AEP STUDY CIRCLE

SINCE 2001...
IIT-NEET-CBSE
ACCENTS EDUCATIONAL PROMOTERS

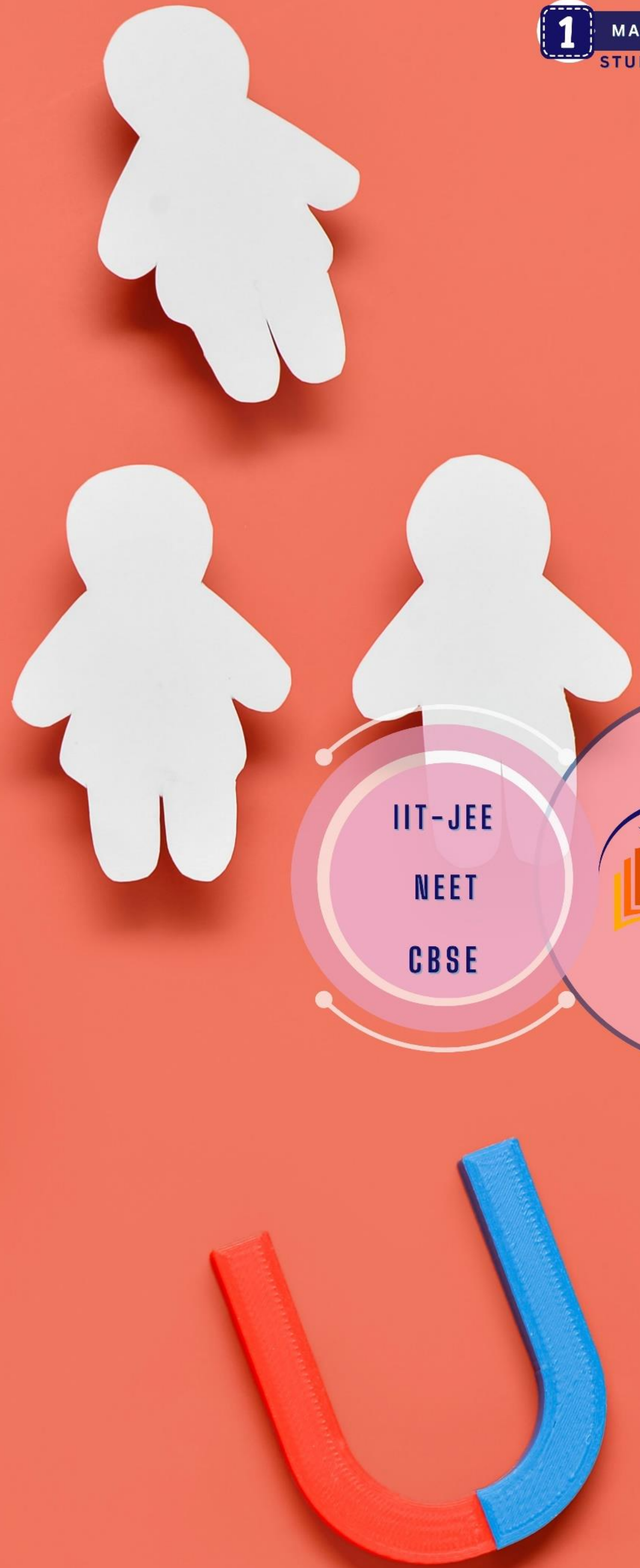
25 YEARS OF LEGACY

XII NEET

1 MAGNETISM
STUDY MODULE

ONLINE-OFFLINE LEARNING ACADEMY

YOUR GATEWAY TO EXCELLENCE IN IIT-JEE, NEET AND CBSE EXAMS



IIT-JEE
NEET
CBSE

MAGNETIC EFFECT OF CURRENT

PHYSICS
NEET

CONTACT US:
+91-9939586130
+91-9955930311

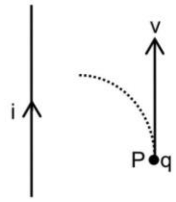
www.aepstudycircle.com

aepstudycircle@gmail.com

2ND FLOOR, SATKOUDI COMPLEX, THANA CHOWK, RAMGARH - 829122-JH

1. Introduction

The branch of physics which deals with the magnetism due to electric current or moving charge (i.e. electric current is equivalent to the charges or electrons in motion) is called electromagnetism. If a charge q is placed at rest at a point P near a metallic wire carrying a current i, it experiences almost no force. We conclude that there is no appreciable electric field at the point P. This is expected because in any volume of wire (which contains several thousand atoms) there are equal amounts of positive and negative charges. The wire is electrically neutral and does not produce an electric field.



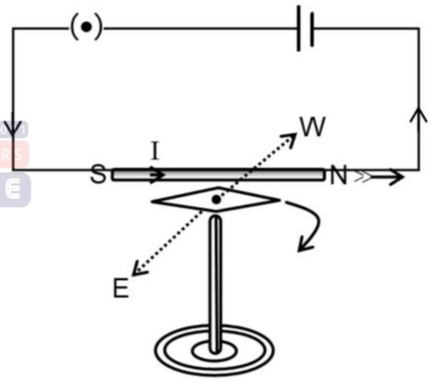
However, if the charge q is projected from the point P in the direction of the current (figure), it is deflected towards the wire (q is assumed positive). There must be a field at P which exerts a force on the charge when it is projected, but not when it is kept at rest. This field is different from the electric field which always exerts a force on a charged particle whether it is at rest or in motion. This new field is called *magnetic field* and is denoted by the symbol $\vec{B}$. The force exerted by a magnetic field is called magnetic force.

2. Oersted Experiment

- **Observations**

  The relation between electricity and magnetism was discovered by Oersted in 1820. Oersted showed that the electric current through the conducting wire deflects the magnetic needle held below the wire.
- When the direction of current in conductor is reversed then deflection of magnetic needle is also reversed
- On increasing the current in conductor or bringing the needle closer to the conductor the deflection of magnetic needle increases.

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



Inferences
- The magnetic field encircle the current carrying wire.
- The magnetic field lie in the plane perpendicular to the wire.
- If the direction of current is reversed, direction of magnetic field is also reversed.
- The strength of the magnetic field is directly dependent on magnitude of current
- The strength of the field at any point is inversely dependent to the distance of the point from the wire.

2.1 Electric field & Magnetic field

Let us discuss some basic facts about electric field & magnetic field.

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

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

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

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

2.2 Unit of Magnetic Field

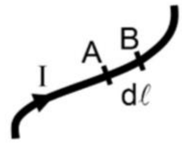
SI $\rightarrow$ Tesla (T)

CGS $\rightarrow$ Gauss (G)

$1T = 10^4 G$

3. Biot-Savart Law

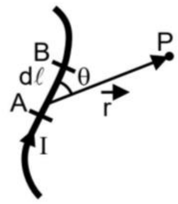
3.1 Current element



A very small element AB of length $d\ell$ of a thin conductor carrying current I is called current element.

Current element is a vector quantity whose magnitude is equal to the product of current and length of small element having the direction of the flow of current. current element AB = $Id\vec{\ell}$

3.2 Mathematical Representation of Biot-Savart Law



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

$dB \propto Id\ell$, $dB \propto \sin\theta$ and $dB \propto \frac{1}{r^2}$

$$dB \propto \frac{Id\ell\sin\theta}{r^2}, \qquad dB = k\frac{Id\ell\sin\theta}{r^2}$$

In C.G.S & vacuum : $k = 1 \Rightarrow dB = \frac{Id\ell\sin\theta}{r^2}$ Gauss

In S.I. & vacuum : $k = \frac{\mu_0}{4\pi} \Rightarrow dB = \frac{\mu_0}{4\pi}\frac{Id\ell\sin\theta}{r^2}$ Tesla

where μ_0 = Absolute permeability of air or vacuum.

$\mu_0 = 4\pi \times 10^{-7}\ \frac{Wb}{A-m}$ or $\frac{Henry}{m}$ or $\frac{N}{A^2}$

or $\frac{T-m}{A}$

3.3 Vector form of Biot-Savart law

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\ell\sin\theta}{r^2}\hat{n}$$

$\hat{n}$ = unit vector perpendicular to the plane of ($Id\vec{\ell}$) and ($\vec{r}$)

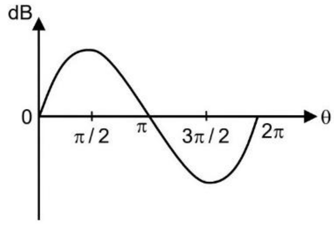
$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{\ell}\times\vec{r}}{r^3} \quad [\because Id\vec{\ell}\times\vec{r} = (Id\ell)(r)\sin\theta]$$

3.4 Features of Biot Savart's Law

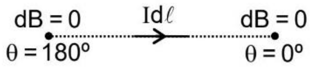
i This law is analogous to Coulomb's law.

ii This law is valid for infinitesimal conductors only.

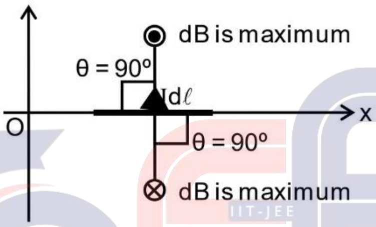
iii $dB \propto \sin\theta$



- If $\theta = 0°$ or $180°$, then $dB = 0$, Which means that there is no magnetic field on the axis of current element.



- If $\theta = 90°$, then dB is maximum, which means perpendicular to the current element magnetic field is maximum.



- Direction of $d\vec{B}$ is perpendicular to the plane containing $\vec{r}$ and $Id\vec{\ell}$.

iv. For a moving charged particle if v << c (speed of light)

$$Id\vec{\ell} = q\vec{v}\left(\text{as } I = \frac{q}{t}\right)$$

so expression of $d\vec{B}$ can be modified as

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{(q\vec{v}\times\vec{r})}{r^3} \quad \therefore \quad dB = \frac{\mu_0}{4\pi}\frac{qv\sin\theta}{r^2}$$

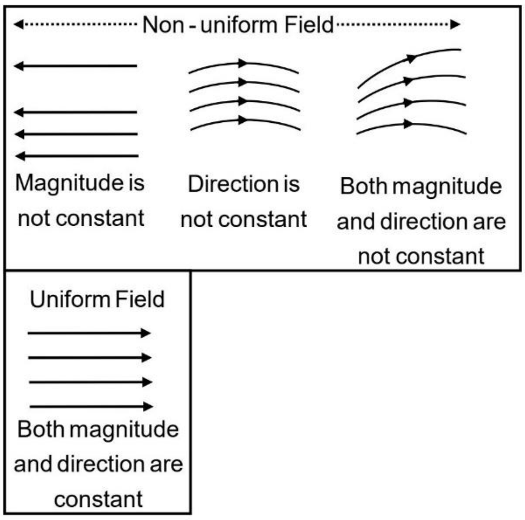
4. Magnetic Field Lines (Michael Faraday's Conception)

In order to visualise a magnetic field graphically, Michael faraday introduced the concept of field lines.

Field lines of magnetic field are imaginary lines which represents direction of magnetic field continuously.

Characteristics

- Magnetic field lines are closed curves.
- Tangent drawn at any point on field line represents direction of the field at that point.
- Field lines never intersects each other.
- At any place, crowded lines represent stronger field while distant lines represent weaker field.
- In any region, if field lines are **equidistant and straight** then the field is uniform otherwise not.
- Magnetic field lines emanate from or enters in the surface of a magnetic material at any angle.
- Magnetic field lines exist inside every magnetised material.
- Magnetic field lines can be mapped by using iron dust or using compass needle.



5. Right Hand Thumb Rule and Maxwell's Screw Rule

Right Hand Thumb Rule

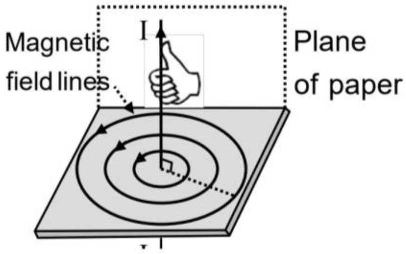
This rule gives the pattern of magnetic field lines due to current carrying wire.

(i) Straight current

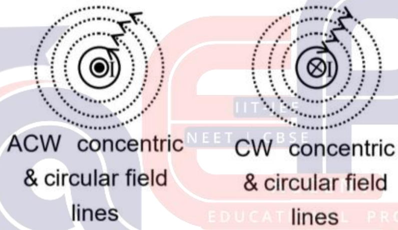
Thumb → In the direction of current

Curling fingers → Gives field line pattern

Case I : wire in the plane of the paper



Case II : Wire is ⊥ to the plane of the paper.

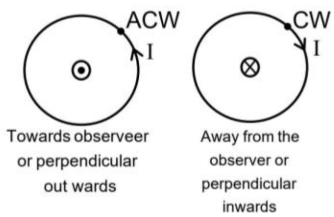


(ii) Circular current

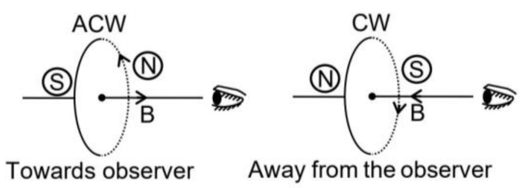
Curling fingers → In the direction of current.

Thumb → Gives field line pattern

Case I : wire in the plane of the paper



Case II : Wire is ⊥ to the plane of the paper



Key Points

- When current is straight, field is circular
- When current is circular, field is straight (along axis near the centre)
- When wire is in the plane of paper, the field is perpendicular to the plane of the paper.
- When wire is perpendicular to the plane of paper, the field is in the plane of the paper.

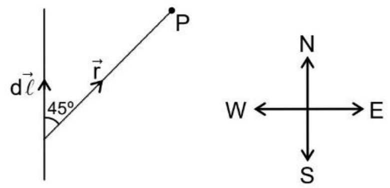
Example 1:

A wire placed along north-south direction carries a current of 10 A from south to north. Find the magnetic field due to a 1cm piece of wire at a point 200 cm north east from the piece.

Solution:

The situation is shown in figure. As the distance of P from the wire is much larger than the length of the wire, we can treat the wire as a small element. The magnetic field is given by

$$d\vec{B} = \frac{\mu_0}{4\pi} i \frac{d\vec{\ell} \times \vec{r}}{r^3} \quad \text{or} \quad dB = \frac{\mu_0}{4\pi} i \frac{d\ell \sin\theta}{r^2}$$



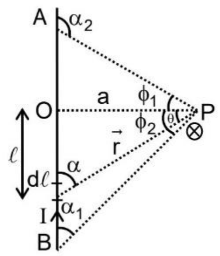
$= (10^{-7} \text{T mA}^{-1})\ (10\ \text{A})\ \dfrac{(10^{-2}\text{m})\sin 45^\circ}{(2\text{m})^2}$

$= 1.8 \times 10^{-9}$ T

The direction of $d\vec{\ell} \times \vec{r}$. is the same as that of From the figure, it is vertically downward.

