CAREER POINT

PHYSICS

THEORY

EXAMPLES

EXERCISES

OLUTION & TIPS

AIEEE

MAGNETIC EFFECT OF CURRENT
MAGNETISM
ELECTRO MAGNETIC INDUCTION
ALTERNATING CURRENT
ELECTRO MAGNETIC WAVES

CAREER POINT

Where **Care** *leads to* **Career**

CONTENTS

MAGNETIC EFFECT OF CURRENT

ELECTRO MAGNETIC INDUCTION

ALTERNATING CURRENT

MAGNETIC EFFECT OF CURRENT

AIEEE Syllabus

1. *Biot – Savert law*
2. *Ampere's law*
3. *Solenoid & Toroid*
4. *Motion of a charged particle in a magnetic fields*
5. *Force between two parallel conductors*

Total No. of questions in **Magnetic effect of current** are:

Solved examples....................................41
Level # 1 75
Level # 2 32
Level # 3 26
Level # 4 50

Total No. of questions................224

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1. Students are advised to solve the questions of exercises (Levels # 1, 2, 3, 4) in the same sequence or as directed by the faculty members.
2. Level #3 is not for foundation course students, it will be discussed in fresher and target courses.

Index : Preparing your own list of Important/Difficult Questions

Instruction to fill

(A) Write down the Question Number you are unable to solve in **column A** below, by Pen.

(B) After discussing the Questions written in **column A** with faculties, strike off them in the manner so that you can see at the time of Revision also, to solve these questions again.

(C) Write down the Question Number you feel are important or good in the **column B**.

EXERCISE NO.	COLUMN :A Questions I am unable to solve in first attempt	COLUMN :B Good/Important questions
Level # 1		
Level # 2		
Level # 3		
Level # 4		

<u>**Advantages**</u>

1. It is advised to the students that they should prepare a question bank for the revision as it is very difficult to solve all the questions at the time of revision.

2. Using above index you can prepare and maintain the questions for your revision.

KEY CONCEPT

1. Oersted experiment (1820)

(a) Oersted found that a magnetic field is established around a current carrying conductor.

(b) A moving charge produces magnetic as well as electric field, unlike a stationary charge which only produces electric field.

(c) The direction of magnetic field was found to be changed when direction of current was reversed.

2. Magnetic field or magnetic induction or intensity of magnetic field ($\vec{B}$)

(a) The field produced by flow of current or charge in a conductor is called magnetic field.

(b) This is a vector quantity.

(c) Unit : CGS – Gauss or Maxwell / cm^2

MKS – Tesla or Weber / m^2

or N/Amp-meter

1 Tesla = 1 weber / m^2 = 10^4 Gauss

= 10^4 Maxwell / cm^2

3. Magnetic lines of force

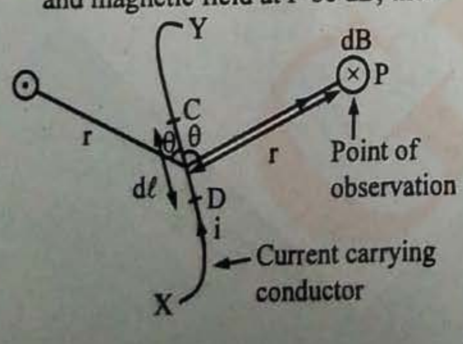
(a) These are the imaginary closed curves drawn in magnetic field, which represent the direction of the magnetic field.

(b) The tangent drawn at any point on a line of force shown the direction of magnetic field at that point.

4. Biot - Savart law

(i) Biot - Savart - A French scientist in 1820 gave a law to study the magnetic field generated by an infinitesimal element of a current carrying conductor at a point P.

(ii) Let the infinitesimal element be of length '$d\ell$' and magnetic field at P be dB, then



(d) $dB \propto \dfrac{id\ell \sin\theta}{r^2}$

$$\Rightarrow dB = \frac{\mu_0}{4\pi}\frac{id\ell\sin\theta}{r^2}$$

Where $\dfrac{\mu_0}{4\pi}$ is a constant

(iii) μ_0 is called the magnetic permeability of vacuum.

Note : ε_0 is called electric permittivity of vacuum i.e. ε_0 refers to electric field while μ_0 refers to magnetic field.

(iv) $\mu_0 = 4\pi \times 10^{-7}$ W/A-m or H/m of N/A^2

(v) Vectorially.

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{i\,d\vec{\ell}\times\vec{r}}{r^3} \text{ or } d\vec{B} = \frac{\mu_0}{4\pi}\frac{i(d\vec{\ell}\times\hat{r})}{r^2}$$

⇒ Direction of $d\vec{B}$ is perpendicular to both $d\vec{\ell}$ and $\hat{r}$. This is given by right hand screw rule.

(vi) Symbolically. The direction is shown by- ⊗ = inwards (in to the paper), ⊙ - outwards (coming out of the paper normally).

(vii) $\vec{B} = \int d\vec{B} = \dfrac{\mu_0 i}{4\pi}\int\dfrac{d\ell\sin\theta}{r^2}$

Cases :

(a) If $\sin\theta = 0$, i.e. $\theta = 0$ or point P lies in the direction of current. Then $B = B_{min} = 0$.

(b) If $\sin\theta = 1$ i.e. $\theta = 90°$ or point P lies perpendicular to the direction of current. The

$$B = B_{max} = \frac{\mu_0}{4\pi}\frac{id\ell}{r^2}$$

(c) Dimension of μ_0 $[MLT^{-2}A^{-2}]$

(d) Dimension of B $[ML^0T^{-2}A^{-1}]$

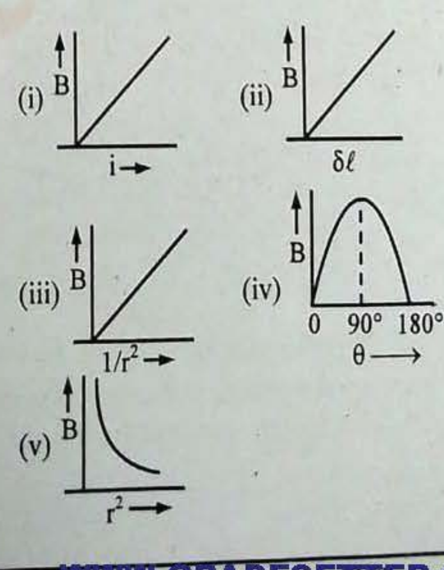
(e) The direction of magnetic field can be found by any one of the following rules :

(i) Right hand palm Rule

(ii) Right hand thumb Rule.

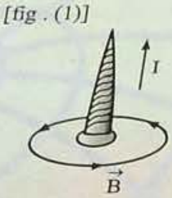
(iii) Maxwell's Right handed screw Rule

(f) Graphically,

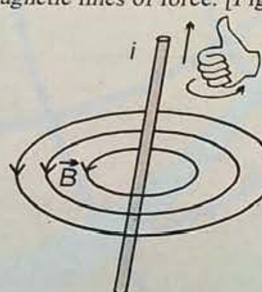


(g) **Direction of magnetic field :** The direction of magnetic field is determined with the help of the following simple laws :

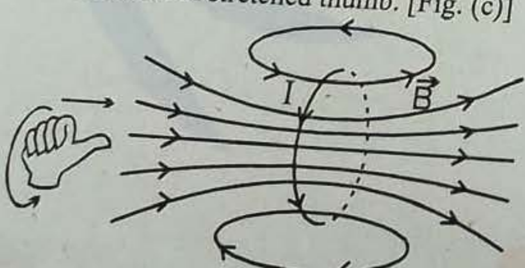
(i) **Maxwell's cork screw rule :**
According to this law if a right handed cork screw is rotated in such a way that it moves forward in the direction of current in the conductor, then the direction of the rotation of the screw will show the direction of lines of force. [fig . (1)]



(ii) **Right hand palm rule :**
According to this rule if a current carrying conductor is held in the right hand such that the thumb of the hand represents the direction of current flow, then the direction of folding fingers will represent the direction of magnetic lines of force. [Fig. (b)]



(iii) **Right hand palm rule of circular currents :**
According to this rule if the direction of current in circular conducting coil is in the direction of folding fingers of right hand, then the direction of magnetic field will be in the direction of stretched thumb. [Fig. (c)]



(h) The magnetic lines of force due to a current carrying element are in the form of concentric circles with their centres at the element.

Note : Biot ... of current de...

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{\vec{J}\times\vec{r}}{r^3}dv \quad (\because j = \frac{i}{A}\frac{id\ell}{Ad\ell} = \frac{id\ell}{dv})$$

where j = current density at any point P of the element dv = volume of element

charge and its velocity

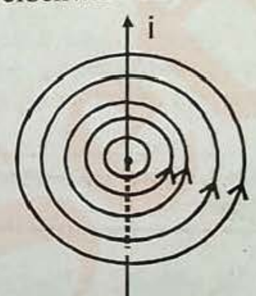
$$d\vec{B} = \frac{\mu_0}{4\pi} q\frac{(\vec{v}\times\vec{r})}{r^3} \text{ where}$$

v = velocity of charge, N = number of charge carriers per unit length of the wire e = charge on charge carrier, q = Nedℓ = Total charge in the element dℓ is i$d\ell$ = Nvedℓ = qv.

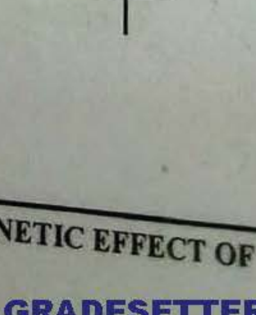
5. Representation of lines of magnetic induction

(a) The lines of magnetic induction due to a straight current carrying conductor are circular.

(b) When the direction of current is upwards i.e. away from plane of paper then lines of magnetic induction are concentric circles in counter clockwise direction.



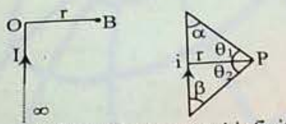
(c) When the direction of current is down wards i.e. towards the plane of paper then the lines of magnetic induction of concentric circles in clockwise direction.



