10^7$ m/s
Lorentz force $F = qvB \sin\theta$
$= 1.6 \times 10^{-19} \times 10^7 \times 2 \times 10^{-4}$ ($\because \theta = 90°$)
$= 3.2 \times 10^{-16}$ N

9. (b) Here, $\vec{F}_{AB} + \vec{F}_{BCDA} = \vec{0}$

$$\Rightarrow \vec{F}_{BCDA} = -\vec{F}_{AB} = -\vec{F}$$

$$(\because F_{AB} = \vec{F})$$

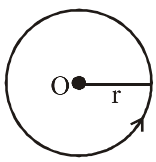
10. (d) Net magnetic field, $B = \sqrt{B_1^2 + B_2^2}$

$$= \sqrt{\left(\frac{\mu_0 I_1}{2\pi d}\right)^2 + \left(\frac{\mu_0 I_2}{2\pi d}\right)^2} \left(\because B_1 = \frac{\mu_0 I_1}{2\pi d} \text{ and } B_2 = \frac{\mu_0 I_2}{2\pi d}\right)$$

$$= \frac{\mu_0}{2\pi d}\sqrt{I_1^2 + I_2^2}$$

11. (c) Radius of circular orbit = r
No. of rotations per second = n

i.e., $T = \frac{1}{n}$



Magnetic field at its centre, B_c =?
As we know, current

$$i = \frac{e}{T} = \frac{e}{(1/n)} = en = \text{equivalent current}$$

Magnetic field at the centre of circular orbit,

$$B_c = \frac{\mu_0 i}{2r} = \frac{\mu_0 ne}{2r}$$

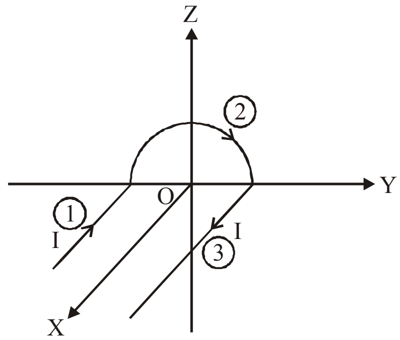
12. (b) Magnetic field due to segment '1'

$$\vec{B_1} = \frac{\mu_0 I}{4\pi R}[\sin 90° + \sin 0°](-\hat{k})$$

$$= \frac{-\mu_0 I}{4\pi R}\left(\hat{k}\right) = \vec{B}_3$$

Magnetic field due to segment 2

$$B_2 = \frac{\mu_0 I}{4R}\left(-\hat{i}\right) = \frac{-\mu_0 I}{4\pi R}\left(\pi\hat{i}\right)$$



$\therefore$ $\vec{B}$ at centre

$$\vec{B}_c = \vec{B}_1 + \vec{B}_2 + \vec{B}_3 = \frac{-\mu_0 I}{4\pi R}\left(\pi\hat{i} + 2\hat{k}\right)$$

13. (c) As we know, $F = qvB = \frac{mv^2}{R}$

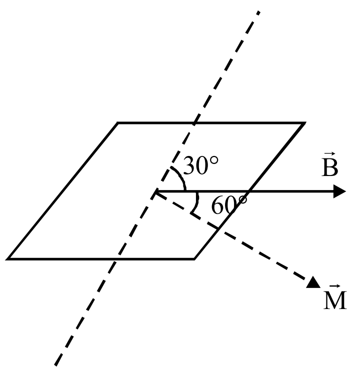
$$\therefore R = \frac{mv}{qB} = \frac{\sqrt{2m(kE)}}{qB}$$

Since R is same so, KE $\propto \frac{q^2}{m}$

Therefore KE of α particle

$$= \frac{q^2}{m} = \frac{(2)^2}{4} = 1 \text{ MeV}$$

14. (a) Here, number of turns of coil, N = 50
Current through the coil I = 2A
Area $A = l \times b = 0.12 \times 0.1 \text{m}^2$
Magnetic field $\vec{B} = 0.2$ ω/m^2



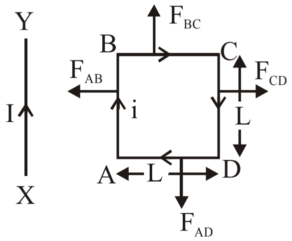
Torque required to keep the coil in stable equilibrium.

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

$$= 50 \times 2 \times 0.12 \times 0.1 \times 0.2 \times \frac{\sqrt{3}}{2}$$

$$= 12\sqrt{3} \times 10^{-2} = 0.20784 \text{ Nm}$$

15. (a) The direction of current in conductor



XY and AB is same

∴ $F_{AB} = i\ell B$ (attractive)

$$F_{AB} = i(L).\frac{\mu_0 I}{2\pi\left(\frac{L}{2}\right)}(\leftarrow) = \frac{\mu_0 iI}{\pi}(\leftarrow)$$

F_{BC} opposite to F_{AD}

$F_{BC}(\uparrow)$ and $F_{AD}(\downarrow)$

⇒ cancels each other

$F_{CD} = i\ell B$ (repulsive)

$$F_{CD} = i(L)\frac{\mu_0 I}{2\pi\left(\frac{3L}{2}\right)}(\rightarrow) = \frac{\mu_0 iI}{3\pi}(\rightarrow)$$

Therefore the net force on the loop

$F_{net} = F_{AB} + F_{BC} + F_{CD} + F_{AD}$

$$\Rightarrow F_{net} = \frac{\mu_0 iI}{\pi} - \frac{\mu_0 iI}{3\pi} = \frac{2\mu_0 iI}{3\pi}$$

16. (c) For points inside the wire i.e., $(r \le R)$

Magnetic field $B = \frac{\mu_0 Ir}{2\pi R^2}$

For points outside the wire $(r \ge R)$

Magnetic field, $B' = \frac{\mu_0 I}{2\pi R}$

$$\therefore \frac{B}{B'} = \frac{\frac{\mu_0 I(a/2)}{2\pi a^2}}{\frac{\mu_0 I}{2\pi(2a)}} = 1:1$$

17. (d) Here, number of turns n = 100; current through the solenoid i = 4A; flux linked with each turn = 4×10^{-3} Wb

∴ Total flux linked, and total

$= 1000[4 \times 10^{-3}] = 4$ Wb

$\phi_{total} = 4 \Rightarrow Li = 4$

⇒ L = 1 H

18. (d) Work done, $W = MB(\cos\theta_1 - \cos\theta_2)$

When it is rotated by angle 180° then

$W = MB(\cos 0° - \cos 180°) = MB(1 + 1)$

$W = 2MB$

$W = 2(NIA)B$

$= 2 \times 250 \times 85 \times 10^{-6}[1.25 \times 2.1 \times 10^{-4}] \times 85 \times 10^{-2}$

$= 9.1\ \mu J$

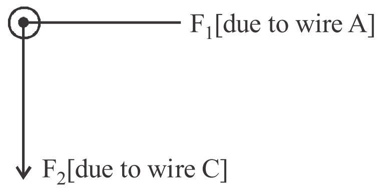
19. (c) Force per unit length between two parallel current carrying conductors,

$$F = \frac{\mu_0 i_1 i_2}{2\pi d}$$

Since same current flowing through both the wires

$i_i = i_2 = i$

so $F_1 = \frac{\mu_0 i^2}{2\pi d} = F_2$



∴ Magnitude of force per unit length on the middle wire 'B'

$$F_{net} = \sqrt{F_1^2 + F_2^2} = \frac{\mu_0 i^2}{\sqrt{2}\pi d}$$