6. Application of Biot-Savart Law

6.1 Magnetic field due to a straight current carrying wire



AB is a straight conductor carrying current I from B to A. At a point P, whose perpendicular distance from AB is OP =a, the direction of field is perpendicular to the plane of paper, inwards (represented by a cross)

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

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

By Biot-Savart's law

due to a current element $id\ell$ at point P

$$\overrightarrow{dB} = \frac{\mu_0}{4\pi}\frac{Id\ell \sin\alpha}{r^2} \otimes$$

due to wire AB

$$\Rightarrow B = \int dB = \int \frac{\mu_0}{4\pi}\frac{Id\ell \sin\alpha}{r^2} \qquad \Rightarrow B = \frac{\mu_0 I}{4\pi}\int \frac{\{a\sec^2\theta\, d\theta\}\cos\theta}{(a\sec\theta)^2}$$

$$\Rightarrow B = \frac{\mu_0 I}{4\pi a}\int \cos\theta d\theta$$

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

$$B = \frac{\mu_0 I}{4\pi a}\int_{-\phi_2}^{\phi_1} \cos\theta d\theta = \frac{\mu_0 I}{4\pi a}\left[\sin\theta\right]_{-\phi_2}^{\phi_1}$$

$$= \frac{\mu_0 I}{4\pi a}[\sin\phi_1 + \sin\phi_2] \text{ (inwards)}$$

$\alpha_2 = 90 + \phi_1 \Rightarrow \phi_1 = \alpha_2 - 90$

$\alpha_1 = 90 + \phi_2 \Rightarrow \phi_2 = 90 - \alpha_1$

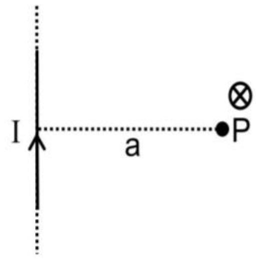
$$\therefore B = \frac{\mu_0 I}{4\pi a}(\cos\alpha_1 - \cos\alpha_2)$$

Some standard arrangements are discussed below

- **Infinite wire**

Here $\phi_1 = \phi_2 = 90°$

So $$B_P = \frac{\mu_0 I}{2\pi a} \otimes$$



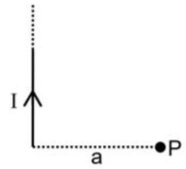
- **Semi - Infinite wire**

(a) Here $\phi_1 = 90°$, $\phi_2 = 0$

$$B_P = \frac{\mu_0 I}{4\pi a}[\sin 90° + \sin 0°] \otimes$$

$$B_P = \frac{\mu_0 I}{4\pi a}[1 + 0]$$

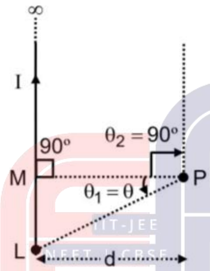
$$B_P = \frac{\mu_0 I}{4\pi a} \otimes$$



(b) Magnetic field due to semi infinite length wire at point 'P'

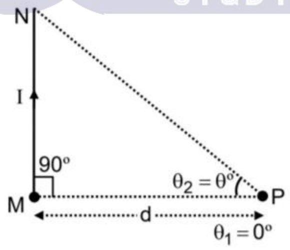
$B_P = [\sin\theta + \sin 90°]$

$B_P = [\sin\theta + 1]$



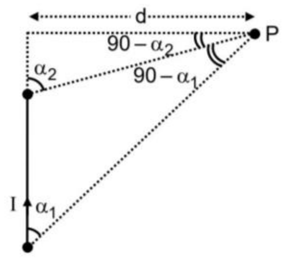
- **Finite length**

(a) Magnetic field due to special finite length wire at point 'P'



$$B_P = \frac{\mu_0 I}{4\pi d}[\sin 0° + \sin\theta] \quad ; \quad B_P = \frac{\mu_0 I}{4\pi d}\sin\theta$$

(b) If point 'P' lies out side the line of wire then magnetic field at point 'P' :

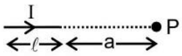
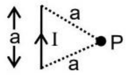
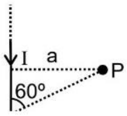


$$B_P = \frac{\mu_0 I}{4\pi d}\left[\sin(90 - \alpha_1) - \sin(90 - \alpha_2)\right]$$

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

Example 2:

Calculate the magnetic field at point ‘P’ due to the following

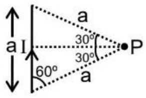
(a)  (b)  (c) 

Solution:

(a) Here $Id\vec{\ell}$ & $\vec{r}$ are parallel to each other. So

$Id\vec{\ell} \times \vec{r} = \vec{0}$

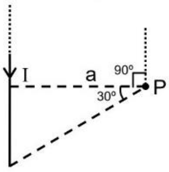
Here $B_p = 0$

(b) 

Here $r = a \sin 60°$, $\phi_1 = \phi_2 = 30°$

$$B_P = \frac{\mu_0 I}{4\pi a \sin 60^\circ}[\sin 30° + \sin 30°] \otimes$$

$$B_P = \frac{\mu_0 I}{2\sqrt{3}\pi a} \otimes$$

(c) 

Here $r = a$, $\phi_1 = 90°$ $\phi_2 = 30°$

$$B_P = \frac{\mu_0 I}{4\pi a}[\sin 90^\circ + \sin 30^\circ] \odot$$

$$B_P = \frac{3}{8}\frac{\mu_0 I}{\pi a} \odot$$

Example 3:

Long straight wire carries a current of 50 amp. Find the magnetic field at a perpendicular distance of 0.4 m from the wire.

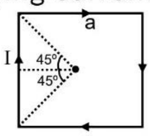
Solution:

$$B = \frac{\mu_0 I}{2\pi a} = \frac{4\pi \times 10^{-7} \times 50}{2\pi \times 0.4}$$

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

Example 4:

Find an expression for the magnetic field induction at the centre of a coil bent in the form of a square of side a, carrying current I.

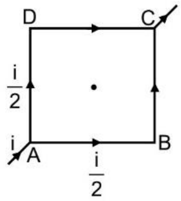
Solution: 

Magnetic field due to the
coil at the centre of the square is into the page and its magnitude is four times that produced by any one side. Therefore,

$$B = 4 \times \frac{\mu_0 I}{4\pi a/2}(\sin 45° + \sin 45°) = \frac{2\sqrt{2}\mu_0 I}{\pi a}$$

Example 5:

Figure shows a square loop made from a uniform wire. Find the magnetic field at the centre of the square of a battery is connected between points A and C.

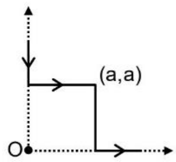


Solution:

The current will be equally divided at A. The fields at the centre due to the currents in the wires AB and DC will be equal in magnitude and opposite in direction. The resultant of these two fields will be zero. Similarly, the resultant of the fields due to the wires AD and BC will be zero. Hence, the net field at the centre will be zero.

Example 6:

Find out the magnetic field at origin.



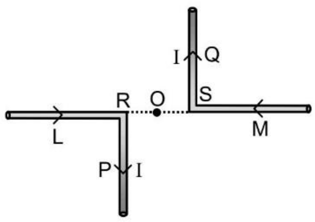
Solution:

B due to segment along x-axis & y-axis will be zero at origin & due to remaining segments will be directed into the plane while intercepting an angle of 45° each.

So $B_O = 2\frac{\mu_0 I}{4\pi a}[\sin 45° + \sin 0°] \otimes = \frac{\mu_0 I}{2\sqrt{2}\pi a} \otimes$

Example 7:

A pair of stationary and infinitely long bent wires are placed in the x-y plane as shown in fig. The wires carry currents of 10 ampere each as shown. The segments L and M are along the x-axis. The segments P and Q are parallel to the y-axis such that OS = OR = 0.02 m. Find the magnitude and direction of the magnetic induction at the origin O.



Solution:

As point O is along the length of segments L and M so the field at O due to these segments will be zero. Further, at point O, magnetic field will be $\vec{B}_O = \vec{B}_P + \vec{B}_Q$

$= \frac{\mu_0}{4\pi}\frac{I}{d}(\hat{k}) + \frac{\mu_0}{4\pi}\frac{I}{d}(\hat{k})$ [as RO = SO = d]

so, $\vec{B}_R = \frac{\mu_0}{4\pi}\left(\frac{2I}{d}\right)(\hat{k})$

Substituting the given data,

$\vec{B}_R = 10^{-7} \times \frac{2 \times 10}{0.02}(\hat{k}) = 10^{-4}\ (\hat{k})$

B = 10^{-4} T and in (+z) direction.

Concept Builder-1

Q.1 Assuming standard directions. Find out the direction of magnetic field due to the current element at the given point in the following conditions

(a) 

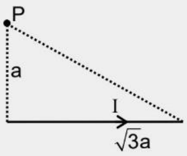
(b) 

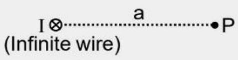
Q.2 Assuming standard directions. Find out the direction of magnetic field due to the current element at the given point in the following conditions –

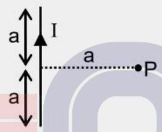
(a) 

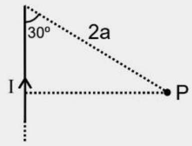
(b) 

Q.3 Calculate the magnetic field at point 'P' due to the following

(A) 

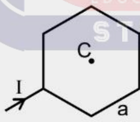
(B) 

(C) 

(D) 

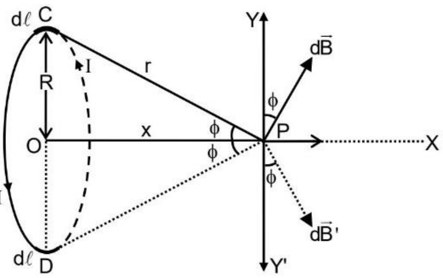
Q.4 A closed circuit is in the form of a regular hexagon of side a. If the circuit carries a current I, what is magnetic induction at the centre of the hexagon?

Q.5 Find out magnetic field at the center of geometry



6.2 Magnetic field due to circular current carrying coil

Let a coil of radius R, is carrying current I, then magnetic field on it's axis at a distance x from its centre is calculated as follows.



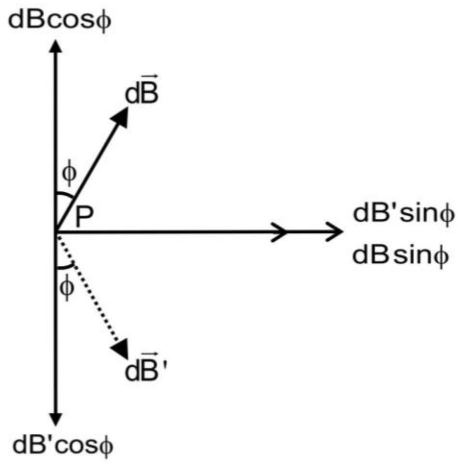
As per Biot-Savart's law, at point P, the magnetic field due to the current element is

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

or $dB = \dfrac{\mu_0}{4\pi}\dfrac{Id\ell \sin\theta}{r^2} = \dfrac{\mu_0}{4\pi}\dfrac{Id\ell \sin 90^\circ}{(R^2 + x^2)}$

Now dB cos ϕ and dB' cosϕ act along PY and PY' so being equal and opposite cancel each other.

$\therefore B_{axis} = \int dB\sin\phi$ as $|d\vec{B}| = |d\vec{B}'|$



Where $\sin\phi = \frac{R}{\sqrt{R^2 + x^2}}$

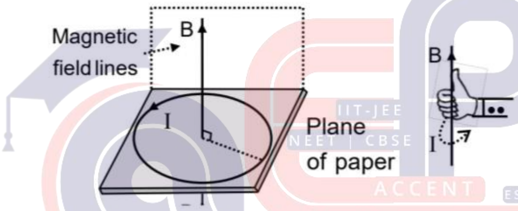
$\Rightarrow B_{axis} = \frac{\mu_0 IR}{4\pi(R^2 + x^2)^{3/2}} \int d\ell$

or $B_{axis} = \frac{\mu_0}{4\pi} \frac{2\pi R^2 I}{(R^2 + x^2)^{3/2}}$ (since $\int d\ell = 2\pi R$)

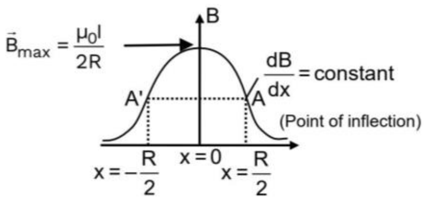
If there are N turns in the coil

$$B_{axis} = \frac{\mu_0 NIR^2}{2\left[R^2 + x^2\right]^{3/2}}$$

Right hand thumb rule of circular currents: According to this rule, if the direction of current in a 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.



The variation of magnetic field due to a circular coil as the distance x varies is shown in the figure.



Special Cases

- If x >> R, then current carrying coil behaves like short bar magnet. This magnet would have same magnetic field as that of ring on its axis as explained.

  For x >> R, B_{axis} becomes

  $$B_{axis} = \frac{\mu_0}{4\pi}\frac{NI2\pi R^2}{x^3} = \frac{\mu_0}{4\pi}.\frac{2NIA}{x^3}$$

  Where area of each turn of coil $A = \pi R^2$ This expression can be written as

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

  A current carrying circular coil behaves as a bar magnet whose magnetic moment is M = NIA Where

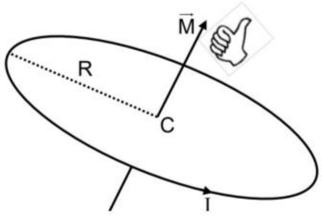
  N = Number of turns in the coil

  I = Current through the coil

  A = Area of the coil

  $M = I \times \pi R^2$

It is a vector quantity having SI unit **A-m²**. and its direction is given by right hand thumb rule.



For a given perimeter, the circular shape has maximum area and so maximum magnetic moment

- At centre x = 0

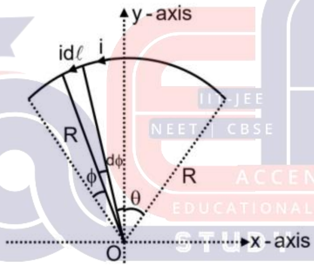
$\Rightarrow B_{centre} = \frac{\mu_0}{4\pi}.\frac{2\pi NI}{R} = \frac{\mu_0 NI}{2R} = B_{max}$

- **Field for circular arc**

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

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

The field due to this element at the centre is



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

Now $d\ell = Rd\phi$

$\therefore dB = \frac{\mu_0}{4\pi}\frac{iRd\phi}{R^2} \Rightarrow dB = \frac{\mu_0}{4\pi}\frac{i}{R}d\phi$

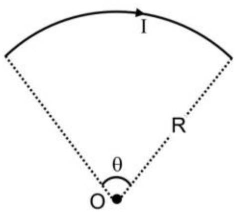
The direction of field is outward perpendicular to plane of paper

Total magnetic field

$$B = \int dB$$

$B = \frac{\mu_0}{4\pi}\frac{i}{R}\int_0^{\theta} d\phi = \frac{\mu_0 i}{4\pi R}\left[\phi\right]_0^{\theta}$ $\therefore B = \frac{\mu_0 i}{4\pi R}\theta$

Alternately we can write



$B_{arc} = \frac{\theta}{2\pi}$ (B_{centre} due to complete circle) $= \frac{\mu_0 I\theta}{4\pi R}$

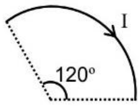
Example 8:

A piece of wire carrying a current of 6 A is bent in the form of a circular arc of radius 10.0 cm, and it subtends an angle of 120° at the centre. Find the magnetic field due to this piece of wire at the centre.

Solution:

Magnetic field at centre of arc

$B = \frac{\mu_0 I\alpha}{4\pi R}$, $\alpha = 120° = \frac{2\pi}{3}$ rad



$$B = \frac{\mu_0 I}{4\pi R} \times \frac{2\pi}{3} = \frac{\mu_0 I}{6R} = \frac{4\pi \times 10^{-7} \times 6 \times 100}{6 \times 10} T$$

$$= 12.57\ \mu T \otimes$$

Example 9:

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

Solution:

Magnetic field induction at a point on the axis at a distance x from the centre of the circular coil carrying current and at its centre is

$$B_{axis} = \frac{\mu_0 N I R^2}{2(R^2 + x^2)^{3/2}}, \quad B_{centre} = \frac{\mu_0 N I}{2R}$$

and both are related as

$$B_{axis} = \frac{B_{centre}}{\left(1 + \frac{x^2}{R^2}\right)^{3/2}}$$

As given in question $B_{axis} = \frac{1}{8} B_{centre}$

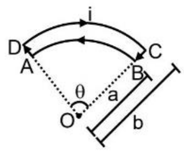
So, $\frac{1}{8} B_{centre} = \frac{B_{centre}}{\left(1 + \frac{x^2}{R^2}\right)^{3/2}}$

or $8 = \left(1 + \frac{x^2}{R^2}\right)^{3/2}$ or $(8)^{2/3} = 4 = 1 + \frac{x^2}{R^2}$

$x = \sqrt{3}\, R$

Example 10:

Figure shows a current loop having two circular arcs joined by two radial lines. Find the net magnetic field B_{net} at the centre O.



Solution:

As the point O is on the line AD, the magnetic field at O due to AD is zero. Similarly, the field at O due to BC is also zero. The field at the centre of a circular current loop is given by $B = \frac{\mu_0 i}{2r}$.

The field due to the circular arc BA will be

$$B_1 = \left(\frac{\theta}{2\pi}\right)\left(\frac{\mu_0 i}{2a}\right) \odot$$

The right hand thumb rule shows that the field is coming out of the plane of the wire DC.

$$B_2 = \left(\frac{\theta}{2\pi}\right)\left(\frac{\mu_0 i}{2b}\right) \otimes$$

The field due to the circular arc DC is going into the plane of the figure. The resultant field at O is

$$B_{net} = B_1 - B_2 = \frac{\mu_0 i\theta(b-a)}{4\pi ab}$$

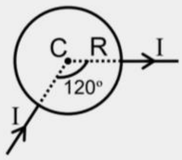
coming out of the plane.

Concept Builder-2

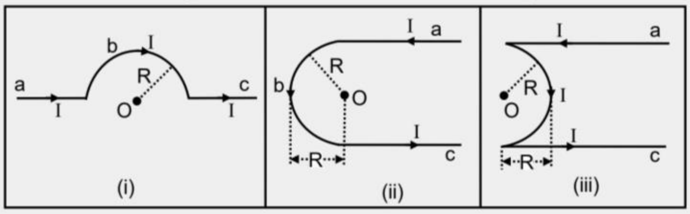
Q.1 Find the magnetic field at the centre for a semi circular ring.

Q.2 A circular coil of 120 turns has a radius of 18 cm and carries a current of 3.0 A. What is the magnitude of the magnetic field (i) at the centre of the coil (ii) at a point on the axis of the coil at a distance from the centre equal to the radius of the coil ?

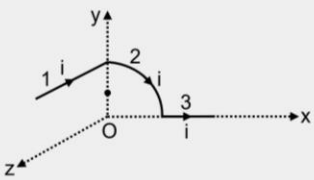
Q.3 What is the magnetic field intensity at the centre in the given arrangement.