Magnetic field due to a wire of finite length

$$B = \frac{\mu_0}{4\pi}\frac{i(\cos\alpha + \cos\beta)}{r} \otimes$$

$$= \frac{\mu_0}{4\pi}\frac{i(\sin\theta_1 + \sin\theta_2)}{r} \otimes$$



Magnetic field due to a semi infinite wire in the formula above,

$\alpha = \frac{\pi}{2}, \beta = 0$ or $\theta_1 = 0, \theta_2 = \frac{\pi}{2}$

$\Rightarrow B = \frac{\mu_0}{4\pi}\frac{i}{r} \otimes$

7. Magnetic field due to a wire of Infinite length

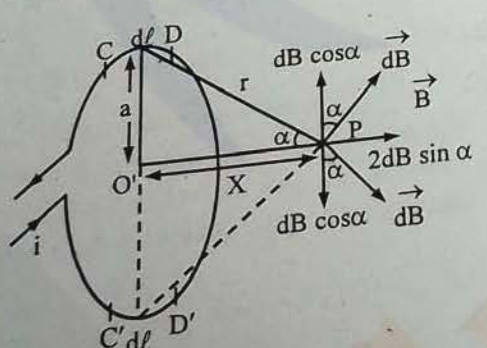
As we know $B = \frac{\mu_0}{4\pi}\frac{i(\sin\theta_1 + \sin\theta_2)}{r}$

[for a wire of finite length]

If $\theta_1 = 90^\circ$ and $\theta_2 = 90^\circ$ it will be the wire of infinite length

$\therefore \quad B_{infinite} = \frac{\mu_0}{4\pi}\frac{i(1+1)}{r} = \left(\frac{\mu_0 i}{2\pi r}\right)$

8. Magnetic field due to a circular current carrying coil



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

If number of turns in coil is 'n', then $B \propto n$

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

Where $\hat{i}$ is the unit vector along x-axis which is the axis of coil in this case.

Special case :

(a) $x = 0$ i.e. P is centre of coil

$$\vec{B} = \frac{\mu_0}{4\pi}\frac{2\pi a^2 i}{a^3} = \frac{\mu_0 i}{2r}\hat{i}$$

(b) $x = \pm a$,

$$B = \frac{\mu_0}{4\pi}\frac{(2\pi a^2)in}{(2a^2)^{3/2}} = \frac{\mu_0}{4\pi}\frac{2\pi a^2 in}{2\sqrt{2}a^3}$$

$$= \frac{\mu_0 ni}{4\sqrt{2}a} \Rightarrow \frac{B_{centre(x=0)}}{B_{(x=\pm a)}} = 2\sqrt{2}$$

(c) $x = \pm 0.766$ R

$$B = \frac{B_0}{2}, \; B_0 = B_{center}$$

Note :

This is the maximum magnetic field, due to coil.

i.e. $B_{max} = \frac{\mu_0 ni}{2r}$

9. Point of Inflection

(a) These are the points at which rate of change of magnetic field is constant

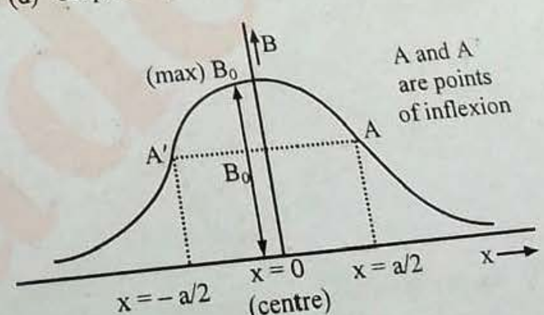
or, $\frac{dB}{dx}$ = constant

or $\frac{d^2B}{dx^2} = 0$

(b) These points are also important because the radius of curvature changes at these point.

(c) In case of circular coil carrying current, $x = \pm a/2$ are called points of inflexion, where 'a' denote the radius of coil.

(d) Graphically, (for circular coil)



10. Helmholtz Coils

(a) This is the set-up of two coaxial coils of same radius such that distance between their centers is equal to their radius. Also, same current flows in both in the same direction.

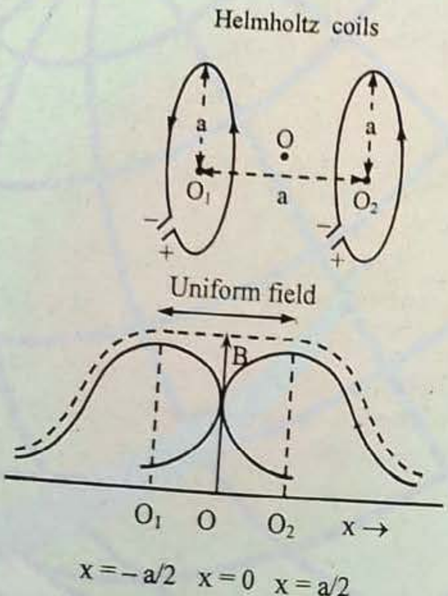
(b) These coils are used to obtain uniform magnetic induction which is obtained between the coils.

(c) Magnitude of the induction between coils is-

$$B = \frac{8\mu_0 ni}{5\sqrt{5}R} = 0.716\frac{\mu_0 ni}{R} = 1.432\,B_0,$$

where $B_0 = \frac{\mu_0 ni}{2R}$

(d)



11. Magnetic field due to an arc making an angle α at the centre

For fig (a) $B = \frac{\mu_0 i\alpha}{4\pi a}$ normal to the plane of paper downwards.

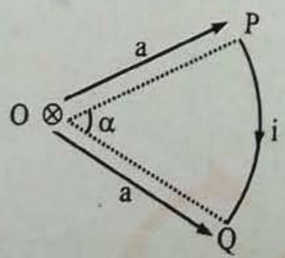
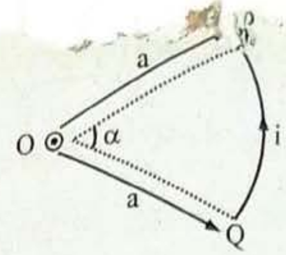
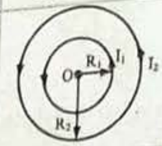
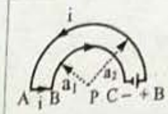
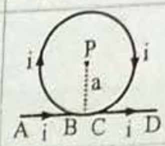
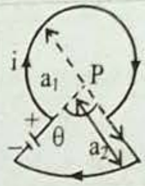
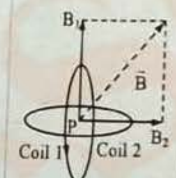


Fig fig (b) $B = \frac{\mu_0 i\alpha}{4\pi a}$, normal to the plane of paper upwards.

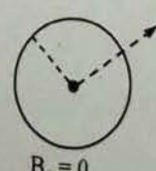


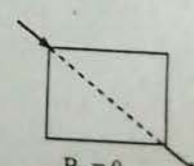
12. Magnetic field due to various geometri

	Geometry	Magnetic field
(a)		$B = \left[\frac{\mu_0 I_1}{2R_1} + \frac{\mu_0 I_2}{2R_2}\right]\odot$
(b)		$B = \frac{\mu_0}{4\pi}(\pi i)\left\{\frac{1}{a_1} - \frac{1}{a_2}\right\}$
(c)		$B = \frac{\mu_0 i}{2a}\left(1 - \frac{1}{\pi}\right)$
(d)		$B = \frac{\mu_0 i}{4\pi}\left\{\frac{2\pi - \theta}{a_1} + \frac{\theta}{a_2}\right\}$
(e)		$B_1 = \frac{\mu_0}{4\pi}\frac{2\pi i_1}{a_1}\hat{k}$ $B_2 = \frac{\mu_0}{4\pi}\frac{2\pi i_2}{a_2}\hat{j}$ $B = \sqrt{B_1^2 + B_2^2}$ $= \frac{\mu_0}{2}\sqrt{\frac{i_1^2}{a_1^2} + \frac{i_2^2}{a_2^2}}$

Note : Check out these formulae yourself

1. **Special Note :** If in a symmetrical geometr current enters from one end and exit from th other, then magnetic field at the center is zero.

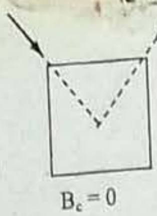
(1) 

(2) 

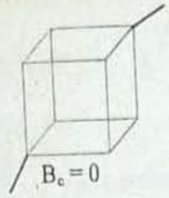
...ic field ... wire be ...

...netic field at

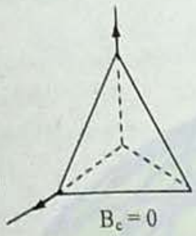
(3)



(4)



(5)

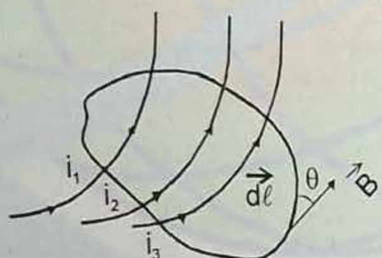


Note : in all the above cases, $B_C = 0$

13. Ampere's law

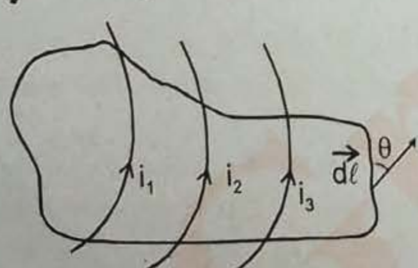
(a) Line integral of the magnetic field $\vec{B}$ around any closed curve is equal to μ_0 times the net current i threading through the area enclosed by the curve i.e.

$$\oint \vec{B}.d\vec{\ell} = \mu_0 \Sigma i = \mu_0 (i_1 + i_2 + i_3)$$



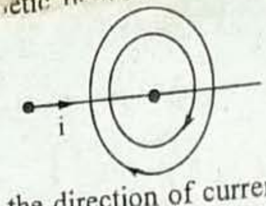
(b) The line integral of magnetic field around a closed path is equal to μ_0 times the total current enclosed by the closed path.

$$\oint \vec{B}.d\vec{\ell} = \mu_0 \Sigma i = \mu_0 \Sigma (-i_1 + i_2 - i_3)$$

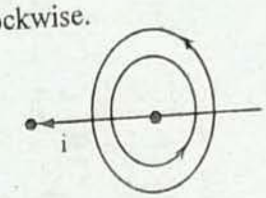


(c) The Ampere's law in magnetostatic is equivalent to Gauss's law in electrostatics.

(d) When the direction of current is away from the observer then the direction of closed path is clockwise.



(e) When the direction of current is towards the observer then the direction of closed path is anticlockwise.



13.1 Difference between Biot - Savart law and Ampere's law

Biot - Savart - Law

(a) This law is valid for asymmetrical current distributions

(b) This law is the differential form of $\vec{B}$ or $\vec{H}$

(c) This law is based only on the principle of magnetism

Ampere's Law

(a) This law is valid for symmetrical current distributions.

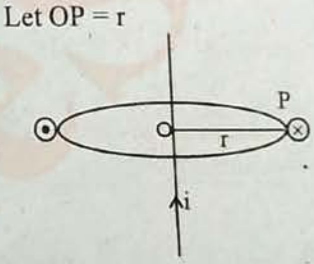
(b) Basically this law is the integral form of $\vec{B}$ or $\vec{H}$

(c) This law is based on the principle of electromagnetism.

13.2 Application of Ampere's law

(a) Magnetic field of a long straight wire :

Let OP = r



By Ampere's Law, $\oint \vec{B}.d\vec{\ell} = \mu_0 i$

Since B is constant through out the circle, Let it be B.

$$B \int d\vec{\ell} = \mu_0 i$$

$$B.\ 2\pi r = \mu_0 i \Rightarrow B = \frac{\mu_0 i}{2\pi r}$$

$$\Rightarrow B \propto \frac{1}{r} \text{ hence } B_\infty = 0$$

(b) Magnetic field due to a current carrying cylinder :

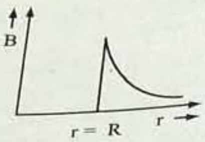
(c) Magnetic moment $M = nA = (qn)(\pi R^2)$

$$\Rightarrow M = \pi q n R^2 \text{ or } M = \frac{q\omega R^2}{2}$$

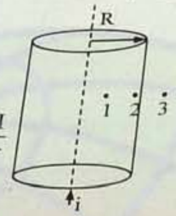
(A) Cylindrical shell :

$B_1 = 0$

$B_2 = \dfrac{\mu_0 I}{2\pi R}$



$B_3 = \dfrac{\mu_0 I}{2\pi r}$

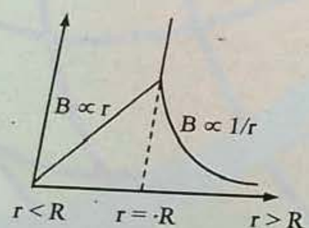


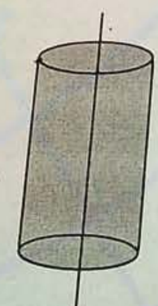
(B) Rigid Cylinder :

$B_1 = \dfrac{\mu_0 I r}{2\pi R^2}$

$B_2 = \dfrac{\mu_0 I}{2\pi R}$

$B_3 = \dfrac{\mu_0 I}{2\pi r}$

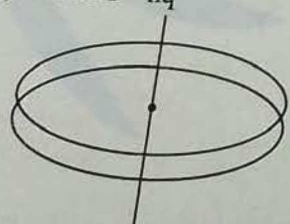




(c) Magnetic field due to a charged ring

Let the frequency of ring = n and charge on ring = q. Then

(a) current I = nq



(b) Magnetic field at the centre

$$= \frac{\mu_0 I}{2R} = \frac{\mu_0 nq}{2R} = \frac{\mu_0 \omega q}{2\pi R} \quad (\omega = 2\pi n)$$

14. Solenoid

(a) It is a long cylindrical helix made by winding closely a large number of turns of insulated copper wire over a card board or china clay.

(b) The winding or wire is uniform.

(c) A magnetic field is produced around and within the solenoid. The magnetic field within the solenoid is uniform and parallel to the axis of Solenoid.

(d) Magnetic field outside the solenoid is negligible.

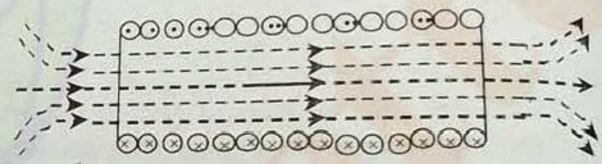
(e) For an ideal solenoid, length is very-very greater than it's radius.

(f) If i is the current flowing in solenoid then magnetic field inside the solenoid

$$B = \mu_0 n i$$

Where n = number of turns in unit length

B = 0



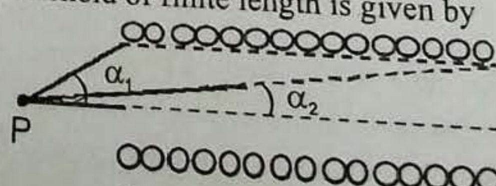
(g) If length of solenoid = L(>> r) and number of turns = N, then

$$n = \frac{N}{L} \Rightarrow B = \mu_0 \frac{N}{L} i$$

(h) Magnetic field at the center is twice the magnetic field at an end of the solenoid i.e.

$$B_{end} = \frac{\mu_0 n i}{2}$$

(i) The magnetic field at any point P due to a solenoid of finite length is given by



$$B = \frac{1}{2}\mu_0 n i (\cos\alpha_2 - \cos\alpha_1)$$

Toroid

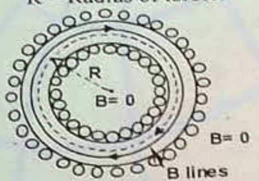
(a) This is a solenoid bent round in the form of a closed ring and carrying a current.

(b) Magnetic field within the toroid is uniform and outside it is zero.

(c) Magnetic field inside the toroid

$$B = \mu_0 ni = \mu_0 \frac{N}{2\pi R} i$$

Where N = Total number of turns.
R = Radius of toroid.



(d) If magnetic permeability of material of toroid, μ then

$B = \mu ni$

Here, $\mu = \mu_0 \mu_r$

$\Rightarrow$ $B = \mu_0 \mu_r ni$

Where μ_r = Relative permeability of medium.

16. Magnetic moment of a current carrying coil

(a) All current carrying conductors behave like a magnet.

(b) If current in a coil is flowing anticlockwise, then that plane of the coil behaves as north pole. Similarly, if current is flowing clock wise, plane behaves as south pole as shown in the figure.

(c) Magnetic moment (M) is given by the product of current and effective area of the coil i.e.

M = I A.

(d) Magnetic moment of a coil of radius r and having 'n' turns is given by

$M = n(\pi r^2) I$

(e) Unit of magnetic moment : Ampere – meter^2

Dimension : $[M^0 L^2 T^0 A^1]$

(f) ...netic field is a vector quantity. Its direction is given as south pole to north pole of the magnet.

(g) Magnetic field at the center of coil can also be written as

$$B = \frac{\mu_0 I}{2R} = \frac{\mu_0 M}{2\pi R^3}$$

Where M = Magnetic moment.

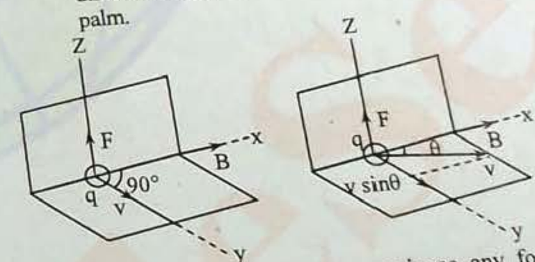
17. Motion of a charged particle in a magnetic fields

(a) If a particle carrying a positive charge q and moving with velocity $\vec{v}$ enters a magnetic field $\vec{B}$ then it experiences a force $\vec{F}$ given by

$\vec{F} = q(\vec{V} \times \vec{B})$, $|F| = qVB \sin\theta$

where θ is the angle between $\vec{v}$ and $\vec{B}$ and direction of F is perpendicular to the plane formed by $\vec{v}$ and $\vec{B}$.

(b) Direction of F is also given by right hand palm rule as shown i.e. $\vec{B}$ is along the thumb Then, $\vec{F}$ has the direction upward perpendicular to the plane of palm. In case the charge is negative, direction is downward perpendicular to plane of palm.



(c) If a charge does not experience any force even if kept in a magnetic field, then the possibilities are-

(i) q = 0 i.e. particle is uncharged

(ii) V = 0 i.e. particle is stationery

(iii) θ = 0 i.e. particle is moving in the direction of magnetic field.

(d) The maximum force experienced by a particle in a magnetic field B is given by

$$F_{max} = qVB$$

i.e. $\theta = \frac{\pi}{2}$ or particle is moving in a direction perpendicular to the magnetic field.

(e) Since [illegible] force [illegible] perpendicular to the direction of motion or displacement, No work is done by the magnetic field on a moving charge.
There is no change in kinetic energy (KE) of the particle in a magnetic field.
There is no change in speed or magnitude of velocity, although direction keeps on changing continuously.
There is no change in momentum of the particle although its direction also keeps on changing continuously.

(f) **(Imp.)** If a particle enters a magnetic field normally or perpendicular to the magnetic field, then it starts moving in a circular orbit. Some facts of this circular motion are given below.

(i) The point at which it enters the magnetic field lies on the circumference. (Most of us confuse it with the center of the orbit).

(ii) Centripetal force is provided by the magnetic force i.e.

$$\frac{mv^2}{R} = qvB \Rightarrow R = \frac{mv}{qB} = \frac{p}{qB} = \frac{\sqrt{2mE}}{qB}$$

where $P = mv$ = linear momentum.
$E = P^2/2m$ = kinetic energy

(iii) Kinetic Energy

$$E = \frac{1}{2}mv^2 = \frac{R^2q^2B^2}{2m}$$

(iv) Time - period (T) of the particle

$$T = \frac{2\pi R}{v} = \frac{2\pi m}{qB}$$

Note :
That time period does not depend upon the velocity with which the particle enters the magnetic field.

Note (Imp) :
When a charged particle enters normally to electric field then its path becomes parabolic while in magnetic field circular.

(g) If the particle enters at an angle θ then the particle will move in to a helical path, Why ?
Velocity 'V' of the particle may be resolved in to two components. One along the magnetic field and the other perpendicular to the magnetic field.
$V_1 = V\cos\theta$ and $V_2 = V\sin\theta$.
V_2 gives a circular path to the particle while V_1 gives a linear path. The resultant is a helical path.