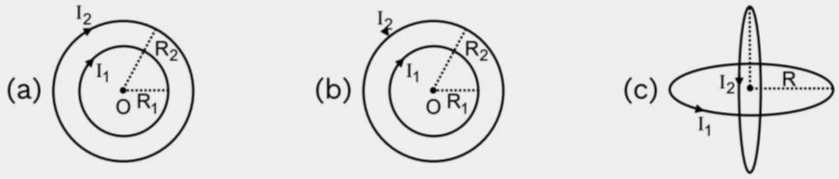
Q.4 Calculate the field at the centre of a semi-circular wire of radius R in situations depicted in figure (i), (ii) and (iii) if the straight wire is of infinite length.



Q.5 A conductor carrying a current i is bented as shown in figure. Find the magnitude of magnetic field at the origin

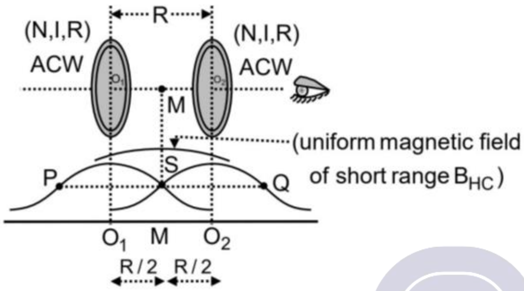


Q.6 For concentric and coplanar / non coplanar current carrying loops shown, find magnetic field at common centre.



6.3 Helmholtz's Coil Arrangement

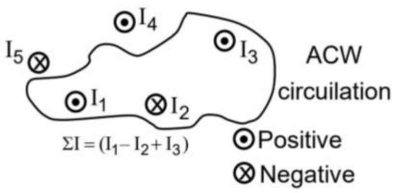
This arrangement is used to produce **uniform** magnetic field of **short range.** It consists :-



- Two identical co–axial coils [N (no. of turns), I (current) and R (Radius) are same]
- Placed at distance (center to center) equal to radius ('R') of coils
- Planes of both coils are parallel to each other.
- Current direction is same in both coils (observed from same side) otherwise this arrangement is not called "Helmholtz coil arrangement".

7. Ampere's Circuital Law

Statement : The line integral of the magnetic field



around any closed path in free space or vacuum is equal to μ_0 times of net current or total current which is enclosed by closed path.

Explanation : Mathematically $\oint \vec{B} \cdot d\vec{\ell} = \mu_0 \Sigma I$

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

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

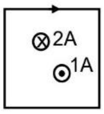
- This law is suitable for infinite long and symmetrical current distribution.
- Radius of cross section of thick cylindrical conductor and current density must be given to apply this law.

Limitations :

It is not valid if time changing electric field is present in region where loop is located.

Example 11:

Evaluate the value of $\oint \vec{B}\cdot d\vec{\ell}$ for the loop shown in the figure.



Solution:

From ampere's law

$\oint \vec{B}\cdot d\vec{\ell} = \mu_0 i_{encl} = \mu_0(2 - 1) = \mu_0$

8. Applications Of Ampere's Circuital Law

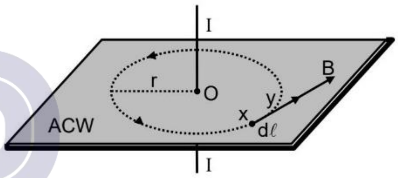
8.1 Magnetic field due to infinite long thin current carrying straight conductor

Consider a circle of radius 'r'. Let XY be the small element of length $d\ell$. are in the same direction because direction of along the tangent of the circle. By Ampere's Circuital Law (A.C.L.)

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

$\oint B\ d\ell \cos 0° = \mu_0 I \Rightarrow B\oint d\ell = \mu_0 I$

(where $\oint d\ell = 2\pi r$); $B(2\pi r) = \mu_0 I \Rightarrow B = \frac{\mu_0 I}{2\pi r}$



8.2 Magnetic field due to current carrying infinite long solid cylindrical conductor

- For a point inside the cylinder (r < R)

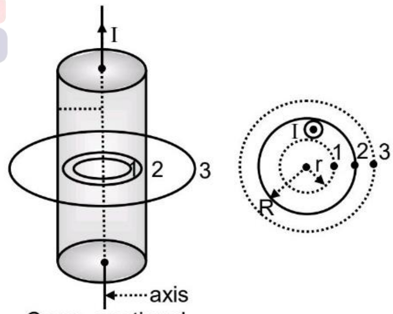
  Current from area πR^2 is = I

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

  By Ampere circuital law for circular path 1 of radius r

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

  $\Rightarrow B_{in} \propto r$



Cross - sectional view

- **For a point on the axis of the cylinder (r = 0)**

  $B_{axis} = 0$

- **For a point on the surface of cylinder (r = R)**

  By Ampere circuital law for circular path 2 of radius R

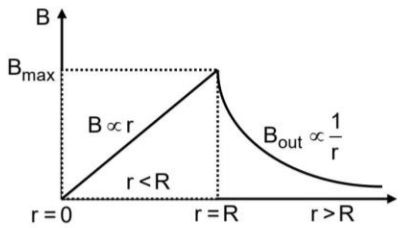
  $B_s(2\pi R) = \mu_0 I \Rightarrow B_s = \frac{\mu_0 I}{2\pi R}$ (it is maximum)

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

  By Ampere circuital law for circular path 3 of radius r

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

  $\Rightarrow B_{out} \propto \frac{1}{r}$



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

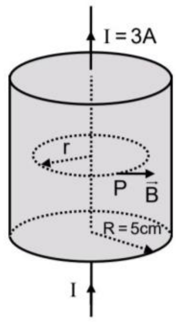
Example 12:

A long straight solid conductor of radius 5 cm carries a current of 3A, which is uniformly distributed over its circular cross-section. Find the magnetic field induction at a distance 4 cm from the axis of the conductor. Relative permeability of the conductor = 1000.

Solution:

Imagine a circular path of radius r whose centre lies on the axis of solid conductor such that the point P lies on it. The current threading this closed path

$$I' = \frac{I}{\pi R^2} \times \pi r^2 = \frac{Ir^2}{R^2}$$



Magnetic field B acts tangential to the amperian circular path at P and is same in magnitude at every point on circular path.

Using Ampere circuital law

$$\oint \vec{B}.d\vec{\ell} = \mu_0 \mu_r I'$$

$$\Rightarrow B(2\pi r) = \mu_0 \mu_r \left(\frac{Ir^2}{R^2}\right) \qquad \Rightarrow B = \frac{\mu_0 \mu_r I r}{2\pi R^2}$$

$$\therefore B = \frac{4\pi \times 10^{-7} \times 1000 \times 3 \times 0.04}{2\pi \times (0.05)^2} = 9.6 \times 10^{-3} \text{ T.}$$

9. Solenoid & Toroid

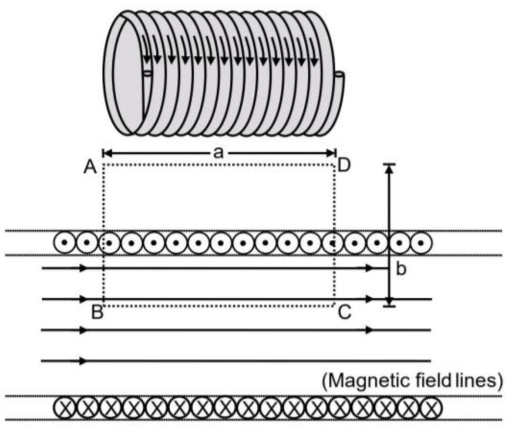
9.1 Solenoid

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

9.2 Magnetic Field due to a long solenoid

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

$$\oint_{ABCD} \vec{B}.\vec{d\ell} = \mu_0 i_{enc}$$



Now

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

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

And, $\oint_{DA} \vec{B}.\vec{d\ell} = 0$ ($\because$ $\vec{B}$ outside the solenoid is negligible

Now, i_{enc} = (n × a) × i

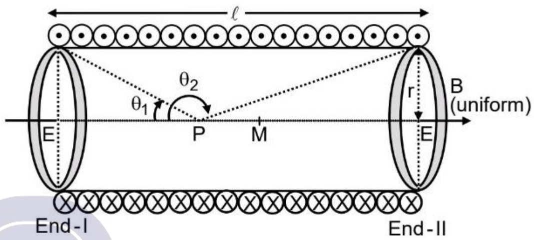
$\Rightarrow$ B × a = μ_0 (n × a × i) $\Rightarrow$ B = $\mu_0$ni [where i = current in the coil]

- **Finite Length Solenoid**

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

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

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



- **Infinite Length Solenoid**

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

(a) Magnetic field at axial point which is well inside the solenoid $\theta_1 \simeq 0°$ and $\theta_2 \simeq 180°$

$$\Rightarrow B \simeq \frac{\mu_0 nI}{2}[\cos 0° - \cos 180°]$$

$$\simeq \frac{\mu_0 nI}{2}[(1) - (-1)]$$

(b) Magnetic field at both axial end points of solenoid θ_1 = 90° and $\theta_2 \simeq 180°$

$$\Rightarrow B \simeq \frac{\mu_0 nI}{2}[\cos 90° - \cos 180°]$$

$$\simeq \frac{\mu_0 nI}{2}[(0) - (-1)] \simeq \frac{\mu_0 nI}{2}$$

Example 13:

A straight solenoid of length 50 cm, having 100 turns carries a current of 2.5A. Find the magnetic field.

(Given $\mu_0 = 4\pi \times 10^{-7}$ Wb $A^{-1}m^{-1}$)

(a) In the interior of the solenoid

(b) At one end of the solenoid

Solution:

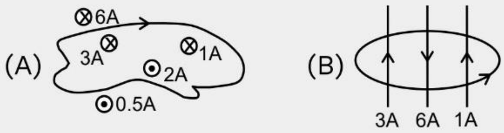
Here, I = 2.5 A, n = $\frac{100}{0.50}$ = 200 m^{-1}

(a) B = μ_0nI = $4\pi \times 10^{-7} \times 200 \times 2.5 = 6.28 \times 10^{-4}$T

(b) $B = \frac{\mu_0 nI}{2} = \frac{4\pi \times 10^{-7} \times 200 \times 2.5}{2} = 3.14 \times 10^{-4}$T

Concept Builder-3

Q.1 Evaluate for the following loops $\oint \vec{B} \cdot \vec{d\ell} = ?$



Q.2 A closely wound, solenoid 80 cm. long has 5 layers of winding of 400 turns each. The diameter of the solenoid is 1.8 cm. If the current carried is 8.0A. Estimate the magnetic field
(a) Inside the solenoid
(b) Axial end points of the solenoid

Q.3 A straight long solenoid is produced magnetic field 'B' at its centre. If it cut into two equal parts and same number of turns wound on one part in double layer. Find magnetic field produced by new solenoid at its centre.

Q.4 B along the axis of a solenoid is given by

Q.5 A solenoid of length 0.4 m and diameter 0.6m consists of a single layer of 1000 turns of fine wire carrying a current of 5×10^{-3} ampere. Calculate the magnetic field on the axis at the middle and at the end of the solenoid.

Example 14:

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

Solution:

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

$B_{net} = B_1 - B_2 = \mu_0 n_1 I_1 - \mu_0 n_2 I_2$

$= \mu_0 \frac{N_1}{\ell} I - \mu_0 \frac{N_2}{\ell} I \quad (\because I_1 = I_2 = I)$

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

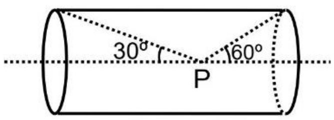
$= 12\pi \times 10^{-5}$ T

Example 15:

Find out magnetic field at axial point 'P' of solenoid shown in figure

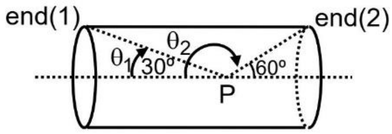
(where turn density 'n' and current through it is I)

Solution:



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

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



where θ_1 = 30° (CW),

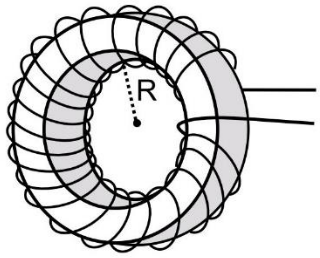
θ_2 = (180°–60°) = 120° (CW)

$$= \frac{\mu_0 nI}{2}[\cos 30° - \cos 120°]$$

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

9.3 Toroid

A hollow circular ring on which a large number of turns of a wire are closely wound is known as a toroid.

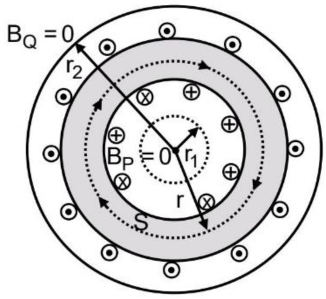


For the ideal toroid

- The magnetic field in the open space inside (point P) and exterior to the toroid (point Q) is **zero**.
- The field B inside toroid is constant in magnitude.

Let the magnetic field along loop 1 be B_P in magnitude. However, the loop encloses no current, so I = 0. Thus,

$$B_P(2\pi r_1) = \mu_0(0),\ B_P = 0.$$



Thus, the magnetic field at point P is zero. Similarly, we can show that magnetic field at Q is likewise zero. As the current coming out of the plane of the paper is cancelled exactly by the current going into it.

Once again we apply Ampere's law for the loop S. The current enclosed is (for N turns of toroidal coil) N I.

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

Let n be number of turns per unit length (circumference), then

$$n = \frac{N}{2\pi r} \qquad \therefore\ B = \mu_0 nI$$

Note : If the inner radius (r_{in}) and outer radius (r_{out}) are given, the mean radius r is

$$r = \frac{r_{in} + r_{out}}{2}$$

Example 16:

A toroid has a core of inner radius 20 cm and outer radius 22 cm around which 4200 turns of a wire are wound. If the current in the wire is 10 A, what is the magnetic field inside the core of toroid.

Solution:

Here, Inner radius r_1 = 20 cm

Outer radius, r_2 = 22 cm

$\therefore$ Mean radius of toroid, $r = \frac{r_1 + r_2}{2}$ = 21cm = 0.21m

Total length of toroid = circumference of toroid

= 2πr = 2π × 0.21 = 0.42π m

$\therefore$ Total number of turns per unit length will be

$$n = \frac{4200}{0.42\pi} = \frac{10000}{\pi} m^{-1}$$

Magnetic field induction inside the core of toroid

$$B = \mu_0 nI = 4\pi \times 10^{-7} \times \frac{10000}{\pi} \times 10 = 0.04T$$

10. Force on a Moving Charged Particle in a Magnetic Field

If a particle carrying a positive charge q and moving with velocity v enters a magnetic field B then it experiences a force F which is given by the expression

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

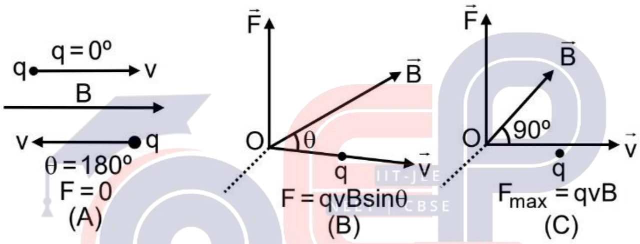
where $\vec{v}$ = velocity of the particle, $\vec{B}$ = magnetic field, θ is the angle between velocity and the magnetic field.

Direction of force : The direction of force $\vec{F}$ is the direction of cross product of $\vec{v}$ and the magnetic field $\vec{B}$, which is perpendicular to the plane containing $\vec{v}$ and $\vec{B}$.

10.1 Right Hand Palm Rule

Key Points

- The force $\vec{F}$ is always perpendicular to both the velocity $\vec{v}$ and the field $\vec{B}$
- A charged particle at rest in a steady magnetic field does not experience any force.
  If the charged particle is at rest then $\vec{v} = \vec{0}$, so $\vec{v} \times \vec{B} = \vec{0}$
- A moving charged particle does not experience any force in a magnetic field if its motion is parallel or antiparallel to the field.



- If the particle is moving perpendicular to the field. In this situation all the three vectors $\vec{F}$, $\vec{v}$ and $\vec{B}$ are mutually perpendicular to each other. Then sin θ = max = 1, i.e., θ = 90°,
  The force will be maximum F_{max} = q v B
- Work done by force due to magnetic field in motion of a charged particle is always zero.
  When a charged particle move in a magnetic field, then force acts on it is always perpendicular to displacement, so the work done,
  $W = \int \vec{F}.d\vec{s} = \int F ds \cos 90° = 0$ (as θ = 90°),
  And as by work-energy theorem W = Δ KE, the kinetic energy $\left(= \frac{1}{2}mv^2\right)$ remains unchanged and hence speed of charged particle v remains constant.
  However, in this situation the force changes the direction of motion, so the direction of velocity $\vec{v}$ of the charged particle changes continuously.
- Power supplied by the field is zero

$$P = \vec{F}_m . \vec{v} = 0$$

Example 17:

A charge of 3μC moves with a speed of 6 × 10^6 m s^{-1} along the positive x-axis. A magnetic field $\vec{B}$ of strength (0.30 $\hat{j}$ + 0.50 $\hat{k}$)T exists in space. Find the magnetic force acting on the charge.