(i) The radius of circular path $= \dfrac{mV\sin\theta}{qB}$

(ii) Time - period does not depend on velocity and hence $T = \dfrac{2\pi m}{qB}$

(iii) P = pitch = distance between two circles

$$= (mV\cos\theta)\left(\frac{2\pi m}{qB}\right)$$

18. [illegible] a magnetic field

(a) Consider an electron inside the conductor with velocity V_d ($\vec{V}_d$ is antiparallel to the direction of current). Force on this electron

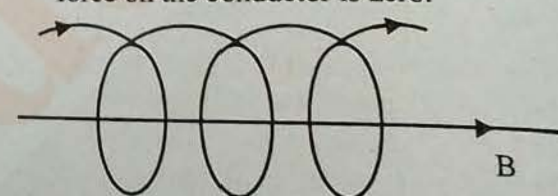
$= e(\vec{V}_d \times \vec{B})$ magnitude of force
$= eV_dB\sin(\pi - \theta) = eV_dB\sin\theta.$

If length of the conductor is 'ℓ' number of electron per unit volume = 'n'
Area of cross section = 'A'
Total number of electrons = $n(A\ell)$
Total force = $n(A\ell)\, eV_dB\sin\theta$
$= (neV_dA)\,\ell B\sin\theta$
$= i\ell B\sin\theta$ ($i = neV_dA$)

(b) Vectorically,
$\vec{F} = i(\vec{\ell} \times \vec{B})$

Where direction of $\vec{\ell}$ is taken along the direction of flow of current. Direction of force $\vec{F}$ is perpendicular to the plane formed by $\vec{\ell}$ and $\vec{B}$. This is given by Fleming's left hand rule. i.e. If the forefinger, the middle finger and thumb of the left hand are stretched mutually at right angles to one another such that direction of magnetic field $\vec{B}$ → along the fore finger, direction of current i → along middle finger. The force $\vec{F}$ will be in the direction of thumb.

(c) $|F| = i\ell B\sin\theta$
i.e. if θ = 0, 180° or wire is kept parallel or antiparallel to the direction of magnetic then force on the conductor is zero.



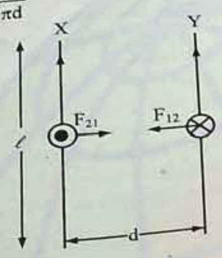
(d) F will be maximum when θ = 90°

(e) $F_{max} = i\ell B$.

...rce be... ic field ... wire ... conduc...s

(a) When i_1, i_2 are parallel. B at a distance 'd' due to i_1

$$B_1 = \frac{\mu_0 i_1}{2\pi d}$$



F_{21} = Force on 2 due to 1

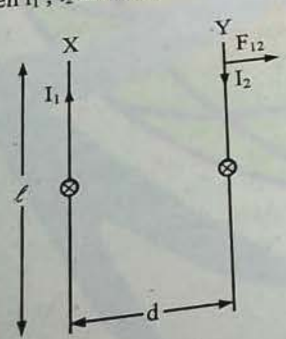
$$= i_2 \ell B_1 , \; F_{21} = \frac{\mu_0 i_1 i_2 \ell}{2\pi d}$$

$$\text{force per unit length} = \frac{F_{21}}{\ell} = \frac{\mu_0 i_1 i_2}{2\pi d}$$

By a careful observation, we can say that $|F_{12}| = |F_{21}|$ and $F_{12} = -F_{21}$

So, the wires experience equal and opposite forces or there is an attractive force acting between wires.

(b) When i_1, i_2 are antiparallel



in this case

$$\vec{F}_{12} = -\vec{F}_{21}$$

$$\frac{|F_{12}|}{\ell} = \frac{|F_{21}|}{\ell} = \frac{\mu i_1 i_2}{2\pi d}$$

This force will be repulsive ⇒ parallel currents attract while antiparallel currents repel each other.

20. Current carrying coil in an external magnetic field

(a) As stated earlier, net force on a closed coil in a magnetic field is zero always but there acts a torque on it.

(b) torque on the coil is given by-

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

where $\vec{M}$ = Magnetic moment

$\vec{B}$ = Magnetic field

$\vec{M} = ni\vec{A}$

(c) $\vec{\tau} = Ni(\vec{A} \times \vec{B}) = BiNA \sin\theta$.

Here $\vec{A}$ is an area vector whose direction is taken perpendicular to the plane.

The angle θ is angle between $\vec{A}$ and $\vec{B}$ (Note that it is not the angle between plane $\vec{A}$ and $\vec{B}$)

(d) Work done to rotate a coil from an angle θ_1 to θ_2

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

$$= \int_{\theta_1}^{\theta_2} BiNA \sin\theta$$

$$= BiNA\,(\cos\theta_1 - \cos\theta_2)$$

Definition of B :

Force on a moving charge is given by

$$|F| = qvB \sin\theta$$

if θ = 90°, q = 1 coulomb, v = 1 m/s,

then $|F| = B$

i.e. B is the force experienced by a unit charge moving with a unit velocity unit of

B = N/coulomb - m/sec

$$= \frac{\text{N-sec}}{\text{coulomb-m}}$$

= N/amp-m.

POINTS TO REMEMBER

1. Lorentz Force zero If :
   (a) The particle is uncharged
   (i.e. $q = 0 \because F = Bq\,v\sin\theta = 0$)
   (b) The charged particle is at rest (i.e. $v = 0$)
   (c) The charged particle is moving parallel or antiparallel to the field. (i.e. $\theta = 0$ or 180°)

2. Lorentz force $\vec{F}$ is maximum when the charged particle moves at right angles to the field.

3. Lorentz force $\vec{F}$ is perpendicular to the velocity vector $\vec{v}$ (i.e. $\vec{F} \perp \vec{v}$)

4. Lorentz force $\vec{F}$ is perpendicular to the field direction (i.e. $\vec{F} \perp \vec{B}$)

5. Since, the Lorentz force is perpendicular to the direction of motion as well as to the field, it does not perform any work on the charged particle, therefore the magnitude of velocity of charged particle does not change, only the direction of motion changes.

6. The kinetic energy of the charged particle moving at right-angle to the field remains constant.

7. Total Lorentz force acting on a charged particle moving in electric and magnetic field is

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

8. Lorentz force is important in detecting the presence of electric and magnetic fields.

9. Lorentz force between two moving charges is

$$F_m = \frac{\mu_0 q_1 q_2 v_1 v_2}{4\pi . r^2}$$

10. Biot-Savart law for moving charge is

$$B = \frac{\mu_0 q v \sin\theta}{4\pi . r^2}$$

11. If the charges move with speeds comparable to the speed of light, magnetic and electric forces between them would become comparable.

12. Where a → radius of toroid and n → number of turns per unit length.

13. The magnetic dipole moment is a vector quantity, directed along the axis of the dipole. The direction of the magnetic moment of a current-loop is determined by the right-hand rule.

14. **Right - hand rule** : "If we stretch our right hand palm and curl the fingers around the loop in the direction of the current, then the thumb will point in the direction of the magnetic moment".

15. A magnetic dipole is in stable equilibrium if $\vec{M}$ and $\vec{B}$ are parallel to each other, while the magnetic dipole is in unstable equilibrium if $\vec{M}$ and $\vec{B}$ are antiparallel to each other.

16. **Repulsion is the surest test for distinguishing between a magnet and a piece of iron** : The pole of a magnet attracts a piece of iron as well as the unlike pole of an other magnet. Therefore, when a testing magnet is brought near the two ends of a specimen, it will show attraction whether it is an iron rod or a magnet. Thus, repulsion is the surest test to distinguish between a magnet and a piece of iron.

17. Most of the magnetic moment is produced due to the electron spin : the contribution of the orbital revolution is very small.

18. It has been observed experimentally that the positions of the earth's magnetic poles change gradually.

SOLVED EXAMPLE

Ex.1 For the magnetic field, due to a small element of a current carrying conductor at a point to be maximum, the angle between the element and the line joining the element to point P must be-

(A) 0° (B) 90° (C) 180° (D) 45°

Sol. (B)

$$dB = \frac{\mu_0 i d\ell \sin\theta}{4\pi r^2}$$

When $\theta = 90°$, then dB will be maximum.

Ex.2 A current of 30 A is flowing in a vertical straight wire. If the horizontal component of earth's magnetic field is 2×10^{-5} Tesla then the position of null point will be-

(A) 0.9 m (B) 0.3 mm
(C) 0.3 cm (D) 0.3 m

Sol. (D)

$B = \frac{\mu_0}{2\pi r}$ At null point the value of B must be equal to the horizontal component of earth's magnetic field (H) but it direction must opposite to that of H.

$$\therefore H = \frac{\mu_0 i}{2\pi r}$$

$$\Rightarrow 2 \times 10^{-5} = \frac{4\pi \times 10^{-7} \times 30}{2 \times \pi \times r}$$

$$\Rightarrow r = 0.3 \text{ m.}$$

Ex.3 A length L of wire carrying current I is bent into a circle of one turn. The field at the center of the coil is B_1. A similar wire of length L carrying current I is bent into a square of one turn. The field at its center is B_2. Then-

(A) $B_1 > B_2$
(B) $B_1 < B_2$
(C) $B_1 = B_2$
(D) Nothing can be predicted.

Sol. (B)

For circular coil $B_1 = \frac{\mu_0 I}{2r}$

Circumference of the coil $= 2\pi r = L$,

Thus $B_1 = \pi\mu_0 I/L = 3.14\, \mu_0 I/L$

For square loop $B_2 = 2\sqrt{2}\, \mu_0 I/L$

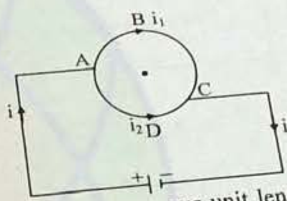
$= 3.60\, \mu_0 I/L$

Thus $B_1 < B_2$.

Ex.4 If a uniform wire loop is connected to the terminals of a battery then the magnetic induction at the centre will be-

(A) zero
(B) infinite
(C) directly proportional to applied e.m.f.
(D) inversely proportional to the radius of the loop.

Sol. (A)



Let the resistance per unit length of the wire be ℓ. The segments ABC and ADC of the wire are in parallel.

$\therefore i_1 \ell_1 \rho = i_2 \ell_2 \rho$ or $i_1 \ell_1 = i_2 \ell_2$.

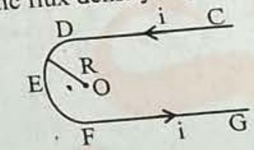
Resultant magnetic induction at the centre

$B = B_1 - B_2$

$B = \frac{\mu_0}{2\pi r^2}(i_1 \ell_1 - i_2 \ell_2)$ $(\because i_1 \ell_1 = i_2 \ell_2)$ $\therefore$

$B = 0$.