Solution:

The force on the charge

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

= (3.0 × 10^{-6}) [6.0 × 10^6 $\hat{i}$ × (0.30 $\hat{j}$ + 0.50 $\hat{k}$)]

= 3(1.8 $\hat{i}$ × $\hat{j}$ + 3.0 $\hat{i} \times \hat{k}$)N = 3(1.8 $\hat{k}$ – 3.0 $\hat{j}$)N

11. Motion of a Charged Particle in a Magnetic Field

11.1 Particle enters parallel to the field

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

Example 18:

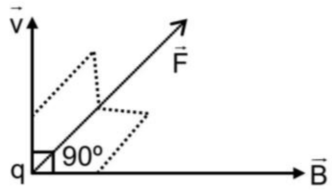
A charge particle of charge 3C enters in a magnetic field of strength $(8\hat{i} - 6\hat{j})$ T with a velocity of $(-3\hat{j} + 4\hat{i})$. Discuss the path & motion of charge particle.

Solution:

The velocity of charge is antiparallel to the direction of magnetic field strength so $\vec{v} \times \vec{B}$ = 0 or F = $q\left(\vec{v} \times \vec{B}\right)$ = 0, so the particle will keep moving in a straight line path with constant velocity.

11.2 Particle Enters perpendicular to the field

When the charged particle is moving perpendicular to the field.



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

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

$$\Rightarrow r = \frac{mv}{qB} = \frac{P}{qB} = \frac{\sqrt{2mK}}{qB} = \frac{\sqrt{2mq\Delta V}}{qB}$$

where K = kinetic energy

ΔV = applied potential

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

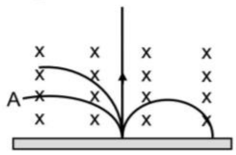
and the time period, $T = \frac{2\pi}{\omega} = 2\pi\frac{m}{qB}$

i.e., time period (or frequency) is independent of speed of particle and radius of the orbit. Time period depends only on the field B and the nature of the particle, i.e., specific charge (q/m) of the particle.

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

Example 19:

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



Solution:

Force on a charged particle in magnetic field

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

For neutron q=0, F=0 hence it will pass undeflected i.e., tracks C corresponds to neutron.

If the particle is negatively charged, i.e. electron.

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

It will experience a force to the right; so track D corresponds to electron.

If the charge on particle is positive. It will experience a force to the left; so both tracks A and B corresponds to positively charged particles (i.e., protons and α-particles). When motion of charged particle perpendicular to the magnetic field the path is a circle with radius

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

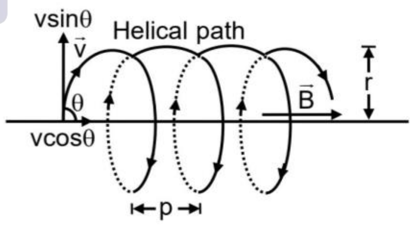
So $r_\alpha > r_p$ track B for α-particle and track A for proton.

11.3 Particle Enters at an angle θ to the field (θ ≠ 0°, 90° or 180°)

The charged particle is moving at an angle θ to the field : (θ ≠ 0°, 90° or 180°). Resolving the velocity of the particle along and perpendicular to the field. The particle moves with constant velocity v cos θ along the field (∵ no force acts on a charged particle when it moves parallel to the field).

And at the same time it is also moving with velocity v sinθ perpendicular to the field due to which it will describe a circle (in a plane perpendicular to the field)

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



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

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

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

Example 20:

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

Solution:

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

$$\Rightarrow v = \sqrt{\frac{2eV}{m}}$$

$$= \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 2 \times 10^3}{9 \times 10^{-31}}} = \frac{8}{3} \times 10^7 \text{ m/s}$$

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

$= 10^{-3}$ m = 1mm

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

$= 1 \times \dfrac{1}{2} = 0.5$ mm

Example 21:

A beam of protons is moving with velocity 4×10^5 m/s enters a uniform magnetic field of 0.3 tesla at an angle of 60° to the magnetic field. Find the radius of the helical path taken by the proton beam. Also find the pitch of helix. Mass of proton = 1.67×10^{-27}kg.

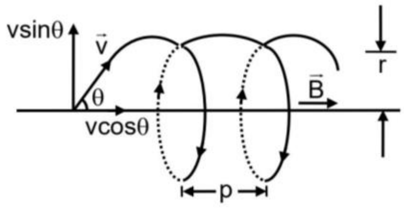
Solution:

Radius of helix $r = \dfrac{mv\sin\theta}{qB}$

($\therefore$ component of velocity $\perp$ to field is $v\sin\theta$)

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

= 1.7 cm



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

$\therefore \quad p = \dfrac{v\cos\theta\times2\pi r}{v\sin\theta} = \dfrac{\cos60°\times2\pi\times(1.2\times10^{-2})}{\sin60°} = 4.35\times 10^{2}$m = 4.35cm

Concept Builder-4

Q.1 A charge of 2.0 μC moves with a speed of 2.0×10^6 m s^{-1} along the positive x-axis. A magnetic field $\vec{B}$ of strength $(0.20\,\vec{j} + 0.40\,\vec{k})$T exists in space. Find the magnetic force acting on the charge.

Q.2 If a positive charge enters parallel to the magnetic field then which of the following are true.
(1) Particle will move in straight line path
(2) No force will act on the particle
(3) The particle may reverse it's direction of motion
(4) All of the above

Q.3 An electron accelerated through a potential difference of 100 V enters a uniform magnetic field of 0.004 T perpendicular to its direction of motion. Calculate the radius of the path described by the electron.

Q.4 A cyclotron is operating with a flux density of 3 Wb/m^2. The ion which enters the field is a proton having mass 1.67×10^{-27} kg. If the maximum radius of the orbit of the particle is 0.5 m, find (a) the maximum velocity of the proton (b) the kinetic energy of the particle and (c) the period for a half cycle.

Q.5 A proton of mass 1.67×10^{-27} kg and charge 1.6×10^{-19}C is projected with a speed of 2×10^6 m/s at an angle of 60° to the x-axis, If a uniform magnetic field of 0.104 T is applied along the y axis, the path of the proton is :

(1) a circle of radius 0.2 m and time period $\pi \times 10^{-7}$ s

(2) a circle of radius 0.1 m and time period $2\pi \times 10^{-7}$s

(3) a helix of radius 0.1 m and time period $2\pi \times 10^{-7}$s

(4) a helix of radius 0.2 m and time period $4\pi \times 10^{-7}$s

Q.6 A proton enters a magnetic field of intensity 1.5 Wb/m^2 with a velocity 2×10^7 m/s in a direction at an angle 30° with the field. The force on the proton will be:

(Charge on proton is 1.6×10^{-19} C.)

(1) 2.4×10^{-12} N (2) 4.8×10^{-12} N (3) 1.2×10^{-12} N (4) 7.2×10^{-12} N

12. Lorentz Force

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

The moving charged particle will experience electric force $\vec{F}_e = q\vec{E}$ and magnetic force $\vec{F}_m = q(\vec{v} \times \vec{B})$.

Net force on the charge particle is **"Lorentz-force"**

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

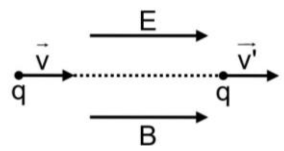
Depending on the direction of $\vec{v}, \vec{E}$ and $\vec{B}$, various situation are possible and the motion in general is quite complex.

12.1 Motion of a charge Particle in combined electric field & Magnetic field

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

As the particle is moving parallel or antiparallel to the field.

The magnetic force on it will be zero and only electric force will act



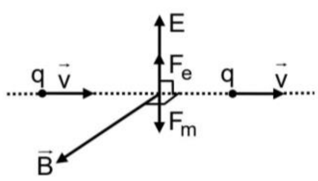
So, acceleration of the particle $\vec{a} = \frac{\vec{F}}{m} = \frac{q\vec{E}}{m}$

Hence, the particle will pass through the field following a straight line path (parallel to the field) with change in its speed.

In this situation speed, velocity, momentum and kinetic energy all will change without change in direction of motion as shown in figure above.

Case II : $\vec{v}$, $\vec{E}$ and $\vec{B}$ are mutually perpendicular:

If in this situation direction and magnitude of $\vec{E}$ and $\vec{B}$ are such that



Resultant force $\vec{F} = \vec{F}_e + \vec{F}_m = 0 \Rightarrow \vec{a} = \frac{\vec{F}}{m} = 0$

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

$\because F_e = F_m$ i.e. $qE = qvB \Rightarrow v = \frac{E}{B}$

Example 22:

A beam of protons is deflected sideways. Could this deflection be caused by

(i) a magnetic field

(ii) an electric field? If either possible, what would be the difference?

Solution:

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

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

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

13. Cyclotron

Cyclotron is a device used to accelerate charged particles like, α-particles and deutrons to high energies. It was invented by E.O. Lawrence and M.S. Livingston in 1934 to investigate nuclear structure.

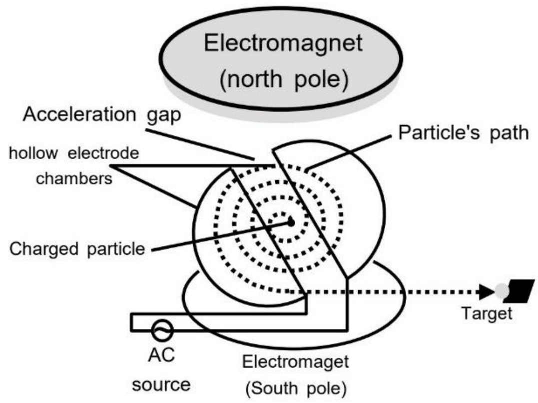
13.1 Principle

The cyclotron uses both electric and magnetic fields in combination to increase the energy of charged particles.

It is based on the fact that the electric field accelerates a charged particle and the magnetic field keeps it revolving in circular orbits with constant frequency.

13.2 Construction

It consists of two hollow D-shaped metallic chambers D_1 and D_2 called dies. The two dies are placed horizontally with a small gap separating them. The dies are connected to the source of high frequency electric field. The dies are enclosed in a metal box containing a gas at a low pressure of the order of 10^{-3} mm mercury. The whole apparatus is placed between the two poles of a strong electromagnet NS. The magnetic field acts perpendicular to the plane of the dies.



13.3 Working

Particle moves most of the time inside the semi-circular discs called dees D_1 and D_2. Inside these metallic dees, particle is shielded and is not acted on by the electric field. The magnetic field however, acts on the particle and makes it go round in a circular path inside a dee. Every time the particle moves from one dee to another it is acted upon by the electric field. The sign of the electric field is changed alternately in tune with the circular motion of the particle. This ensures that the particle is always accelerated by the electric field. Each time acceleration increases the energy of the particle. As energy increases, the radius of the circular path increases. So, the path is a spiral.

- **Cyclotron frequency :** Time taken by ion to describe a semicircular path is given by

  $t = \frac{\pi r}{v} = \frac{\pi m}{qB}$

  If T = time period of oscillating electric field then

  $T = 2t = \frac{2\pi m}{qB}$

  The cyclotron frequency $\nu = \frac{1}{T} = \frac{Bq}{2\pi m}$

- **Maximum Energy of particle :** Maximum energy gained by the charged particle

  $E_{max} = \left(\frac{q^2B^2}{2m}\right)r_0^2$.

  where r_0 = maximum radius of the circular path followed by the positive ion.

- **Numbers of revolutions a particle makes in field before coming out**

  During one revolution particle is accelerated twice while crossing the gap.

  If V is the potential difference between the Dees, then the kinetic energy gained by the ion in one revolution is 2qV

  Total KE gained after N revolution is 2NqV

Limitations

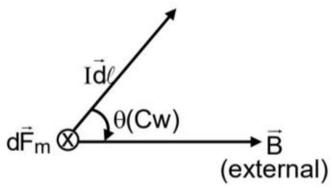
- As velocity increases mass increases thus ion will take longer time to complete semi-circular path than the time for half cycle for oscillating field.
- Electron being lighter is not used in cyclotron.
- Uncharged particle can not be accelerated.

14. Current Carrying Wire in a Magnetic Field

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

- **Magnetic force on current element**

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



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

  $dF_m = 0$ (min.)

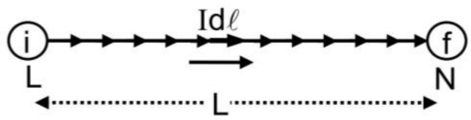
- Current element in a magnetic field experiences maximum force if the current in it is perpendicular with the field $\theta = 90°$, $dF_m = BId\ell$ (max.)

- Magnetic force on current element is always perpendicular to the current element vector and magnetic field vector. $\vec{dF_m} \perp I d\vec{\ell}$ and

  $\vec{dF_m} \perp \vec{B}$ (always)

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

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

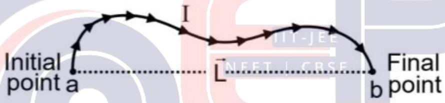
  

  $\vec{F}_m = I(\vec{\ell} \times \vec{B})$

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

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

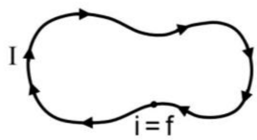
  $\int_i^f d\vec{F}_m = I\left[\int_i^f d\vec{\ell}\right] \times \vec{B}$, $\vec{F}_m = I(\vec{L} \times \vec{B})$ (L = ab)

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

Key Points

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

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

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

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

Example 23:

A horizontal wire 0.2 m long carries a current of 4A. Find the magnitude and direction of the magnetic field, which can support the weight of the wire. Given, the mass of the wire is 3×10^{-3} kg/m.

Solution:

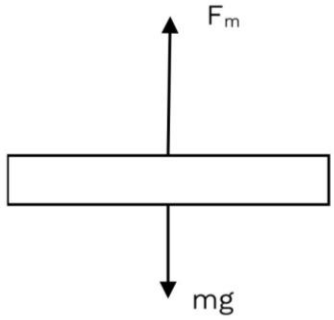
Here mass of wire, m = $(3 \times 10^{-3}) \times 0.2$ kg; I = 4A; B =?; ℓ = 0.2 m

Force on the wire carrying current due to magnetic field applied

$F = I\ell B$

Weight of wire = mg

In equilibrium position, $F = I\ell B = mg$



or $B = \dfrac{mg}{I\ell} = \dfrac{(3\times10^{-3}\times0.2)\times9.8}{4\times0.2} = 7.35 \times 10^{-3}$T

The weight of wire can be supported by force F. If F is acting vertically upwards (i.e. opposite to the weight of wire). It will be so is the direction of $\vec{B}$ is horizontal and perpendicular to wire carrying current.

Example 24:

A current loop of arbitrary shape lies in a uniform magnetic field B. Show that the net magnetic force acting on the loop is zero.

Solution:

F_1 = Force on AD = $i\ell B\ (-\hat{j})$

F_2 = Force on BC = $i\ell B\ (+\hat{j})$

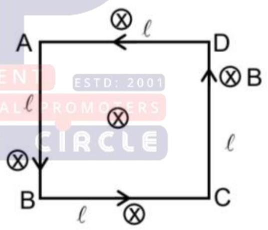
They cancel each other

F_3 = Force on CD = $i\ell B(-\hat{i})$

F_4 = Force on AB = $i\ell B(+\hat{i})$

They also cancel each other

So the net force on the body is 0.

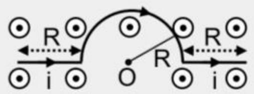


Concept Builder-5

Q.1 The magnetic flux density applied in a cyclotron is 3.5 T. What will be the frequency of electric field that must be applied between the dies in order (a) to accelerate proton (b) α-particles ? mass of proton 1.67×10^{-27} kg.

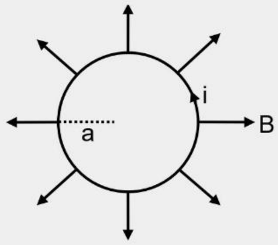
Q.2 Magnetic field applied on a cyclotron is 0.7 T and radius of its dies is 1.8 m. What will be the energy of emergent proton in MeV ? Mass of proton = 1.67×10^{-27}kg.

Q.3 A wire bent as shown in fig carries a current i and is placed in a uniform field of magnetic induction $\vec{B}$ that emerges from the plane of the figure. Calculate the force acting on the wire.

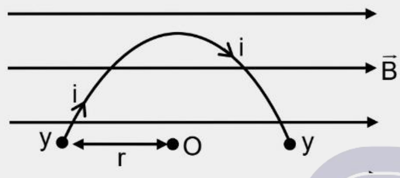


Q.4 A wire is bent in the form of an equilateral triangle PQR of side 10 cm and carries a current of 5.0 A. It is placed in a magnetic field B of magnitude 2.0 T directed perpendicularly to the plane of the loop. Find the forces on the three sides of the triangle.