Ex.5 An electric current is flowing in a very long pin as shown in the figure. The value of magnetic flux density at point O will be-



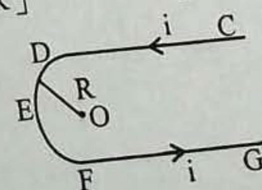
(A) $\frac{\mu_0 i}{4\pi R}[\pi + 2]$ (B) $\frac{\mu_0 i}{4\pi R}[\pi + 1]$

(C) $\frac{\mu_0 i}{4\pi R}[\pi - 2]$ (D) $\frac{\mu_0 i}{4\pi R}[\pi - 1]]$

Sol. (A)

$B_0 = B_{CD} + B_{DEF} + B_{FG}$, $B_{CD} = B_{FG}$

$= 2\left[\frac{\mu_0 i}{4\pi R}\right]$, $B_{DEF} = \frac{1}{2}\left[\frac{\mu_0 i}{2R}\right]$

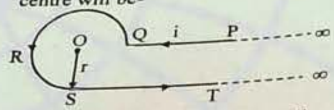


$$\therefore B_0 = \frac{\mu_0 i}{4\pi R} + \frac{\mu_0 i}{4R} + \frac{\mu_0 i}{4\pi R}$$

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

$= \frac{\mu_0 i}{4\pi R}[2+\pi].$

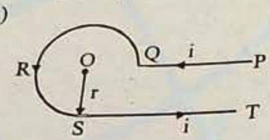
Ex.6 A current i is flowing in a conductor shaped as shown in the figure. The radius of curved part is r and length of straight portions is very large. The value of magnetic field at the centre will be-



(A) $\frac{\mu_0 i}{4\pi r}\left[\frac{3\pi}{2}+1\right]$ (B) $\frac{\mu_0 i}{4\pi r}\left[\frac{3\pi}{2}-1\right]$

(C) $\frac{\mu_0 i}{4\pi r}\left[\frac{\pi}{2}+1\right]$ (D) $\frac{\mu_0 i}{4\pi r}\left[\frac{\pi}{2}-1\right]$

Sol. (A)



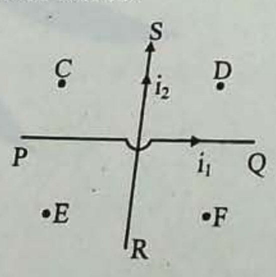
$$B_0 = B_{PQ} + B_{QRS} + B_{ST},\ B_{ST} = \frac{1}{2}\left[\frac{\mu_0 i}{2\pi r}\right]$$

$$B_{PQ} = 0,\ B_{QRS} = \frac{\mu_0 i}{4\pi r^2} \times \frac{3}{4} \times 2\pi r.$$

$$B_0 = \frac{\mu_0 i}{4\pi r} + \frac{3}{4}\frac{\mu_0 i}{2r} = \frac{\mu_0 i}{4r}\left[\frac{3}{2}+\frac{1}{\pi}\right]$$

$$= \frac{\mu_0 i}{4\pi r}\left[\frac{3\pi}{2}+1\right]$$

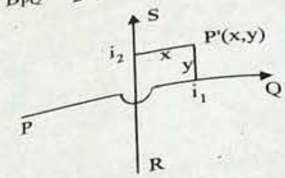
Ex.7 Electric currents i_1 and i_2 are flowing in two mutually perpendicular conductors as shown in the figure. The equation of zero magnetic field points will be-



(A) $y = x$ (B) $y = \frac{i_1}{i_2}x$

(C) $y = \frac{xi_2}{i_1}$ (D) $y = x\, i_1\, i_2$

$B_{PQ} = \frac{\mu_0 i_1}{2\pi y},\ B_{RS} = \frac{\mu_0 i_2}{2\pi x}$



$\therefore$ for magnetic field $B_{PQ} = B_{RS}$

$$\frac{\mu_0 i_1}{2\pi y} = \frac{\mu_0 i_2}{2\pi x}$$

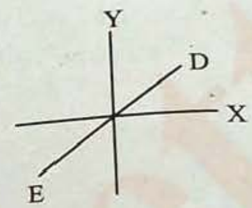
$$\Rightarrow \frac{i_1}{y} = \frac{i_2}{x} \text{ or } y = \frac{i_1}{i_2}x$$

Ex.8 In the above problem the locus of zero magnetic field points will be-

(A) a circle (B) an ellipse

(C) a straight line (D) a parabola

Sol. (C)



$y = \frac{i_1}{i_2}x,\ y = mx$ where $m = \frac{i_1}{i_2}$

This is the equation of a straight line passing through origin.

Ex.9 In the above problems the points of zero magnetic field are-

(A) C (B) C and D

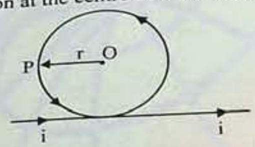
(C) D and E (D) E

Sol. (C)

The points D and E are situated on the line

$$y = \frac{i_1}{i_2}x.$$

...ic field ... wire b... long conductor as shown in the figure. The magnitude and direction of magnetic induction at the centre of circular part will be-

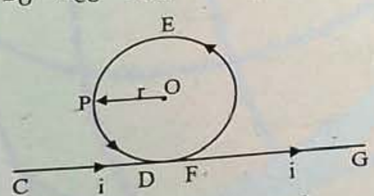


(A) $\frac{\mu_0 i}{2r}\left(1+\frac{1}{\pi}\right)$, ⊙ (B) 0

(C) $\frac{\mu_0 i}{2r}\left(1-\frac{1}{\pi}\right)$, ⊗ (D) $\frac{\mu_0 i}{2r}$, ⊙

Sol. (A)

$B_O = B_{CG} + B_{DEF}$



$$B_0 = \frac{\mu_0 i}{2\pi r} + \frac{\mu_0 i}{2r} = \frac{\mu_0 i}{2r}\left(1+\frac{1}{\pi}\right) \odot$$

Its direction will be normal to plane of paper upwards.

Ex.11 A circular arc of wire of radius of curvature r subtends an angle of $\frac{\pi}{4}$ radian at its centre. If i current is flowing in it then the magnetic induction at its centre will be-

(A) $\frac{\mu_0 i}{8r}$ (B) $\frac{\mu_0 i}{4r}$ (C) $\frac{\mu_0 i}{16r}$ (D) 0

Sol. (C)

The magnetic induction produced due to a current carrying arc at its centre of curvatureis-

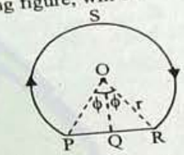
$$B = \frac{\mu_0 i\alpha}{4\pi r} \quad \text{......... (A)}$$

$$\therefore \alpha = \frac{\pi}{4} \quad \text{...........(B)}$$

From eqs. (A) and (B)

$$B = \frac{\mu_0 i\pi}{4\times4\times\pi r} = \frac{\mu_0 i}{16r}$$

Ex.12 The magnetic field at ... induction at point O due to curve portion and straight portion in the following figure, will be-



(A) $\frac{\mu_0 i}{2\pi r}[\pi - \phi + \tan\phi]$

(B) $\frac{\mu_0 i}{2\pi r}$

(C) 0

(D) $\frac{\mu_0 i}{2\pi r}[\pi - \phi + \tan\phi]$

Sol. (A)

$B_0 = B_{PSR} + B_{PQR}$ .... (A)

$$B_{PSR} = \frac{\mu_0 i}{2\pi}\left[\frac{2\pi - 2\phi}{r}\right] = \frac{\mu_0 i}{2\pi r}[\pi - \phi] \quad \text{.... (B)}$$

$$B_{PQR} = \frac{\mu_0 i}{4\pi}\cdot\frac{2\sin\theta}{OQ}$$

From the figure $OQ = r\cos\theta$

$$B_{PQR} = \frac{\mu_0 i}{4\pi}\,\frac{2\tan\phi}{r} \quad \text{.... (C)}$$

From eqs. (A) and (C)

$$B = \frac{\mu_0 i}{2\pi r}[\pi - \phi] + \frac{\mu_0 i}{2\pi r}\tan\phi$$

$$= \frac{\mu_0 i}{2\pi r}[\pi - \phi + \tan\phi]$$

Ex.13 A 6.28m long wire is turned into a coil of diameter 0.2m and a current of 1 amp. is passed in it. The magnetic induction at its centre will be-

(A) 6.28×10^{-5} Tesla

(B) 0

(C) 6.28 Tesla

(D) 6.28×10^{-3} Tesla

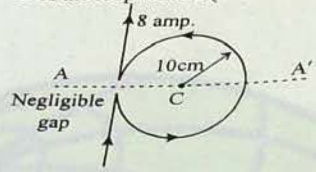
Sol. (A)

$\ell = (2\pi r)n$ or $n = \frac{\ell}{2\pi r}$

$$B = \frac{\mu_0 n i}{2r} = \frac{\mu_0 i\ell}{4\pi r^2} \quad \text{or}$$

$$B = \frac{4\pi\times10^{-7}\times6.28\times1}{2\times2\times\pi\times(0.10)2} = 6.28 \times 10^{-5} \text{ Tesla.}$$

Ex.14 A long, straight wires is turned into a loop radius 10 cm (as shown in figure). If a current of 8 ampere is passed through the loop, then the value of the magnetic field B at the centre C of the loop will be (Wb/m^2)-



(A) 3.424×10^{-5}, vertically upward
(B) 3.424×10^{-5}, vertically downward
(C) 4.24×10^{-5}, vertically upward
(D) 4.24×10^{-5}, vertically downward

Sol. (A)

The field at C due to the straight part of the conductor is

$B_1 = \frac{\mu_0}{4\pi}.\frac{2i}{r}$ or

$B_1 = \frac{10^{-7} \times 2 \times 8}{0.1} = 16 \times 10^{-6}$ wb/m^2,

acting vertically downwards.

The field at C due to the circular part of the conductor is

$B_2 = \frac{\mu_0 \, n \, i}{2r} = \frac{4\pi \times 10^{-7} \times 1 \times 8}{2 \times 0.1}$

$= 16\pi \times 10^{-6}$ wb/m^2, vertically upwards.

Thus, the net field at C is

$B = (16\pi \times 10^{-6} - 16 \times 10^{-6})$ wb/m^2 vertically upwards.

or

$B = 3.424 \times 10^{-5}$ wb/m^2 vertically upwards.

Ex.15 The magnetic dipole moment of a coil is 5.4×10^{-6} joule/tesla and it is lined up with an external magnetic field whose strength is 0.80 T. Then the work done in rotating the coil end for end ($\theta = 180°$) is-

(A) 4.32 μJ
(B) 2.16 μJ
(C) 8.6 μJ
(D) None of the above.

Sol. (C)

The potential energy of a magnetic dipole m placed in an external magnetic dipole is $U = -\vec{M}.\vec{B}$. Therefore, work done in rotating the dipole is-

$W = \Delta U = 2mB = 2 \times 5.4 \times 10^{-6} \times 0.8$

$= 8.6 \times 10^{-6}$ Joule.

Ex.... amp ... radius 5 cm and 100 turns. The magnetic moment of the coil is-

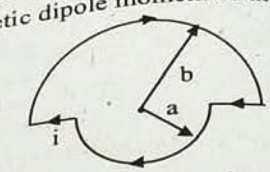
(A) 3.14 Am^2 (B) 3.14 cm^2
(C) 314 Am^2 (D) 0.0314 Am^2

Sol. (A)

$M = NiA = 100 \times 4 \times \pi r^2$

$= 400 \times 3.14 \times 25 \times 10^{-4} = 3.14$ Am^2.

Ex.17 You are given a closed circuit with radii a and b as shown in fig carrying current i. The magnetic dipole moment of the circuit is-



(A) $\pi (a^2 + b^2)\, i$ (B) $\frac{1}{2}\pi (a^2 + b^2)\, i$

(C) $\pi (a^2 - b^2)\, i$ (D) $\frac{1}{2}\pi (a^2 - b^2)\, i$

Sol. (B)

$M = \text{current} \times \text{area} = i\,(\frac{1}{2}\pi a^2 + \pi b^2)$

$= \frac{1}{2} i\pi (a^2 + b^2)$.

Ex.18 A proton, a deutron and an α-particle are accelerated through same potential difference and then they enter a normal uniform magnetic field. The ratio of their kinetic energies will be-

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

Sol. (B)

$E_{kp} = eV$, $\therefore E_k = qV$,

$\therefore E_k \propto q$, $\therefore V = \text{constant}$

$E_{kp} : E_{kd} : E_{ka} :: 1 : 1 : 2$.

Ex.19 A proton of energy 8eV is moving in circular path in a uniform magnetic field. The energy of an α-particle moving in the same magnetic field and along the same path will be-

(A) 4eV (B) 2eV (C) 8eV (D) 6eV

$$E_K = \frac{q^2r^2B^2}{2m}$$

$$E_{K(P)} \propto \frac{q_p}{m_p}$$

$$\therefore \frac{E_{KP}}{E_{K\alpha}} = \frac{q_{p^2}}{m_p} \times \frac{m_\alpha}{q_\alpha^2}$$

$$E_{K\alpha} = \frac{m_p \times q_\alpha^2 \times E_{KP}}{q_P^2 \times m_\alpha} = 8eV$$

$$= \frac{4}{1} \times \frac{1}{4} = E_{K_*} = 8eV.$$

Ex.20 An electron is revolving in a circular path of radius 2×10^{-10} m with a speed of 3×10^6 m/s. The magnetic field at the centre of circular path will be-

(A) 1.2 Tesla (B) 2.4 Tesla
(C) 0 (D) 3.6 Tesla.

Sol. (A)

$$B = \frac{KVe}{r^2} = \frac{10^{-7}\times3\times10^6\times10^{-19}}{(2\times10^{-10})^2}$$

$= 1.2$ Tesla.

Ex.21 An α particle is moving in a magnetic field of $(3\hat{i} + 2\hat{j})$ tesla with a velocity of $5\times10^5\,\hat{i}$ m/s. The magnetic force acting on the particle will be-

(A) 3.2×10^{-13} dyne
(B) 3.2×10^{13} N
(C) 0
(D) 3.2×10^{-13} N

Sol. (D)

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

$F = 2e\,[5 \times 10^5\,\hat{i} \times (3\hat{i} + 2\hat{j})]$

$F = 2e\,[10 \times 10^5\,\hat{k}]$

$F = 2 \times 10^6 \times 1.6 \times 10^{-19}\,\hat{k}$

$F = 3.2 \times 10^{-13}\,\hat{k}$

Ex.22 If an α-particle moving with velocity 'v' enters a perpendicular to a magnetic field then the magnetic force acting on it will be-

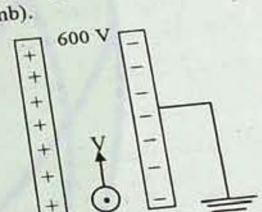
(A) 1eVB (B) 2eVB
(C) 0 (D) 4eVB

Sol. (B)

$F = q(\vec{V} \times \vec{B}) = 2eVB \sin 90^\circ$

or $F = 2eVB$

Ex.23 A potential difference of 600 volt is applied across the plates of a parallel plate condenser placed in a magnetic field. The separation between the plates is 3 mm. An electron projected vertically upward parallel to the plates with a velocity of 2×10^6 m/s moves undeflected between the plates. The magnitude and direction of the magnetic field in the region between the condenser plates will be (in Wb/m^2)
(Given charge of electron = -1.6×10^{-19} coulomb).



(A) 0.1, vertically downward
(B) 0.2 vertically downward
(C) 0.3 vertically upward
(D) 0.4 vertically downward.

Sol. (A)
The electron will pass undeviated if the electric force and magnetic force are equal and opposite. Thus
E.e. = Bev or B = E/v but
E = V/d

Therefore, $B = \frac{V}{v.d.} = \frac{600}{3\times10^{-3}\times2\times10^6}$

$\therefore B = 0.1\ wb/m^2$.

The direction of field is perpendicular to the plane of paper vertically downward.

Ex.24 A beam of protons enters a uniform magnetic field of 0.3 tesla with a velocity of 4×10^5 m/s at an angle of 60° to the field. The radius of the helical path taken by the beam and the pitch of the helix (which is the distance travelled by a proton parallel to the magnetic field during one period of rotation) will be respectively-
(Mass of the proton = 1.7×10^{-27} kg.)

(A) 1.226×10^{-2} m, 4.45×10^{-3} m
(B) 1.226×10^{-2} m, 4.45×10^{-2} m
(C) 1.226×10^{-3} m, 4.45×10^{-3} m
(D) 1.226×10^{-4} m, 4.45×10^{-4} m

Sol. (B)

The component of velocity of the beam of protons, parallel to the field direction

$= v\cos\theta = 4 \times 10^5 \times \cos 60°$

$= 2 \times 10^5$ m/sec.

and the component of velocity of the proton beam at right angle to the direction of field

$= v\sin\theta = 4 \times 10^5 \times \sin 60°$

$= 2\sqrt{3} \times 10^5$ m/sec.

therefore, the radius of circular path

$= (mv\sin\theta / Be)$

or $r = \dfrac{1.7\times10^{-27}\times2\sqrt{3}\times10^5}{0.3\times1.6\times10^{-19}}$

$= 12.26 \times 10^{-3}$ metre

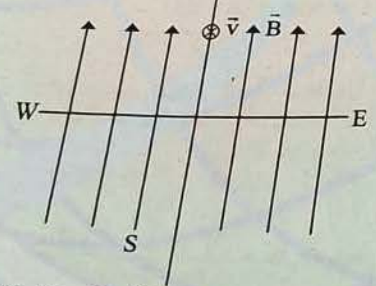
or $r = 1.226 \times 10^{-2}$ metre.

Pitch of the Helix $= v\cos\theta \times (2\pi m/Be)$

$\therefore$ Pitch $= \dfrac{2\times10^5\times2\times3.14\times1.7\times10^{-27}}{0.3\times1.6\times10^{-19}}$

$= 44.5 \times 10^{-3}$ m $= 4.45 \times 10^{-2}$ m.

Ex.25 A 5 MeV proton moves vertically downward through a magnetic field of induction 1.5 weber/m^2 pointing horizontally from south to north. The force acting on the proton, mass of proton $= 1.6 \times 10^{-27}$ kg. will be-



(A) 7.44×10^{-12} N (B) 3.1×10^{-12} N

(C) 5×10^{-12} N (D) 6×10^{-12} N

Sol. (A)

Kinetic energy of the proton $= \dfrac{1}{2}mv^2$

$= 5$ MeV

or $v^2 = \dfrac{2\times5\text{MeV}}{m} = \dfrac{2\times5\times10^6\times1.6\times10^{-19}}{1.6\times10^{-27}}$

$= 3.1 \times 10^7$ m/s.

The magnetic field is horizontal from south to north and velocity $\vec{v}$ is vertically downward, i.e. angle between $\vec{v}$ and is $\vec{B}$ is 90° therefore force on proton

$F = qvB\sin 90 = qvB = evB$

$= 1.6\times10^{-19}\times3.1 \times 10^7 \times 1.5 = 7.44 \times 10^{-12}$ N.

∴ According ... had ... direction of force is horizontal from w... east.

Ex.26 A proton is to circulate the earth along equator with a speed of 1.0×10^7 m/s. The minimum magnetic field which should be created at the equator for this purpose (The mass of proton $= 1.7 \times 10^{-27}$ kg, radius of earth $= 6.37 \times 10^6$ m.) will be (in Wb/m^2)-

(A) 1.6×10^{-19} (B) 1.67×10^{-8}

(C) 1.0×10^{-7} (D) 2×10^{-7}

Sol. (B)

In order to make a proton circulate the earth along the equator, the minimum magnetic field induction should be horizontal perpendicular to equator.

The magnetic force provides the necessary centripetal force.

i.e. $qvB = \dfrac{mv^2}{r}$

or $B = \dfrac{mv}{qr}$

Here $m = 1.7 \times 10^{-27}$ kg,

$v = 1.0 \times 10^7$ m/s

$q = e^- = 1.6 \times 10^{-19}$ coulomb,

$r = 6.37 \times 10^6$ m

$B = \dfrac{1.7\times10^{-27}\times1.0\times10^7}{1.6\times10^{-19}\times6.37\times10^6}$

$= 1.67 \times 10^{-8}$ weber/m^2.

Ex.27 An α-particle is describing a circle of radius 0.45 m in a field of magnetic induction 1.2 weber/m^2. The potential difference required to accelerate the particle, so as to give this much energy to it (The mass of α particle is 6.8×10^{-27} kg and its charge is 3.2×10^{-19} coulomb.) will be-

(A) 6×10^6 V (B) 2.3×10^{-12} V

(C) 7×10^6 V (D) 3.2×10^{-12} V

Sol. (C)

We have $F = qvB = \dfrac{mv^2}{r}$ or $v = \dfrac{qBr}{m}$

$= \dfrac{3.2\times10^{-19}\times1.2\times0.45}{6.8\times10^{-27}} = 2.6 \times 10^7$ m/s.