Q.5 A circular loop or radius a, carrying a current i, is placed in a two-dimensional magnetic field. The centre of the loop coincides with the centre of the field. The strength of the magnetic field at the periphery of the loop is B. Find the magnetic force on the wire.

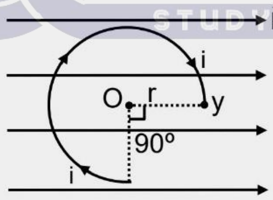


Q.6 A semicircular wire carrying current i is placed in a uniform magnetic field $\vec{B}$ as shown in figure. Here the semiciruclar wire and also $\vec{B}$ are in the plane of paper. Force acting on the wire is :



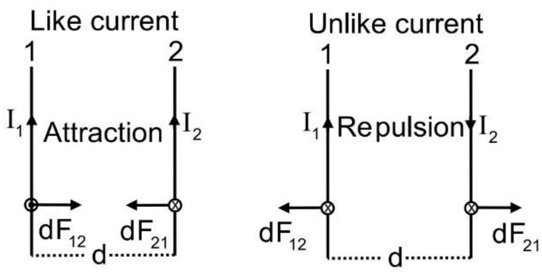
(1) $i\pi rB$ (2) $\frac{i\pi rB}{2}$ (3) $\frac{i\pi rB}{4}$ (4) Zero

Q.7 A wire carrying current 'i' is bent as shown in figure and placed in the plane of paper in a uniform magnetic field $\vec{B}$. Force experienced by the wire can be expressed as :



(1) irB (2) i2rB (3) $ir\sqrt{2}B$ (4) Zero

15. Magnetic Force Between Two Parallel Current Carrying Conductors



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

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

Magnetic field at each point on conductor (i) due to current I_2 is $B_2 = \frac{\mu_0 I_2}{2\pi d}$ [Uniform field for conductor (1)] consider a small element of length '$d\ell$' on each conductor. These elements are right angle to the external magnetic field, so magnetic force experienced by elements of each conductor given as

$dF_{12} = B_2 I_1 d\ell = \quad I_1 d\ell$ ...(i)

(Where $I_1 d\ell \; B_2$)

$dF_{21} = B_1 I_2 d\ell = I_2 d\ell$ ... (ii)

(Where $I_2 d\ell \; B_1$)

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

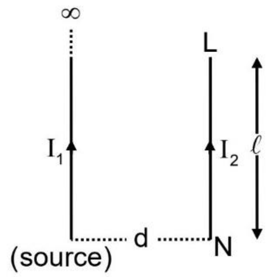
Magnetic force per unit length of each conductor is $\frac{dF_{12}}{d\ell} = \frac{dF_{21}}{d\ell} = \frac{\mu_0 I_1 I_2}{2\pi d}$

$f = \frac{\mu_0 I_1 I_2}{2\pi d}$ N/m (in S.I.) $\qquad f = \frac{\vec{F}}{\ell}$

$f = \frac{2 I_1 I_2}{d}$ dyne/cm (In C.G.S.)

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

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

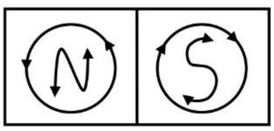


16. Magnetic Dipole & Magnetic Dipole Moment

A magnetic dipole consists of a pair of magnetic poles of equal and opposite strength separated by small distance. Ex. Magnetic needle, bar magnet, solenoid, coil or loop.

16.1 Magnetic dipole moment of current carrying coil (loop)

Current carrying coil (or loop) behaves like magnetic dipole. The face of coil in which current appears to flow anticlockwise acts as north pole while face of coil in which current appears to flow clockwise acts as south pole.



- A loop of geometrical area 'A', carries a current 'I' then magnetic moment of coil M = I A .
- A coil of turns 'N', geometrical area 'A', carries a current 'I' then magnetic moment M = N I A.

Magnetic moment of current carrying coil is an axial vector $\vec{M} = NI\vec{A}$

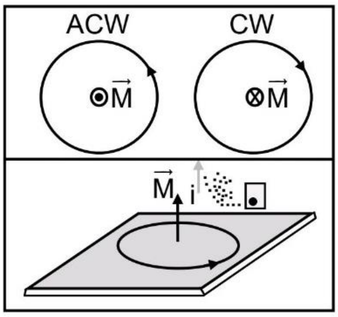
where $\vec{A}$ is a area vector perpendicular to the plane of the coil and along its axis.

SI unit : A-m^2 or J/T

Direction of $\vec{M}$ is determined by right hand thumb rule

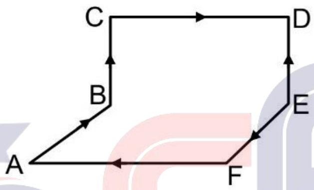
- Curling fingers $\Rightarrow$ In the direction of current
- Thumb $\Rightarrow$ Gives the direction of $\vec{M}$

For a current carrying coil, its magnetic moment and magnetic field vectors both are parallel axial vectors.



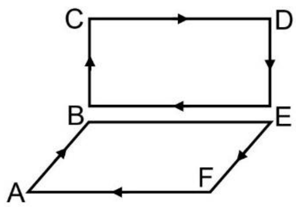
Example 25:

Find the magnitude of magnetic moment of the current carrying loop ABCDEFA. Each side of the loop is 10 cm long and current in the loop is i = 2.0 A



Solution:

By assuming two equal and opposite currents in BE, two current carrying loops (ABEFA and BCDEB) are formed. Their magnetic moments are equal in magnitude but perpendicular to each other.



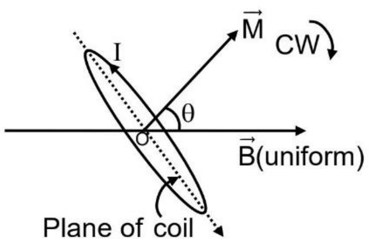
Hence, $M_{net} = \sqrt{M^2 + M^2} = \sqrt{2}M$

where $M = iA = (2.0)(0.1)(0.1) = 0.02$ A-m^2 $\Rightarrow M_{net} = (\sqrt{2})(0.02)$ A-m^2 = 0.028 A-m^2

16.2 Current carrying loop in a magnetic field

(A) Torque

$\vec{\tau} = \vec{M} \times \vec{B}$ $\qquad \vec{\tau} = NI(\vec{A} \times \vec{B})$



$\boxed{\tau = BINA\sin\theta}$ → $\theta = 90^\circ \Rightarrow \tau = BINA$ (maximum)

→ $\theta = 0^\circ$ or $180^\circ \Rightarrow \tau = 0$ (minimum)

Key Points

- Torque on dipole is an axial vector and it is directed along axis of rotation of dipole.
- Tendency of torque on dipole is try to align the $\vec{M}$ in the direction of $\vec{B}$ or tries to makes the axis of dipole parallel to $\vec{B}$ or makes the plane of coil (or loop) perpendicular to $\vec{B}$.
- Dipole in unifrom magnetic field → $F_{net} = 0$ (no translatory motion); τ may or may not be zero (decides by θ)
- Dipole in non unifrom magnetic field → $F_{net} \neq 0$ (no translatory motion); τ may or may not be zero (decides by θ)
- When a current carrying coil (or loop) is placed in longitudinal magnetic field then maximum torque acts on it. $\theta = 90°$ $(\vec{M} \perp \vec{B})$
  $\Rightarrow \tau_{max} = MB = BINA$
- When a current carrying coil (or loop) is placed in transverse magnetic field then no torque acts on it. $\theta = 0°$ $(\vec{M} \| \vec{B})$ or $\theta = 180°$ $(\vec{M}\ \text{anti} \| \vec{B})$ $\Rightarrow \tau_{min} = 0$

(B) Potential Energy :

Since the above results of torque and work done are analogous to that for an electric dipole in uniform electric field, it is convenient to define potential energy as the work done in rotating a magnetic dipole from a direction perpendicular to the field to the given direction.

$U = -MB\cos\theta$ or $U = -\vec{M}.\vec{B}$

Angle	Potential Energy $U = -MB\cos\theta$	Torque $\tau = MB\sin\theta$	Equilibirum
$\theta = 0º$	–MB(min)	0	stable
$\theta = 90º$	0	MB(max)	–
$\theta = 180º$	MB(max)	0	unstabe

(C) Work done in rotating a Magnetic Dipole :

Work done in rotating a dipole in a uniform magnetic field through small angle '$d\theta$'

$dW = \tau.d\theta = MB\sin\theta d\theta$

So work done in rotating a dipole from angular position θ_1 to θ_2 with respect to the Magnetic field direction

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

- If magnetic dipole is rotated from field direction i.e. $\theta_1 = 0°$ to position $\theta_2 = \theta$ then work done is
  $W_\theta = MB(1 - \cos\theta) = 2MB\sin^2\theta/2$
  in one rotation $\theta = 0°$ or $360° \Rightarrow W = 0$
  in 1/4 rotation $\theta = 90° \Rightarrow W = MB$
  in half rotation $\theta = 180° \Rightarrow W = 2MB$
  in 3/4 rotation $\theta = 270° \Rightarrow W = MB$
- Work done to rotate a dipole in a magnetic field is stored in the form of potential energy of magnetic dipole.

Example 26:

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

Solution:

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

$W = NI\pi r^2 B(\cos\theta_1 - \cos\theta_2) = 100\times0.1\times3.14\times(0.05)^2\times1.5(\cos 0° - \cos\pi) = 0.2355J$

17. Atomic Magnetism

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

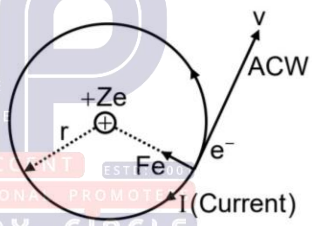
Bohr's postulates :

(i) $\dfrac{mv^2}{r} = \dfrac{kze^2}{r^2}$

(ii) $L = mvr = n\left(\dfrac{h}{2\pi}\right)$,

where n = 1, 2,3 ....

Basic elements of atomic magnetism :



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

(b) Magnetic induction at nucleus position:

As circular orbit behaves like current carrying loop, so magnetic induction at nucleus position

$B_N = \dfrac{\mu_0 I}{2r}$

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

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

M = IA where A is area of circular orbit.

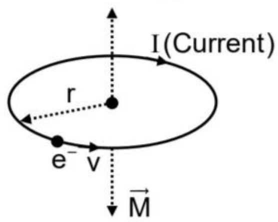
$M = ef(\pi r^2) = \dfrac{\pi er^2}{T} = \dfrac{evr}{2} = \dfrac{e\omega r^2}{2}$

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

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

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

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



Bohr Magneton (μ_B)

According of Bohr's theory, angular momentum of orbital electron is given by

$L = \frac{nh}{2\pi}$, where n = 1, 2, 3 .... and h is plank's constant.

Magnetic moment of orbital electron is given by $M = \frac{eL}{2m} = n\frac{eh}{4\pi m}$

- If n = 1 then $M = \frac{eh}{4\pi m}$, which is Bohr magneton denoted by μ_B
- **Definition of μ_B :**

  Bohr magneton can be defined as the magnetic moment of orbital electron which revolves in first orbit of an atom.
- $\mu_B = \frac{eh}{4\pi m} = \frac{1.6\times10^{-19}\times6.6\times10^{-34}}{4\times3.14\times9.1\times10^{-31}}$

  $= 0.923 \times 10^{-23}\ Am^2$

- **Basic elements of atomic magnetism for first orbit of H-atom (n = 1, z = 1)**

  $v = 2.18 \times 10^6$ m/sec,

  $f = 6.6 \times 10^{15}$ cy/sec. r = 0.529Å
- Orbital current I = 0.96 mA
- Magnetic induction at nucleus position

  $B_N = 12.8$ T
- Magnetic moment of orbital electron

  $M = 0.923 \times 10^{-23}\ Am^2 = \mu_B Am^2$

18. Rotation of Charged Conducting Body

In this case the ratio of magnetic moment and angular momentum is constant which is equal to $\frac{q}{2m}$ here q = charge and m = the mass of the body. $\frac{M}{L}$ known as gyrometric ratio.

Example

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

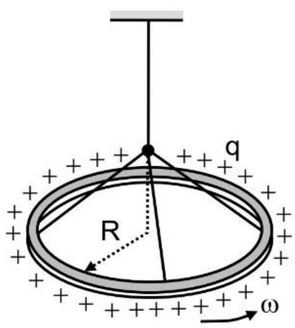
Angular momentum

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

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

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

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



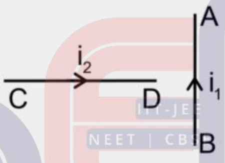
Although this expression is derived for simple case of a ring, it holds good for other bodies also.

For example, for a disc or a sphere. $M = \dfrac{qL}{2m} \Rightarrow M = \dfrac{q(I\omega)}{2m}$, where $L = I\omega$

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

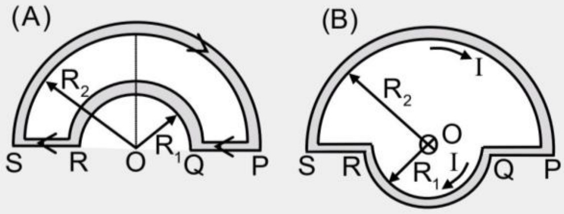
Concept Builder-6

Q.1 In figure, AB and CD are long current carrying wires placed as shown. Wire AB is fixed while CD is free to move then



(1) wire CD has translational motion and also has rotational motion in the anticlockwise sense.
(2) wire CD has translational motion and also has rotational motion in the clockwise sense.
(3) wire CD has rotational motion in the clockwise sense.
(4) wire CD has rotational motion in the anti clockwise sense.

Q.2 The wire loop PQRSP formed by joining two semicircular wires of radii R_1 and R_2 carries a current I as shown in fig. What is the magnetic induction at the centre O and magnetic moment of the loop in cases (A) and (B) ?



Q.3 When a current loop is placed in a uniform magnetic field :

(i) $\vec{F}_R = 0$ and $\vec{\tau} = 0$ (ii) $\vec{F}_R = 0$ and $\vec{\tau} \neq 0$

(iii) $\vec{F}_R \neq 0$ and $\vec{\tau} = 0$ (iv) $\vec{F}_R \neq 0$ and $\vec{\tau} \neq 0$

(1) i, ii (2) i, iii (3) i, iv (4) iii, iv

Q.4 When a current loop is placed in a non-uniform magnetic field :

(i) $\vec{F}_R = 0$ and $\vec{\tau} = 0$ (ii) $\vec{F}_R = 0$ and $\vec{\tau} \neq 0$

(iii) $\vec{F}_R \neq 0$ and $\vec{\tau} = 0$ (iv) $\vec{F}_R \neq 0$ and $\vec{\tau} \neq 0$

(1) ii, iv (2) i, iii (3) i, iv (4) iii, iv

Q.5 When a current-carrying coil is situated in a uniform magnetic field with its magnetic moment antiparallel to the field :

(i) torque on it is maximum

(ii) torque on it is minimum

(iii) potential energy of the loop is maximum

(iv) potential energy of the loop is minimum

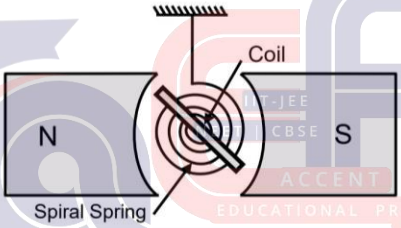
(1) (i, iv) (2) (ii, iii) (3) (i, ii) (4) (ii, iv)

Q.6 Consider a nonconducting plate of radius r and mass m which has a charge q distributed uniformly over it. The plate is rotated about its axis with an angular speed. Find magnetic moment μ.

Q.7 Consider a solid sphere of radius r and mass m which has a charge q distributed uniformly over its volume. The sphere is rotated about a diameter with an angular speed ω. Find the magnetic moment.

19. Moving Coil Galvanometer

A galvanometer is used to detect the current and has moderate resistance.



- **Principle.** When a current carrying coil is placed in a magnetic field, it experiences a torque given by = NiAB sinθ, where θ is the angle between normal to plane of coil and direction of magnetic field. In actual arrangement the coil is suspended between the cylindrical pole pieces of a strong magnet. The cylindrical pole pieces give the field radial such that sin θ=1 (always).
  So torque τ = NiAB.
  If C is torsional rigidity (i.e., restoring couple per unit twist of the suspension wire), then for deflection of coil $\tau = C\theta$.
  In equilibrium we have external couple = Restoring couple.
  i.e. $C\theta = NiAB$ or $\theta = \frac{NAB}{C} i$, i.e., $\theta \propto i$
  In words the deflection produced is directly proportional to current in the coil.
  The quantity $\frac{\theta}{i} = \frac{NAB}{C}$ is called the **current sensitivity** of the galvanometer. Obviously for greater sensitivity of galvanometer the number of turns N, area of coil A and magnetic field B produced by pole pieces should be larger and torsional rigidity C should be smaller. That is why the suspension wire is used of phosphor bronze for which torsional rigidity C is smaller.
  The quantity $\frac{\theta}{V} = \frac{NAB}{CR}$ is called the **voltage sensitivity**.