The frequency of rotation $n = \dfrac{v}{2\pi r}$

$= \dfrac{2.6\times10^7}{2\times3.14\times0.45} = 9.2 \times 10^6$ sec^{-1}.

Kinetic energy of α-particle,

$E_K = \frac{1}{2} \times ... \times 10^{-..} \times (2.6 \times 10^7)^2$

$= 2.3 \times 10^{-12}$ joule.

$= \frac{2.3 \times 10^{-12}}{1.6 \times 10^{-19}}$ eVolt $= 14 \times 10^6$ eV

$= 14$ MeVolt.

If V is accelerating potential of α-particle, then Kinetic energy = qV

14×10^6 eVolt = 2eV (since charge on α-particle = 2e)

$\therefore \quad V = \frac{14 \times 10^6}{2} = 7 \times 10^6$ Volt.

Ex.28 (a) A stream of positive charges, each of charge q is projected into a region where are electric and magnetic fields at right angles to each other. The initial direction of stream is perpendicular to both the fields. The fields have magnitudes E and B respectively. Show that only those particles which have speed v = E/B will be transmitted undeflected.

(b) An electron beam passes through a magnetic field of 2×10^{-3} weber/m² and an electric field of 1.0×10^4 volt/m both acting simultaneously. The path of electrons remaining undeviated, calculate the speed of the electrons. If the electric field is removed, what will be the radius of the electron path ?

Sol. (a) The total force acting on the particle of charge q moving with velocity v in simultaneous electric and magnetic fields of strength $\vec{E}$ and $\vec{B}$ respectively is

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

The particle passes undeviated, if net force is zero of if electric and magnetic forces are equal and opposite i.e. $q\vec{E} = -q(\vec{v} \times \vec{B})$.

As $\vec{q}$, $\vec{E}$ and $\vec{B}$ are mutually perpendicular, we have

$[-q(\vec{V} \times \vec{B})] = q\,v\,B$

$\therefore qE = q\,v\,B$ or $v = \frac{E}{B}$

(b) If electron beam passes undeflected in simultaneous electric and magnetic fields $\vec{E}$ and $\vec{B}$ velocity of beam $\vec{v}$ much be mutually perpendicular and the required speed v is given by-

$$v = \frac{E}{B} = \frac{1 \times 10^4}{2 \times 10^{-3}} = 5 \times 10^6 \text{ m/s.}$$

If electric field is removed, the electron traverses a circular path of radius r given by

$\frac{mv^2}{r} = evB$ or $r = \frac{mv}{eB}$.

Here $m = 9.1 \times 10^{-31}$ kg, $v = 5 \times 10^6$ m/s. $e = 1.6 \times 10^{-19}$ coul. and $B = 2 \times 10^{-3}$ weber/m²

$\therefore r = \frac{(9.1 \times 10^{-31})(5 \times 10^6)}{(1.6 \times 10^{-19})(2 \times 10^{-3})}$

$= 1.43 \times 10^{-2}$ m = 1.43 cm.

Ex.29 A straight horizontal stretch of copper wire carries a current i = 30 A. The linear mass density of the wire is 45 g/m. What is the magnitude of the magnetic field needed to "float" the wire, that is to be balance its weight?

(A) 147 G
(B) 441 G
(C) 14.7 G
(D) 0 G

Sol (A)

For L length or wire, to balance,

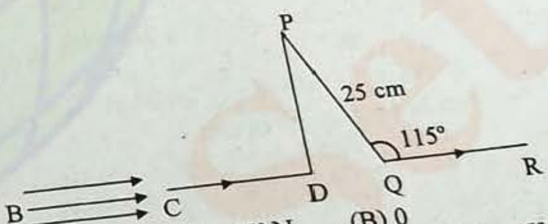
$F_{magnetic} = mg \Rightarrow ILB = mg,$

Therefore B = mg/IL = (m/L) (g/I)

$= \frac{45 \times 10^{-3} \times 9.8}{30} = 1.47 \times 10^{-2}$ tesla.

= 147 Gauss.

Ex.30 The magnetic force on segment PQ, due to a current of 5 amp. flowing in it, if it is placed in a magnetic field of 0.25 Tesla, will be-



(A) 0.3125 sin 65° N
(B) 0
(C) 31.25 sin 65° N
(D) 3.125 sin 65° N

Sol. (A)

$F = Bi\ell\sin\theta = 0.25 \times 5 \times 0.25 \sin 65°$

$= 0.3125 \sin 65°$

Ex.31 A 1m long conducting wire is lying at right angles to the magnetic field. A force of 1 kg. wt is acting on it in a magnetic field of 0.98 Tesla. The current flowing in it will be-

(A) 100 A (B) 10 A (C) 1 A (D) 0

Sol. (B) $\because$ Weight = $IB\ell$

1kg wt = 9.8 N

$\therefore$ $9.8 = Bi\ell$

$i = 10A$

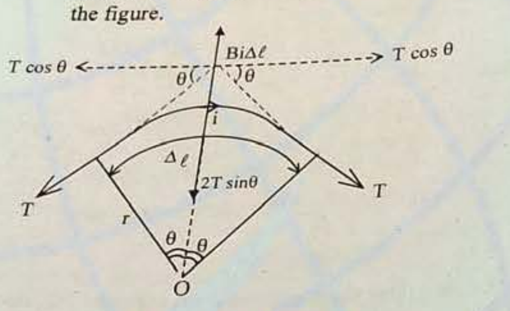
Ex.32 A loop of flexible conducting wire of length 0.5 m lies in a magnetic field of 1.0 tesla perpendicular to the plane of the loop. The tension developed in the wire if the current is of 1.57 amp. will be-

(A) 0.15 N (B) 0.25 N

(C) 0.125 N (D) 0.138 N

Sol. (C)

When the current is passed in the loop, magnetic force 'Bil' acts at every point of the loop. This force is at right angles to the current but lies in the plane of the loop. So the loop stretches out into a circle. Figure shows a part of this circle. The tension in the loop is T. Then according to the geometry of the figure.



$2T \sin\theta = Bi\,\Delta \ell$

where $\Delta \ell$ is the length of the element.

Since, θ is small, $\sin\theta \cong \theta$, therefore

$2\theta . T = Bi\,\Delta \ell$

or $(\Delta \ell / r) . T = Bi\,\Delta \ell$ or $T = B.\,ri$

but $2\pi r = \ell$ length of wire

$\therefore T = \frac{Bi.\ell}{2\pi} = \frac{1 \times 157 \times 0.5}{3 \times 3.14} = 0.125$ N.

Ex.33 A coil in the shape of equilateral triangle of side 0.2 m is suspended from the vertex such that it is hanging in a vertical plane between the pole-pieces of a permanent magnet producing a horizontal magnetic field of 5×10^{-2} Tesla. The couple acting on the coil when a current of 0.1 amp. is passed through it and the magnetic field is parallel to its plane will be-

(A) 3.28×10^{-7} N.m.

(B) 5.28×10^{-7} N.m.

(C) 8.66×10^{-7} N.m.

(D) 1.23×10^{-7} N.m.

Sol. (C)

The torque on a closed flat current loop of any shape, placed in a magnetic field of flux density B is given by $\tau = Bi\,NA \sin\theta$, According to the question the area of this ... is

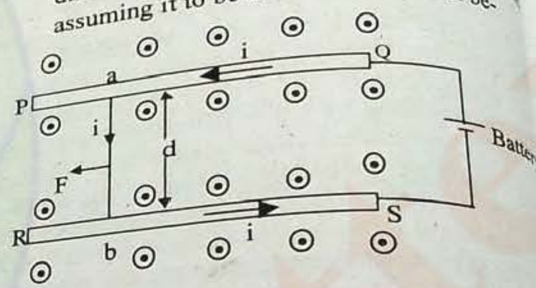
A = (1/2) base × height

$A = (1/2)(0.2 \times 0.1732) = 1.732 \times 10^{-4}$ m²

$\tau = 1 \times 0.1 \times 1.732 \times 10^{-4} \times (5 \times 10^{-2}) \times 1$

$\tau = 8.66 \times 10^{-7}$ N-m.

Ex.34 A metal wire of mass m slides without friction on two rails spaced at a distance d apart. The track lies in a vertical uniform field of induction B, a constant current i flows along one rail, across the wire and back down the other rail. The velocity (speed and direction) of the wire as a function of time, assuming it to be at rest initially will be-



(A) $\frac{Bid}{m} t$ (B) 0

(C) Bidmt (D) none

Sol. (A)

Let ab be a metal wire sliding on rails PQ and RS, in a region of uniform field of induction $\vec{B}$ pointing vertically upward. The magnetic field $\vec{B}$ is normal to length of wire ab (θ = 90°); therefore magnetic force on the wire of length (ab = d) is given by F = Bid sin 90° = Bid

By Fleming left hand rule, this force is directed away from battery as shown in fig. If m is mass of wire and a the acceleration, then

$F = ma = Bid$. or $a = \frac{Bid}{m}$ = const.

∴ From relation v = u + at, we have velocity after time t

(initial velocity u = 0)

$v = 0 + \frac{Bid}{m} t$ or $v = \frac{Bid}{m} t$

An ele... each of ... 5 cm a... on eithe...

(A) 3.6

(B) 3.6

(C) 3.

(D) 3.

Sol. (A) F

or F

Ex.36 Th... ma... w... fl...

Sol. (

Ex.37

An ele... ...ic field... wire be... ...pere is flowing in each of two parallel conducting wires places 5 cm apart. The force acting per unit length on either of the wires will be-

(A) 3.6×10^{-3} N/m

(B) 3.6×10^{-3} Dyne/cm

(C) 3.6×10^{-5} N/m

(D) 3.6×10^{-2} N/m.

Sol. (A) $F/\ell = \frac{\mu_0 i_1 i_2}{2\pi r}$

or $F/\ell = \frac{4\pi \times 10^{-7} \times 30 \times 30}{2 \times \pi \times 5 \times 10^{-2}} = 3.6 \times 10^{-3}$ N/m.

Ex.36 The distance between the wires of electric mains is 12 cm. These wires experience 4 mg wt. per unit length. The value of current flowing in each wire will be-

(A) 4.85 A (B) 0

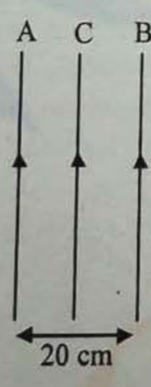
(C) 4.85×10^{-2} A (D) 4.85×10^{-4} A

Sol. (A)

$\frac{F}{\ell} = \frac{\mu_0 i^2}{2\pi d} \Rightarrow 9.8 \times 4 \times 10^{-6}$

$= \sqrt{\frac{4 \times 10^{-6} \times 9.8 \times 0.12}{2 \times 10^{-7}}} = 4.85$ A

Ex.37 In the adjoining figure, two very long, parallel wires A and B carry currents of 10 ampere and 20 ampere respectively, and are at a distance 20 cm apart. If a third wire C (length 15 cm) having a current of 10 ampere is placed between them, then how much force will act on C ? The direction of current in all the three wires is same.



(A) 3×10^{-5} N (left)

(B) 3×10^{-5} N (right)

(C) 6×10^{-5} N (left)

(D) 6×10^{-5} N (right)

...netic field at

Sol. (B)

The wires A and C carry current in same direction, therefore they attract each other. The force on C due to A towards the wire A and is given by.

$F_{CA} = \frac{\mu_0}{4\pi} \cdot \frac{2 i_A i_C}{r_{AC}} \cdot$

$\ell = \frac{10^{-7} \times 2 \times 10 \times 10}{0.10} 0.15$

or $F_{CA} = 3 \times 10^{-5}$ Nt (towards left).

Similarly, the wires B and C attract each other as they also carry the currents in same direction. the force on C due to current in B is towards right hand side. Therefore, the force on C due to B is given by

$F_{BC} = \frac{\mu_0}{4\pi} \cdot \frac{2 i_B i_C}{r_{BC}} \cdot \ell$

$= \frac{10^{-7} \times 2 \times 20 \times 10 \times 0.15}{0.10}$

or $F_{BC} = 6 \times 10^{-5}$ Nt (towards right)

Therefore, the net force on C is

$F = (6 \times 10^{-5} - 3 \times 10^{-5})$

$= 3 \times 10^{-5}$ N (towards right).

Ex.38 A 5 cm × 12 cm coil with number of turns 600 is placed in a magnetic field of strength 0.10 Tesla. The maximum magnetic torque acting on it when a current of 10^{-5} A is through it will be-

(A) 3.6×10^{-6} N-m

(B) 3.6×10^{-6} dyne-cm

(C) 3.6×10^{6} N-m

(D) 3.6×10^{6} dyne-m

Sol. (A)

$\tau_{max} = MB = niAB = ni(\ell \times b) B$

$\tau_{max} = 600 \times 10^{-5} \times 5 \times 10^{-2} \times 12 \times 10^{-2} \times 12 \times 10^{-2} \times 0.10 = 3.6 \times 10^{-6}$ N-m.

Ex.39 The length of a solenoid is 0.4 m and the number turns in it is 500. A current of 3 amp, is flowing in it. In a small coil of radius 0.01 m and number of turns 10, a current of 0.4 amp. is flowing. The torque necessary tp keep the axis of this coil perpendicular to the axis of solenoid will be-

(A) 5.92×10^{-6} N-m

(B) 5.92×10^{-4} N-m

(C) 5.92×10^{-6} Dyne-cm

(D) 5.92×10^{-4} Dyne-cm

Sol. (A)

$$B_{solenoid} = \mu_0 n_s i_s = \frac{\mu_0 N_S i_S}{L_S},$$

$$\tau = B_S\, iNA = \frac{\mu_0 N_S i_S\, iN\pi r^2}{L_S}$$

$$\tau = \frac{4\pi \times 10^{-7} \times 500 \times 3 \times 0.4 \times 10 \times \pi \times (0.01)^2}{0.4}$$

$$= 5.92 \times 10^{-6} \text{ N-m}.$$

Ex.40 A conducting wire of length ℓ is turned in the form of a circular coil and a current i is passed through it. For torque due to magnetic field produced at its centre, to be maximum, the number of turns in the coil will be-

(A) 1 (B) 2
(C) any value (D) more than

Sol. (A)

$\tau_{max} = MB$ or $\tau_{max} = ni\pi a^2 B$

Let number of turns in length ℓ is n

$\ell = n\,(2\pi a)$ or $a = \dfrac{1}{2\pi n}$

$$\tau_{max} = \frac{n\, i\, \pi B \ell^2}{4\pi^2 n^2} = \frac{\ell^2 iB}{4\pi^2 n_{min}}\ \frac{\ell^2 iB}{4\pi n_{min}}$$

$$\therefore \tau_{max} \propto \frac{1}{n_{min}},\ n_{min} = 1$$

Ex.41 A mono-energetic (18 KeV) electron beam initially in the horizontal direction is subjected to a horizontal magnetic field of 0.40 G normal to the initial direction. Estimate the up or down deflection of the beam over a distance of 30 cm ($m_e = 9.11 \times 10^{-31}$ kg and $e = 1.60 \times 10^{-19}$ C).

Sol. Speed acquired by the electron, when it is accelerated under a potential difference V, is given by

$$\frac{1}{2} mv^2 = eV \quad \text{or} \quad v = \sqrt{\frac{2eV}{m}} \quad ....(1)$$

When the magnetic field B is applied normal to the direction of motion of electron, it will deflect the electron beam along a circular path of radius R, so that

$$\frac{mv^2}{R} = Bev \quad \text{or} \quad R = \frac{mv}{Be} \quad ....(2)$$

Where m is the mass and v is the velocity of electron. Putting the value of v from equation (1) into (2)

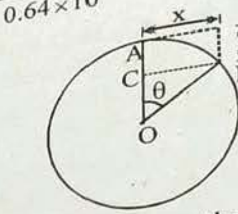
$$R = \frac{m}{Be}\sqrt{\frac{2eV}{m}} = \frac{\sqrt{2meV}}{Be}$$

Given that $m = 9.11 \times 10^{-31}$ kg, $V = 18$ kV $= 18 \times 10^3$ V, $e = 1.60 \times 10^{-19}$ C and $B = 0.40$ Gauss $= 0.4 \times 10^{-4}$ T

Hence,

$$R = \frac{\sqrt{2 \times 9.11 \times 10^{-31} \times 1.60 \times 10^{-19} \times 18 \times 10^3}}{0.40 \times 10^{-4} \times 1.60 \times 10^{-19}}$$

$$= \frac{\sqrt{57.47 \times 10^{-46}}}{0.64 \times 10^{-23}} \text{ m} = \mathbf{11.30\ m}$$



It is clear from figure that during the circular motion of electron beam, in moving distance x horizontally either from A to B to A, the beam moves a distance y either down or up respectively.

Suppose the distance AB = 30 cm = 0.3 m and the angle subtended by AB at the centre be θ. Then from right angled ΔOBC

$$\sin\theta = \frac{x}{R}$$

or $\theta = \dfrac{AB}{AO} = \dfrac{0.3\text{ m}}{11.3\text{ m}} = 0.0265$

or $\theta = 1.5°$

$\therefore \cos\theta = \cos 1.5° = 0.9997$

Again from the figure,

y = down deflection

$= AO - CO = R - R\cos\theta$

$= R\,(1 - \cos\theta)$

$= 11.3\,(1 - 0.9997) = 11.3 \times 0.0003$

$= 0.004$ m

= 4 mm

LEVEL-1

Questions based on: Biot-Savart law

Q.1 Along the direction of current carrying wire, the value of magnetic field is ?
(A) zero
(B) infinity
(C) depends on the length of the wire
(D) uncertain

Q.2 A linear small part of a circuit PQ is situated on X-axis from $x = -a/2$ to $x = +a/2$ and a current I is flowing through it. The magnetic field produced due to part PQ at point $x = +a$ will be-
(A) proportional to a
(B) proportional to a^2
(C) proportional to (1/a)
(D) equal to zero

Q.3 Value of Tesla in gauss is -
(A) 10^3 (B) 10^6 (C) 10^4 (D) 10^2

Q.4 The vector form of Biot-Savart law is -
(A) $d\bar{B} = \frac{kid\bar{\ell}\times\bar{r}}{r^2}$ (B) $d\bar{B} = \frac{kid\bar{\ell}\times\bar{r}}{r^3}$
(C) $d\bar{B} = \frac{kid\bar{\ell}\times\bar{r}}{r}$ (D) $d\bar{B} = \frac{kid\bar{\ell}\times\hat{r}}{r}$

Q.5 To obtain maximum intensity of magnetic field at a point the angle between position vector of point and small elements of length of the conductor is -
(A) 0 (B) $\pi/4$ (C) $\pi/2$ (D) π

Q.6 The value of intensity of magnetic field at a point due to a current carrying conductor is obtained from-
(A) Gauss's law (B) Faraday's law
(C) Coulomb's law (D) Biot Savart's law

Q.7 The value of intensity of magnetic field at a point due to a current carrying conductor depends -
(A) Only on the value of current
(B) Only on a small part of length of conductor
(C) On angle between the line joining the given point to the mid point of small length and the distance between the small length of the point
(D) On all and the above

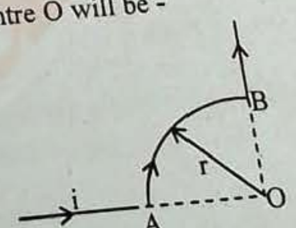
Questions based on: Magnetic field due to different current carrying system

Q.8 The radii of two concentric coils having same number of turns are 10 cm and 20 cm respectively. Equal currents are passed through them first in same direction and then in opposite direction. In these two conditions the ratio of resultant magnetic fields at the centre will be -
(A) 3 : 1 (B) 2 : 1
(C) 3 : 2 (D) 1 : 1

Q.9 Which of the following statements is false for Helmholtz coils ?
(A) In Helmholtz coils, both coils are coaxial
(B) The planes of Helmholtz coils are perpendicular to each other
(C) The distance between the coils is equal to the radius of the coil
(D) The magnetic field produced in the middle region between the coils is uniform

Q.10 The diameter of a circular coil is 0.16m and it has 100 turns. If a current of 5 ampere is passed through the coil, then the intensity of magnetic field at a point on the axis at a distance 0.06 m from its centre will be -
(A) 2×10^{-3} Wb/m^2 (B) 2×10^{-2} Wb/m^2
(C) 2×10^{3} Wb/m^2 (D) 2×10^{2} Wb/m^2

Q.11 The section AB in the following figure is a quarter of a circle of radius r. The magnitude and direction of magnetic induction at the centre O will be -



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