ANSWER KEY FOR CONCEPT BUILDERS

CONCEPT BUILDER-1

1. (a) Inwards to the plane of paper
(b) Inwards to the plane of paper

2. (a) clockwise
(b) Outward to the plane of paper

3. (A) $\frac{\sqrt{3}}{8}\frac{\mu_0 I}{\pi a}\odot$ (B) $\frac{\mu_0 I}{2\pi a}(-\hat{j})$

(C) $\frac{\mu_0 I}{2\sqrt{2}\pi a}\otimes$ (D) $\frac{\mu_0 I(2+\sqrt{3})}{8\pi a}\otimes$

4. $\frac{\sqrt{3}\mu_0 I}{\pi a}$ **5.** Zero

CONCEPT BUILDER-2

1. $\frac{\mu_0 I}{4R}$

2. (i) $= 1.257 \times 10^{-3}$ T
(ii) $= 4.4 \times 10^{-4}$ T

3. Zero

4. (i) $\frac{\mu_0 I}{4R}\otimes \perp^r$ to plane of paper

(ii) $= \frac{\mu_0}{4\pi}\frac{I}{R}[\pi + 2] \perp^r$ to plane of paper

(iii) $= \frac{\mu_0}{4\pi}\frac{I}{R}[\pi - 2]\otimes$ ($\perp^r$ to plane of paper)

5. $-\frac{\mu_0 i}{4r}\left[\frac{\hat{i}}{\pi}+\frac{\hat{k}}{2}\right]$

6. (a) $B = \frac{\mu_0}{2}\left[\frac{I_1}{R_1}+\frac{I_2}{R_2}\right]\otimes$

(b) $B = \frac{\mu_0 I}{2}\left[\frac{I_1}{R_1}-\frac{I_2}{R_2}\right]\otimes$

(c) $B = \frac{\mu_0}{2R}\sqrt{I_1^2+I_2^2}$

CONCEPT BUILDER-3

1. (A) $\oint B.d\ell = \mu_0[3 + 1 - 2] = 2\mu_0$

(b) $\oint B.d\ell = \mu_0[3 + 1 - 6] = -2\mu_0$

2. (a) $8\pi \times 10^{-3}$ T (b) $4\pi \times 10^{-3}$ T

3. $2\left(\frac{\mu_0 NI}{\ell}\right) = 2B$ **4.** (1)

5. $B_{mid} = 5\pi \times 10^{-6}$T $B_{end} = 2.5\pi \times 10^{-6}$T

CONCEPT BUILDER-4

1. $(0.8\vec{k} - 1.6\vec{j})$ N **2.** (1, 2)

3. 8.43×10^{-3} m

4. (a) 1.43×10^8 m/s (b) 108 MeV
(c) 1.09×10^{-8} s

5. (3) **6.** (1)

CONCEPT BUILDER-5

1. (a) 5.35×10^7 Hz
(b) 2.675×10^7 Hz

2. 76 MeV

3. 4RIB **4.** F = 0

5. $2\pi aiB$ **6.** (4)

7. (1)

CONCEPT BUILDER-6

1. (2)

2. (A) $\frac{1}{2}\pi I\left[R_2^2 - R_1^2\right]\otimes$

(B) $\vec{M} = \frac{1}{2}\pi I\left[R_2^2 + R_1^2\right]\otimes$

3. (1) **4.** (4)

5. (2) **6.** $\frac{q\omega R^2}{4}$ **7.** $\frac{1}{5}q\omega R^2$

Exercise - I

Introduction, Biot-Savart Law, Magnetic Field Lines & Thumb Rule

1. A moving charge produces:
(1) Electric field only
(2) Magnetic filed only
(3) Both of them
(4) None of these

2. The vector form of Biot savart law for a current carrying element is :

(1) $d\vec{B} = \frac{\mu_0}{4\pi}\frac{id\ell \sin\phi}{r^2}$

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

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

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

3. Gauss is the unit of :
(1) B (2) H
(3) M (4) I

4. If permeability of vacuum is μ_0 and relative permeability is μ_r then permeability of the medium will be :

(1) $\frac{\mu_0}{\mu_r}$ (2) $\mu_0 \times \mu_r$

(3) $\frac{\mu_0}{\mu_r}$ (4) $\frac{1}{\mu_0\mu_r}$

5. The dimension of magnetic field in M, L, T and C (Colulomb) is given as :
(1) $[MLT^{-1} C^{-1}]$ (2) $[MT^2C^{-2}]$
(3) $[MT^{-1}C^{-1}]$ (4) $[MT^{-2}C^{-1}]$

Magnetic Field Due to a Straight Wire

6. π ampere current is flowing through a long straight wire. Due to this a field of 5×10^{-5} T produced, then distance of the point from the axis of the wire is :
(1) $10^4\ \mu_0$m (2) $10^4/\mu_0$ m
(3) $10^6\ \mu_0$ m (4) $10^8\ \mu_0$ m

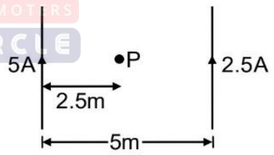
7. A small linear segment of an electric circuit is lying on x-axis extending from x = –a/2 to x = a/2 and a current i is flowing in it. The magnetic induction due to the segment at a point x = a on x-axis will be-
(1) $\propto a$ (2) zero
(3) $\propto a^2$ (4) $\propto$

8. A current i is flowing in a straight conductor of length L. The magnetic induction at a point distant L/4 from its centre point will be -

(1) $\frac{4\mu_0 i}{\sqrt{5}\pi L}$ (2) $\frac{\mu_0 i}{2\pi L}$

(3) $\frac{\mu_0 i}{\sqrt{2}L}$ (4) zero

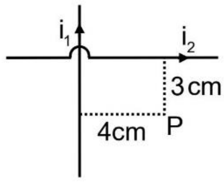
9. For the given current distribution the magnetic field at point, 'P' is :



(1) $\frac{\mu_0}{4\pi}\odot$ (2) $\frac{\mu_0}{\pi}\otimes$

(3) $\frac{\mu_0}{2\pi}\otimes$ (4) $\frac{\mu_0}{2\pi}\odot$

10. Two insulated wires of infinite length are lying mutually at right angles to each other as shown in. Currents of 2A and 1.5A respectively are flowing in them. The value of magnetic induction at point P will be-



(1) 2×10^{-3} N/A-m (2) 2×10^{-5} N/A-m
(3) zero (4) 2×10^{-4} N/A-m

11. Two infinite long parallel wires carry equal currents in same direction. The magnetic field at a mid point in between the two wire is :–

(1) Twice the magnetic field produced due to each of the wires

(2) Half of the magnetic field produced due to each of the wires

(3) Square of the magnetic field produced due to each of the wires

(4) Zero

12. A current of i ampere is flowing in an equilateral triangle of side a. The magnetic induction at the centroid will be-

(1) $\frac{\mu_0 i}{3\sqrt{3}\pi a}$ (2) $\frac{3\mu_0 i}{2\pi a}$

(3) $\frac{5\sqrt{2}\mu_0 i}{3\pi a}$ (4) $\frac{9\mu_0 i}{2\pi a}$

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

(1) twice the earlier value

(2) one-half of the earlier value

(3) one quarter of the earlier value

(4) same as earlier value

14. A long straight wire carries an electric current of 2 A. The magnetic induction at a perpendicular distance of 5m from the wire will be

(1) 4×10^{-8} T (2) 8×10^{-8} T

(3) 12×10^{-8} T (4) 16×10^{-8} T

15. The strength of the magnetic field at a point distant r near a long straight current carrying wire is B. The field at a distance r/2 will be

(1) B/2 (2) B/4

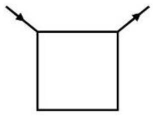
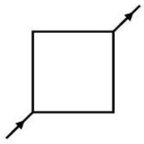
(3) 4B (4) 2B

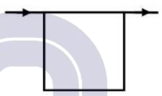
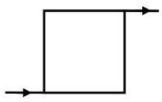
16. A wire in the form of a square of side 'a' carries a current 'i'. Then the magnetic induction at the centre of the square wire is (Magnetic permeability of free space = μ_0)

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

(3) $\frac{2\sqrt{2}\mu_0 i}{\pi a}$ (4) $\frac{\mu_0 i}{\sqrt{2}\pi a}$

17. Current flows through uniform, square frames as shown. In which case is the magnetic field at the centre of the frame not zero?

(1)  (2) 

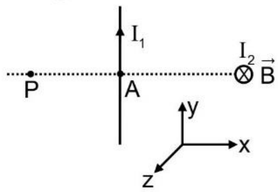
(3)  (4) 

18. Equal current i is flowing in three infinitely long wires along positive x, y and z directions. The magnitude of magnetic field at a point (0, 0, –a) would be

(1) $\frac{\mu_0 i}{2\pi a}(\hat{j}-\hat{i})$ (2) $\frac{\mu_0 i}{2\pi a}(\hat{j}+\hat{i})$

(3) $\frac{\mu_0 i}{2\pi a}(\hat{i}-\hat{j})$ (4) $\frac{\mu_0 i}{2\pi a}(\hat{i}+\hat{j}+\hat{k})$

19. Two infinitely long linear conductors are arranged perpendicular to each other and are in mutually perpendicular planes as shown in figure.



If I_1=2A along the y–axis and I_2 = 3A along –ve z–axis and AP = AB = 1cm. The value of magnetic field strength $\vec{B}$ at P is

(1) $(3 \times 10^{-5}\text{ T})\hat{j} + (-4 \times 10^{-5}\text{ T})\hat{k}$

(2) $(3 \times 10^{-5}\text{ T})\hat{j} + (4 \times 10^{-5}\text{ T})\hat{k}$

(3) $(4 \times 10^{-5}\text{ T})\hat{j} + (3 \times 10^{-5}\text{ T})\hat{k}$

(4) $(-3 \times 10^{-5}\text{ T})\hat{j} + (4 \times 10^{-5}\text{ T})\hat{k}$

20. 1A current flows through an infinite long straight wire. The magnetic field produced at a point 1m. away from it is:

(1) 2×10^{-3} T (2) $2\pi \times 10^{-8}$ T
(3) 2×10^{-7} T (4) $2\pi \times 10^{-6}$ T

Magnetic Field Due to a Circular Current Carrying Coil

21. Two concentric circular loops of radii 0·08m and 0·1m carries current such that magnetic field at the centre is zero. If the current in the outer loop is 8A clockwise, current in the inner loop is :

(1) 6.4 A anticlockwise
(2) 6.4 A clockwise
(3) 8A anticlockwise
(4) 3.2 A clockwise

22. When the current flowing in a circular coil is doubled and the number of turns of the coil in it is halved, the magnetic field at its centre will become :

(1) Same (2) Four times
(3) Half (4) Double

23. Radius of a current carrying coil is 'R'. The ratio of magnetic field at a axial point which is R distance away from the centre of the coil to the magnetic field at the centre of the coil :

(1) $\left(\frac{1}{2}\right)^{1/2}$ (2) $\frac{1}{2}$
(3) $\left(\frac{1}{2}\right)^{3/2}$ (4) $\frac{1}{4}$

24. An electric current i is flowing in a circular coil of radius a. At what distance from the centre on the axis of the coil will the magnetic field be $\frac{1}{8}$th of its value at the centre -

(1) 3a (2) $\sqrt{3}$a
(3) $\frac{a}{3}$ (4) $\frac{a}{\sqrt{3}}$

25. The magnetic field on the axis of a current carrying circular coil of radius a at a distance 2a from its centre will be-

(1) $\frac{\mu_0 i}{2}$ (2) $\frac{\mu_0 i}{10\sqrt{5}a}$
(3) $\frac{\mu_0 i}{4a}$ (4) $\mu_0 i$

26. A circular coil of radius R carries an electric current. The magnetic field due the coil at a point on the axis of the coil located at a distance r from the center of the coil, such that r >> R varies as :

(1) 1/r (2) $1/r^{3/2}$
(3) $1/r^2$ (4) $1/r^3$

27. The use of Helmholtz coils is to produce-

(1) uniform magnetic field
(2) non-uniform magnetic field
(3) varying magnetic field
(4) zero magnetic field

28. 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 induction at their centres will be :

(1) 2 : 1 (2) 1 : 4
(3) 4 : 1 (4) 1 : 2

29. Magnetic field due to 0.1A current flowing through a circular coil of radius 0.1 m and 1000 turns at the centre of the coil is :

(1) 0.2 T (2) 2×10^{-4} T
(3) 6.28×10^{-4} T (4) 9.8×10^{-4} T

30. A circular arc of wire subtends an angle $\pi/2$ at the centre. If it carries a current I and its radius of curvature is R, then the magnetic field at the centre of the arc is

(1) $\frac{\mu_0 I}{8R}$ (2) $\frac{\mu_0 I}{R}$
(3) $\frac{\mu_0 I}{2R}$ (4) $\frac{\mu_0 I}{4R}$

31. Two concentric coils each of radius equal to 2π cm are placed at right angles to each other. 3A and 4A are the currents flowing in each coil respectively. The magnetic induction in Wb/m^2 at the centre of the coils will be:–

($\mu_0 = 4\pi \times 10^{-7}$ Wb/Am)

(1) 12×10^{-5} (2) 10^{-5}
(3) 5×10^{-5} (4) 7×10^{-5}

32. Which of the following statement is not true; magnetic field at the centre of current carrying loop :

(1) proportional to current
(2) inversely proportional to radius
(3) proportional to number of turns
(4) none

33. If radius of coil becomes two times and current becomes half then magnetic field at centre of the coil will be :

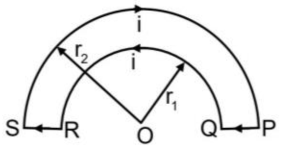
(1) Two times (2) Four times
(3) Half (4) One fourth

34. 2 A current is flowing in a circular loop of radius 1m. Magnitude of magnetic field at the centre of circular loop will be :

(1) $\frac{\mu_0}{2}$ (2) $2\mu_0$
(3) μ_0 (4) $\frac{\mu_0}{2\pi}$

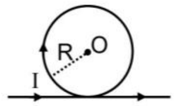
Magnetic Field Due to Various Miscellaneous Arrangements

35. A wire loop PQRSP is constructed by joining two semi circular coils of radii r_1 and r_2 respectively as shown in the fig. Current i is flowing in the loop. The magnetic induction at point O will be-



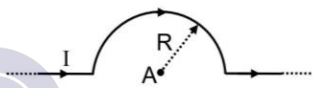
(1) $\frac{\mu_0 i}{4}\left[\frac{1}{r_1} - \frac{1}{r_2}\right]$ (2) $\frac{\mu_0 i}{4}\left[\frac{1}{r_1} + \frac{1}{r_2}\right]$
(3) $\frac{\mu_0 i}{2}\left[\frac{1}{r_1} - \frac{1}{r_2}\right]$ (4) $\frac{\mu_0 i}{2}\left[\frac{1}{r_1} + \frac{1}{r_2}\right]$

36. An infinitely long straight conductor is bent into the shape as shown in figure. It carries a current I ampere and the radius of the circular loop is r meter. Then the magnetic induction at the centre of the circular part is :–



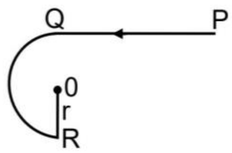
(1) Zero (2) ∞
(3) $\frac{\mu_0}{4\pi}\frac{2I}{r}(\pi + 1)$ (4) $\frac{\mu_0}{4\pi}\frac{2I}{r}(\pi - 1)$

37. In the shown figure magnetic field at point A will be :



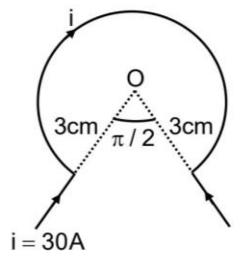
(1) $\frac{\mu_0 I}{4\pi}$ (2) $\frac{\mu_0 I}{4R}$
(3) $\frac{\mu_0 I}{4\pi R}$ (4) Zero

38. The magnetic induction at centre O due to the arrangement shown in fig.-



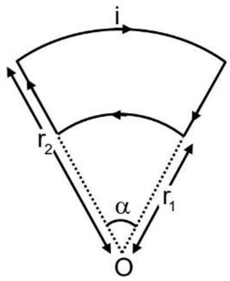
(1) $\frac{\mu_0 i}{4\pi r}(1+\pi)$ (2) $\frac{\mu_0 i}{4\pi r}$
(3) $\frac{\mu_0 i}{4\pi r}(1-\pi)$ (4) $\frac{\mu_0 i}{r}$

39. A current of 30 amp. is flowing in a conductor as shown in the fig. The magnetic induction at point O will be:



(1) 1.5 Tesla (2) $1.5\pi \times 10^{-4}$ Tesla
(3) zero (4) 0.15 Tesla

40. The magnetic induction at centre O in the following figure will be -



(1) $\frac{\mu_0 i\alpha}{4\pi}\left(\frac{1}{r_1}-\frac{1}{r_2}\right)\odot$ (2) $\frac{\mu_0 i\alpha}{4\pi}\left(\frac{1}{r_1}+\frac{1}{r_2}\right)\odot$

(3) $\frac{\mu_0 i\alpha}{2\pi}\left[\frac{1}{r_1}-\frac{1}{r_2}\right]\otimes$ (4) $\frac{\mu_0 i\alpha}{2\pi}\left[\frac{1}{r_1}+\frac{1}{r_2}\right]\otimes$

Solenoid & Toroid

41. When the number of turns in a toroidal coil is doubled, then the value of magnetic flux density will becomes:

(1) four times (2) eight times

(3) half (4) double

42. The magnetic field inside a solenoid is -

(1) infinite (2) zero

(3) uniform (4) non-uniform

43. An long solenoid has 200 turns per cm and carries a current of 2.5 amp. The magnetic field at its centre is

[$\mu_0 = 4\pi \times 10^{-7}$ weber/amp-m]:

(1) 3.14×10^{-2} weber/m^2

(2) 6.28×10^{-2} weber/m^2

(3) 9.42×10^{-2} weber/m^2

(4) 12.56×10^{-2} weber/m^2

44. A long solenoid has length L, average diameter D and n layer of turns. Each layer contains N turns. If current flowing through the solenoid is i, the value of magnetic field at the centre:–

(1) Proportional to D

(2) Inversely proportional to D

(3) Does not depend on D

(4) Proportional to L

Force on a Moving Charged Particle in a Magnetic Field, Motion of a Charged Particle in a Magnetic Field, Lorentz Force, Cyclotron, Ampere circuital law

45. A proton, deuteron and an α–particle are accelerated by same potential, enters in uniform magnetic field perpendicularly. Ratio of radii of circular path respectively:

(1) $1 : \sqrt{2} : \sqrt{2}$ (2) 2 : 2 : 1

(3) 1 : 2 : 1 (4) 1 : 1 : 1

46. A charge particle is moving in the opposite direction of a magnetic field. The magnetic force acting on the particle:

(1) is in the direction of its velocity

(2) is in the direction opposite to its velocity

(3) is perpendicular to its velocity

(4) is zero

47. An electric field E and a magnetic field B applied on a proton which moves with velocity v, it goes undeflected through the region if :

(1) $E \perp B$

(2) E is parallel to v and perpendicular to B

(3) E, B and v all three are mutually perpendicular to each other and $v = \frac{E}{B}$

(4) E and B both are parallel but perpendicular to v

48. When a charged particle enters in a uniform magnetic field its kinetic energy:

(1) remains constant (2) increases

(3) decreases (4) becomes zero

49. When a charged particle moves at right angles to a magnetic field then which of the following quantities changes-

(1) energy (2) momentum

(3) speed (4) all of above

50. The velocities of two particles entering a uniform magnetic field are in the ratio 1 : 3. Their path becomes circular in the magnetic field. The ratio of radii of their circular paths will be-

(1) 1 : 3 (2) 3 : 1

(3) 1 : 9 (4) 9 : 1

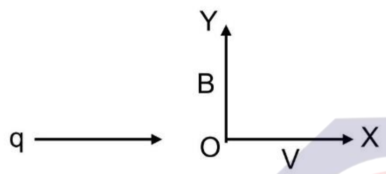
51. A proton and an α-particle enter a uniform magnetic field at right angles to it with same velocity. The time period of α particle as compared to that of proton, will be -

(1) four times (2) two times
(3) half (4) one fourth

52. A charged particle with charge q is moving in a uniform magnetic field. If this particle makes any angle with the magnetic field then its path will be-

(1) circular (2) straight line
(3) helical (4) parabolic

53. If a positively charged particle is moving as shown in the fig., then it will get deflected due to magnetic field towards -



(1) +x direction (2) +y direction
(3) −x direction (4) +z direction

54. An electron is travelling along the x-direction. It encounters a magnetic field in the y-direction. Its subsequent motion will be:

(1) straight line along the x-direction
(2) a circle in the xz plane
(3) a circle in the yz plane
(4) a circle in the xy plane

55. A charge having q/m equal to 10^8 C/kg and with velocity 3×10^5 m/s enters into a uniform magnetic field B = 0.3 tesla at an angle 30^0 with direction of field. Then radius of curvature will be:

(1) 0.01 cm (2) 0.5cm
(3) 1 cm (4) 2 cm

56. A charged particle of charge q and mass m enters perpendicularly in a magnetic field. Kinetic energy of the particle is E; then frequency of rotation is :

(1) $\frac{qB}{m\pi}$ (2) $\frac{qB}{2\pi m}$
(3) $\frac{qBE}{2\pi m}$ (4) $\frac{qB}{2\pi E}$

57. A charge of 1C is moving in a perpendicular magnetic field of 0.5 Tesla with a velocity of 10 m/sec. Force experienced is:

(1) 5 N (2) 10 N
(3) 0.5 N (4) 0 N

58. An electron accelerated by 200 V, enters a magnetic field. If its velocity is 8.4×10^6 m/sec. then (e/m) for it will be : (in C/kg)

(1) 1.75×10^{10} (2) 1.75×10^{11}
(3) 1.75×10^{9} (4) 1.75×10^{6}

59. A charge q is moving in a uniform magnetic field. The magnetic force acting on it does not depend upon

(1) charge (2) mass
(3) velocity (4) magnetic field

60. A proton enters a magnetic field with velocity parallel to the magnetic field. The path followed by the proton is a

(1) circle (2) parabola
(3) helix (4) straight line

61. An electron (mass = 9.0×10^{-31} kg and charge = 1.6×10^{-19} coulomb) is moving in a circular orbit in a magnetic field of 1.0×10^{-4} weber/m². Its period of revolution is:

(1) 3.5×10^{-7} sec (2) 7.0×10^{-7} sec
(3) 1.05×10^{-6} sec (4) 2.1×10^{-6} sec

62. An electron is moving with velocity $\vec{v}$ in the direction of magnetic field $\vec{B}$, then force acting on electron is :

(1) Zero (2) $e(\vec{v} \times \vec{B})$
(3) $e(\vec{B} \times \vec{v})$ (4) $\frac{1}{2} e(\vec{v} \times \vec{B})$

63. An electron moves with velocity v in uniform transverse magnetic field B on circular path of radius 'r', then e/m for it is:

(1) $\frac{v}{Br}$ (2) $\frac{B}{rv}$
(3) Bvr (4) $\frac{vr}{B}$

64. In an experiment electron are accelerated, from rest, by applying a voltage of 500 V. Calculate the radius of the path if a magnetic field 100 mT is then applied. [Charge of the electron = 1.6×10^{-19} C, Mass of the electron = 9.1×10^{-31} kg]

(1) 7.5×10^{-1} m (2) 7.5×10^{-3} m
(3) 7.5×10^{-4} m (4) 7.5×10^{-2} m

65. In a region constant uniform electric and magnetic field is present. Both field are parallel. In this region a charge released from rest, then path of the particle is :

(1) Circle (2) Helical
(3) Straight line (4) Ellipse

66. A beam of protons enters a uniform magnetic field of 0.3T with velocity of 4×10^5m/s in a direction making an angle of 60º with the direction of magnetic field. The path of motion of the particle will be

(1) Circular (2) Straight line
(3) Spiral (4) Helical

67. In the above question, the radius of path of the particle will be

(1) 12.0m (2) 1.2m
(3) 0.12m (4) 0.012m

68. In above question the pitch of the helix will be

(1) 4.37 m (2) 0.437 m
(3) 0.0437 m (4) 0.00437 m

69. In a certain region of space electric field $\vec{E}$ and magnetic field $\vec{B}$ are perpendicular to each other and an electron enters in region perpendicular to the direction of $\vec{B}$ and $\vec{E}$ both and moves undeflected, then velocity of electron is :

(1) $\frac{|\vec{E}|}{|\vec{B}|}$ (2) $\vec{E} \times \vec{B}$
(3) $\frac{|\vec{B}|}{|\vec{E}|}$ (4) $\vec{E} \cdot \vec{B}$

70. A charged particle with velocity 2×10^3 m/s passed undeflected through electric and perpendicular magnetic field. Magnetic field is 1.5 Tesla. Find electric field intensity.

(1) 2×10^3 N/C (2) 1.5×10^3 N/C
(3) 3×10^3 N/C (4) $4/3 \times 10^{-3}$ N/C

71. A charge particle moves in a region having a uniform magnetic field and a parallel, uniform electric field. At some instant, the velocity of the particle is perpendicular to the field direction. The path of the particle will be

(1) a straight line
(2) a circle
(3) a helix with uniform pitch
(4) a helix with nonuniform pitch

72. An α-particle experiences a force of 3.84×10^{-14} N when its moves perpendicular to magnetic field of 0.2 Wb/m^2 then speed of the α - particle is :

(1) 6.0×10^5 m/sec (2) 5.0×10^5 m/sec
(3) 1.2×10^6 m/sec (4) 3.8×10^6 m/sec

73. A magnetic field :

(1) Always exerts a force on charged particle
(2) Never exerts a force on charged particle
(3) Exert a force, if the charged particle is moving across the magnetic field line
(4) Exerts a force, if the charged particle is moving along the magnetic field line

Force on Current Carrying Wire in a Magnetic Field, Force Between Two Parallel Wires

74. A current carrying wire is arranged at any angle in an uniform magnetic field, then

(1) only force acts on wire
(2) only torque acts on wire
(3) both
(4) none

75. A current i is flowing in a circular conductor of radius r. It is lying in a uniform magnetic field B such that its plane is normal to B. The magnetic force acting on the loop will be -

(1) zero (2) πirB

(3) 2πirB (4) irB

76. Using mass (M), length (L), time (T) and current (A) as fundamental quantities, the dimension of permeability is :

(1) $M^{-1}LT^{-2}A^{1}$ (2) $ML^{2}T^{-2}A^{-1}$

(3) $MLT^{-2}A^{-2}$ (4) $MLT^{-1}A^{-1}$

77. Two parallel wires one of length 1 m and other is infinitive, are lying at a distance of 2m. If the current flowing in each wire is 1 ampere then the force between them will be -

(1) 2×10^{-7} N (2) 10^{-7} N

(3) 0.5 N (4) 10^{7} N

78. A 0.5 m long straight wire in which a current of 1.2 A is flowing is kept at right angle to a uniform magnetic field of 2.0 tesla. The force acting on the wire will be-

(1) 2N (2) 2.4 N

(3) 1.2 N (4) 3 N

79. Two parallel wires P and Q carry electric currents of 10 A and 2A respectively in mutually opposite directions. The distance between the wires is 10 cm. If the wire P is of infinite length and wire Q is 2m long, then the force acting Q will be-

(1) 4×10^{-5} N (2) 8×10^{-5} N

(3) 4×10^{5} N (4) 0 N

80. Two long parallel wires are at a distance of 1 m. Both of them carry one ampere of current. The force of attraction per unit length between the two wires is :

(1) 2×10^{-7} N/m (2) 2×10^{-8} N/m

(3) 5×10^{-8} N/m (4) 10^{-7} N/m

81. A current-carrying, straight wire is kept along the axis of a circular loop carrying a current. The straight wire

(1) Will exert an inward force on the circular loop

(2) Will exert an outward force on the circular loop

(3) Will not exert any force on the circular loop

(4) Will exert a force on the circular loop parallel to itself.

Magnetic Dipole & Dipole Moment

82. A circular loop has a radius of 5 cm. and it is carrying a current of 0.1 A. its magnetic moment is :–

(1) 1.32×10^{-4} amp-m^2

(2) 2.62×10^{-4} amp-m^2

(3) 5.25×10^{-4} amp-m^2

(4) 7.85×10^{-4} amp-m^2

83. If the angular momentum of electron is J, then its magnetic moment will be -

(1) $\frac{eJ}{m}$ (2) $\frac{eJ}{2m}$

(3) eJ2m (4) $\frac{2m}{eJ}$

84. The dipole moment of a current loop is independent of

(1) current in the loop

(2) number of turns

(3) area of the loop

(4) magnetic field in which it is situated

85. Due to the flow of current in a circular loop of radius R, the magnetic induction produced at the centre of the loop is B. The magnetic moment of the loop is :

(1) $BR^3 / 2\pi\mu_0$ (2) $2\pi BR^3 / \mu_0$

(3) $BR^2 / 2\pi\mu_0$ (4) $2\pi BR^2 / \mu_0$

86. The magnetic moment has dimensions of:

(1) [L A] (2) $[L^2 A]$

(3) $[LT^{-1} A]$ (4) $[L^2T^{-1} A]$

87. The magnetic moment of a circular coil carrying current is :
(1) directly proportional to the length of the wire in the coil
(2) inversely proportional to the length of the wire in the coil
(3) directly proportional to the square of the length of the wire in the coil
(4) inversely proportional to the square of the length of the wire in the coil

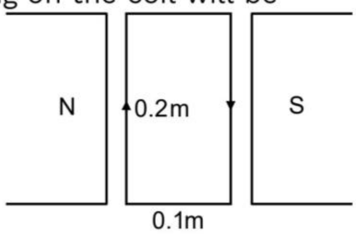
88. Magnetic dipole moment of rectangular loop is
(1) Inversely proportional to current in loop
(2) Inversely proportional to area of loop
(3) Parallel to plane of loop and proportional to area of loop
(4) Perpendicular to plane of loop and proportional to area of loop

Torque, potential Energy of Dipole in Magnetic field and Work Done

89. A current loop of area 0.01m^2 and carrying a current of 10A is held perpendicular to a magnetic field of 0.1T, the torque in N–m acting on the loop is :
(1) 0 (2) 0.001
(3) 0.01 (4) 1.1

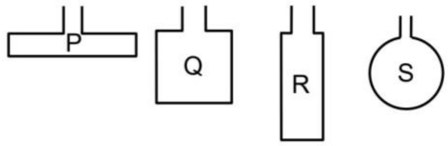
90. A current carrying coil behave like tiny magnet. If area of coil is A and magnetic moment is 'M' then current through the coil is:
(1) $\frac{M}{A}$ (2) $\frac{A}{M}$
(3) MA (4) $\frac{A^2}{M}$

91. A coil of 100 turns is lying in a magnetic field of 1T as shown in the figure. A current of 1A is flowing in this coil. The torque acting on the coil will be



(1) 1N–m (2) 2N–m
(3) 3N–m (4) 4N–m

92. Four wires of equal length are bent in the form of four loops P, Q, R and S. These are suspended in a uniform magnetic field and same current is passed in them. The maximum torque will act on.



(1) P (2) Q
(3) R (4) S

93. Current I is carried in a wire of length L. If the wire is formed into a circular coil, the maximum magnitude of torque in a given magnetic field B, will be:
(1) $\frac{LIB}{4\pi}$ (2) $\frac{L^2IB}{4\pi}$
(3) $\frac{L^2IB}{2}$ (4) $\frac{LIB^2}{2}$

94. A current carrying coil is placed in a constant uniform magnetic field B. Torque is maximum on this coil when plane of coil is :
(1) perpendicular to B
(2) parallel to B
(3) at 45° to B
(4) at 60° to B

Oscillation of Current Coil in a Magnetic Field Atomic Magnetism, Rotation of a Charged Conducting Body Moving Coil Galvanometer

95. An electron is moving in a circle of radius 5.1×10^{-11} m. at a frequency of 6.8×10^{15} revolution/sec. The equivalent current is approximately :–
(1) 5.1×10^{-3} A (2) 6.8×10^{-3} A
(3) 1.1×10^{-3} A (4) 2.2×10^{-3} A

96. The minimum magnetic dipole moment of electron in hydrogen atom is :
(1) $\frac{eh}{2\pi m}$ (2) $\frac{eh}{4\pi m}$
(3) $\frac{eh}{\pi m}$ (4) 0

97. An electron revolves with frequency 6.6×10^{15} r.p.s. around nucleus in circular orbit of radius 0.53 Å of hydrogen atom, then magnetic field produced at centre of orbit is:

(1) 0.125 T (2) 1.25 T
(3) 12.5 T (4) 125 T

98. When direct current passed through a spring then it :

(1) Contracts (2) Expands
(3) Oscillates (4) Unchanged

99. The magnetic moment (μ) of a revolving electron around the nucleus varies with principal quantum number n as :

(1) $\mu \propto n$ (2) $\mu \propto 1/n$
(3) $\mu \propto n^2$ (4) $\mu \propto 1/n^2$

100. The charge on a particle is 100 times that of electron. It is revolving in a circular path of radius 0.8 m at a frequency of 10^{11} revolutions per second. The magnetic field at the centre of path will be -

(1) $10^{-7}\,\mu_0$ (2) $\frac{10^{-7}}{\mu_0}$
(3) $10^{-17}\,\mu_0$ (4) $10^{-6}\,\mu_0$

101. A ring of radius r is uniformly charged with charge q. If the ring is rotated with angular frequency ω, then the magnetic induction at its centre will be -

(1) $10^{-7} \times \frac{\omega}{qr}$ (2) $10^{-7} \times \frac{q}{\omega r}$
(3) $10^{-7} \times \frac{r}{q\omega}$ (4) $10^{-7} \times \frac{q\omega}{r}$

102. If an electron revolves in the path of a circle of radius of 0.5×10^{-10} m at a frequency of 5×10^{15} cycles/s, the electric current in the circle is (charge of an electron 1.6×10^{-19} C)

(1) 0.4 mA (2) 0.8 mA
(3) 1.2 mA (4) 1.6 Ma

103. A long cylindrical wire carrying current of 10 A. has radius of 5 mm, then find its magnetic field induction at a point 2 mm from the centre of the wire. Current is uniformly distributed.

(1) 1.6×10^{-4} T (2) 2.4×10^{-4} T
(3) 3.2×10^{-4} T (4) 0.8×10^{-4} T

ANSWER KEY

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ans.	3	2	1	2	3	1	2	1	3	2	4	4	4	2	4	3	3	1	2	3	1	1	3	2	2
Que.	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Ans.	4	1	2	3	1	3	4	4	3	1	4	2	1	2	1	4	3	2	3	1	4	3	1	2	1
Que.	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Ans.	2	3	4	2	2	2	1	2	2	4	1	1	1	3	3	4	4	3	1	3	4	1	3	1	1
Que.	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
Ans.	3	2	3	2	1	3	4	2	4	2	2	3	4	1	1	2	4	2	2	3	2	3	1	1	4
Que.	101	102	103																						
Ans.	4	2	1																						

Exercise - II

1. Two parallel, long wires carry currents i_1 and i_2 with $i_1 > i_2$. When the current are in the same direction, the magnetic field at a point midway between the wire is 10μT. If the direction of i_2 is reversed, the field becomes 30μT. The ratio i_1/i_2 is

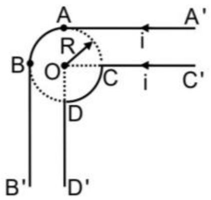
(1) 4 (2) 3 (3) 2 (4) 1

2. Two similar coils of radius R and number of turns N are lying concentrically with their planes at right angles to each other. The currents flowing in them are I and $I\sqrt{3}$ respectively. The resultant magnetic induction at the centre will be (in Wb/m^2).

(1) $\frac{\mu_0 NI}{2R}$ (2) $\frac{\mu_0 NI}{R}$

(3) $\sqrt{3}\mu_0 \frac{NI}{2R}$ (4) $\sqrt{5}\frac{\mu_0 NI}{2R}$

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



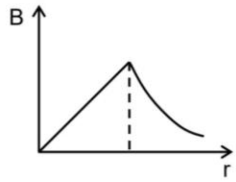
(1) $\frac{\mu_0 i}{4\pi R}$ (2) $\frac{\mu_0 i}{4\pi R}\sqrt{2}$

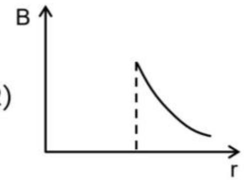
(3) $\frac{\mu_0 i}{2\pi R}$ (4) $\frac{\mu_0 i}{2\pi R}(\pi + 1)$

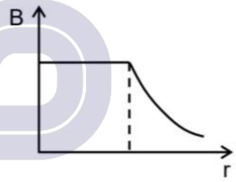
4. Two thick wires and two thin wires, all of the same materials and same length form a square in the three different ways P, Q and R as shown in fig with current direction shown, the magnetic field at the centre of the square is zero in cases

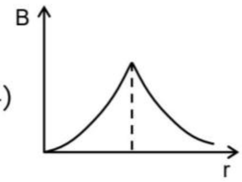
(1) in P only (2) in P and Q only
(3) in Q and R only (4) P and R only

5. Current I is flowing in infinitely long wire. Which of the following graph represents the variation of B w.r.t. axial distance?

(1) 

(2) 

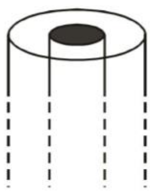
(3) 

(4) 

6. Two long parallel current carrying wire placed at 30 cm distance from each other, current flowing in them is 10A in opposite direction. A point situated in between the wires at 10 cm distance from any wire then magnetic field at that point will be :

(1) 1×10^{-5} T (2) 6×10^{-5} T
(3) 1.5×10^{-5} T (4) 3×10^{-5} T

7. In a coaxial, straight cable, the central conductor and the outer conductor carry equal currents in opposite directions. The magnetic field is zero.



(1) outside the cable
(2) inside the inner conductor
(3) inside the outer conductor
(4) in between the two conductors

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

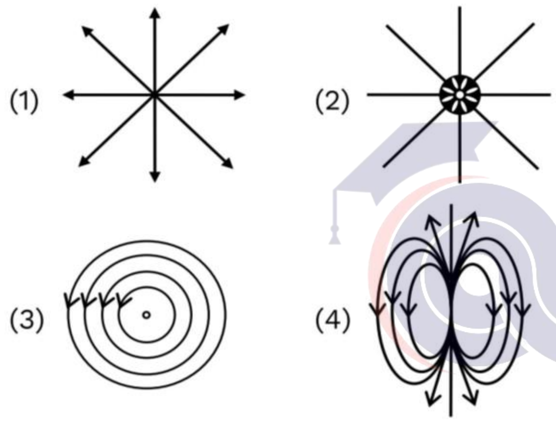
(1) the magnetic field at all points inside the pipe is the same, but not zero

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

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

(4) the magnetic field is different at different points inside the pipe.

9. Which of the field pattern given in the figure is valid for electric field as well as for magnetic field?



10. A toroid of mean radius 'a', cross section radius 'r' and total number of turns N. It carries a current 'i'. The torque experienced by the toroid if a uniform magnetic field of strength B is applied :

(1) is zero

(2) is $B\,i\,N\,\pi\,r^2$

(3) is $B\,i\,N\,\pi\,a^2$

(4) depends on the direction of magnetic field.

11. A proton beam is going from north to south and an electron beam is going from south to north. Neglection the earth's magnetic field, the electron beam will be deflected:

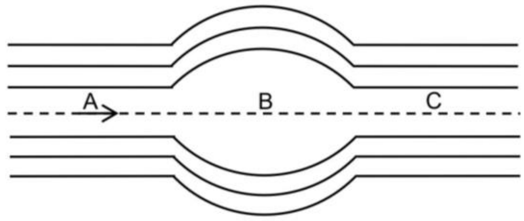
(1) towards the proton beam

(2) away from the proton beam

(3) away from the electron beam

(4) None of these

12. A charged particle is projected from A in nonuniform magnetic field as shown in figure.



The magnitude of velocities at point A, B and C respectively during the motion is :

(1) Maximum at A and C

(2) Maximum at B

(3) Minimum at A and C

(4) Equal at A, B and C

13. A vertical wire carries a current in upward direction. An electron beam sent horizontally towards the wire will be deflected (gravity free space)

(1) towards right (2) towards left

(3) upwards (4) downwards

14. Which of the following particles will experience maximum magnetic force (magnitude) when projected with the same velocity perpendicular to a magnetic field?

(1) Electron (2) proton

(3) He^+ (4) Li^{++}

15. An electric current i enters and leaves a uniform circular wire of radius a through diametrically opposite points. A charged particle q moving along the axis of the circular wire passes through its centre at speed υ. The magnetic force acting on the particle when it passes through the centre has a magnitude

(1) $q\upsilon\frac{\mu_0 i}{2a}$ (2) $q\upsilon\frac{\mu_0 i}{2\pi a}$

(3) $q\upsilon\frac{\mu_0 i}{a}$ (4) zero

16. A negative charged particle falling freely under gravity enters a region having uniform horizontal magnetic field pointing towards north. The particle will be deflected towards

(1) East (2) West

(3) North (4) South

17. A charge particle is moved along a magnetic field line. The magnetic force on the particle is
(1) along its velocity
(2) opposite to its velocity
(3) perpendicular to its velocity
(4) zero

18. A proton, a deuteron and an α-particle having the same kinetic energy are moving in circular trajectories in a constant magnetic field. If r_p, r_d and r_α denote respectively the radii of the trajectories of these particles then
(1) $r_\alpha = r_p < r_d$ (2) $r_\alpha > r_d > r_p$
(3) $r_\alpha = r_d > r_p$ (4) $r_p = r_d = r_\alpha$

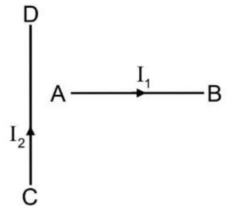
19. A charged particle is released from rest in a region of steady and uniform electric and magnetic fields which are parallel to each other. The particle will move in a
(1) Straight line (2) Circle
(3) Helix (4) Cycloid

20. Two thin long parallel wires separated by a distance 'b' are carrying a current 'i' ampere each. The magnitude of the force per unit length exerted by one wire on the other is
(1) $\frac{\mu_0 i^2}{b^2}$ (2) $\frac{\mu_0 i^2}{2\pi b}$
(3) $\frac{\mu_0 i}{2\pi b}$ (4) $\frac{\mu_0 i}{2\pi b^2}$

21. A particle having the same charge as of electron moves in a circular path of radius 0.5 cm under the influence of a magnetic field of 0.5 T. If an electric field of 100 V/m makes it to move in a straight path, then the mass of the particle is (Given charge of electron = 1.6×10^{-19} kg)
(1) 1.6×10^{-19} kg (2) 2×10^{-24} kg
(3) 1.6×10^{-27} kg (4) 9.1×10^{-31} kg

22. A particle of mass 0.6 g and having charge of 25 nC is moving horizontally with a uniform velocity 1.2×10^4 ms^{-1} in a uniform magnetic field, then the value of the minimum magnetic field is (g = $10ms^{-2}$)
(1) Zero (2) 10 T
(3) 20 T (4) 200 T

23. A current I_1 carrying wire AB is placed near another long wire CD carrying current I_2. If wire AB is free to move, it will have



(1) rotational motion only
(2) translational motion only
(3) rotational as well as translational motion
(4) neither rotational nor translational motion

24. Two very long, straight, parallel wires carry steady currents I and – I respectively. The distance between the wires is d. At a certain instant of time, a point charge q is at a point equidistant from the two wires, in the plane of the wires. Its instantaneous velocity $\vec{v}$ is perpendicular to this plane. The magnitude of the force due to the magnetic field acting on the charge at this instant is:
(1) $\frac{\mu_0 Iqv}{2\pi d}$ (2) $\frac{\mu_0 Iqv}{\pi d}$
(3) $\frac{2\mu_0 Iqv}{\pi d}$ (4) 0

25. Two parallel wires carry currents of 20 A and 40 A in opposite directions. Another wire carrying a current antiparallel to 20 A is placed midway between the two wires. The magnetic force on it will be
(1) towards 20 A
(2) towards 40 A
(3) zero
(4) perpendicular to the plane of the currents

26. A steady current 'I' flows in a small square loop of wire of side L in a horizontal plane. The loop is now folded about its middle such that half of it lies in a vertical plane. Let $\vec{\mu}_1$ and $\vec{\mu}_2$ respectively denote the magnetic moments of the current loop before and after folding. Then :

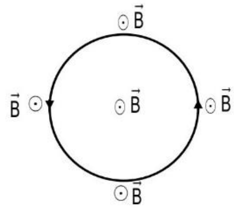
(1) $\vec{\mu}_2 = 0$

(2) $\vec{\mu}_1$ and $\vec{\mu}_2$ are in the same direction

(3) $\frac{|\vec{\mu}_1|}{|\vec{\mu}_2|} = \sqrt{2}$

(4) $\frac{|\vec{\mu}_1|}{|\vec{\mu}_2|} = \frac{1}{\sqrt{2}}$

27. An elastic circular wire of length ℓ carries a current I_0. It is placed in a uniform magnetic field $\vec{B}$ (out of paper) such that its plane is perpendicular to the direction of $\vec{B}$. The wire will experiences:



(1) No force
(2) A stretching force
(3) A compressive force
(4) A torque

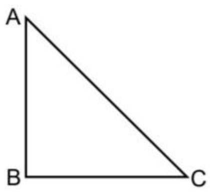
ANSWER KEY

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ans.	3	2	3	4	1	4	1	2	3	1	1	4	3	4	4	2	4	1	1	2	2	3	3	4	2
Que.	26	27																							
Ans.	3	2																							

Exercise – III (Previous Year Question)

1. A current carrying closed loop in the form of a right angle isosceles triangle ABC is placed in a uniform magnetic field acting along AB. If the magnetic force on the arm BC is $\vec{F}$, the force on the arm AC is:

[AIPMT (Pre) 2011]



(1) $-\sqrt{2}\vec{F}$ (2) $-\vec{F}$

(3) $\vec{F}$ (4) $\sqrt{2}\vec{F}$

2. A uniform electric field and a 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 electrons:

[AIPMT (Pre) 2011]

(1) will turn towards right of direction of motion

(2) speed will decrease

(3) speed will increase

(4) will turn towards left of direction of motion

3. Two similar coils of radius R are lying concentrically with their planes at right angles to each other. The currents flowing in them are I and 2I respectively. The resultant magnetic field induction at the centre will be : **[AIPMT (Pre) 2012]**

(1) $\frac{\mu_0 I}{2R}$ (2) $\frac{\mu_0 I}{R}$

(3) $\frac{\sqrt{5}\mu_0 I}{2R}$ (4) $\frac{3\mu_0 I}{2R}$

4. An alternating electric field of frequency ν, is applied across the dies (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:

[AIPMT (Pre) 2012]

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

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

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

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

5. A proton carrying 1 MeV kinetic energy is moving in a circular path of radius R in uniform magnetic field. What should be the energy of an α-particle to describe a circle of same radius in the same field ?

[AIPMT (Mains) 2012]

(1) 0.5 MeV (2) 4 MeV

(3) 2 MeV (4) 1 MeV

6. A current loop in a magnetic field:

[NEET-2013]

(1) Can be in equilibrium in two orientations, one stable while the other is unstable.

(2) Experiences a torque whether the field is uniform or non uniform in all orientations

(3) Can be in equilibrium in one orientation

(4) Can be equilibrium in two orientations, both the equilibrium states are unstable

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 field in the room are : **[NEET-2013]**

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

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

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

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

8. 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 : **[NEET -2014]**

(1) $\frac{\mu_0}{2\pi d}\left(I_1^2 - I_2^2\right)$ (2) $\frac{\mu_0}{2\pi d}\left(I_1^2 + I_2^2\right)^{1/2}$

(3) $\frac{\mu_0}{2\pi d}\left(\frac{I_1}{I_2}\right)$ (4) $\frac{\mu_0}{2\pi d}\left(I_1 + I_2\right)$

9. A proton and an alpha particle both enter a region of uniform magnetic field B moving right angles to the field B. If the radius of circular orbits for both the particles is equal and the kinetic energy acquired by proton is 1 MeV, the energy acquired by the alpha particle will be : **[NEET -2015]**

(1) 1 MeV (2) 4 MeV
(3) 0.5 MeV (4) 1.5 MeV

10. 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/m². The coil carries a current of 2 A . If the plane of the coil is inclined at an angle of 30° with the direction of the field, the torque required to keep the coil in stable equilibrium will be: **[NEET- 2015]**

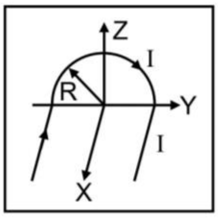
(1) 0.12 Nm (2) 0.15 Nm
(3) 0.20 Nm (4) 0.24 Nm

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: **[NEET- 2015]**

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

(3) $\frac{\mu_0 ne}{2r}$ (4) $\frac{\mu_0 ne}{2\pi r}$

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 : **[NEET- 2015]**



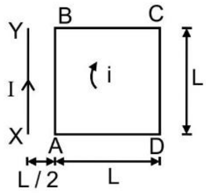
(1) $\vec{B} = -\frac{\mu_0}{4\pi}\frac{I}{R}\left(\pi\hat{i} - 2\hat{k}\right)$

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

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

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

13. 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 : **[NEET - 2016]**



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

(3) $\frac{2\mu_0 IiL}{3\pi}$ (4) $\frac{\mu_0 IiL}{2\pi}$

14. A long straight wire of radius a carries a steady current I. The current is uniformly distributed over its cross-section. The ratio of the magnetic fields B and B', at radial distances a/2 and 2a respectively, from the axis of the wire is : **[NEET - 2016]**

(1) 1/4 (2) 1/2

(3) 1 (4) 4

15. A long wire carrying a steady current is bent into a circular loop of one turn. The magnetic field at the centre of the loop is B. It is then bent into a circular coil of n turns. The magnetic field at the centre of this coil of n turns will be : **[NEET- 2016]**

(1) 2nB (2) $2n^2B$

(3) nB (4) n^2B

16. An electron is moving in a circular path under the influence of a transverse magnetic field of 3.57×10^{-2} T. If the value of e/m is 1.76×10^{11} C/kg, the frequency of revolution of the electron is: **[NEET-2016]**

(1) 62.8 MHz (2) 6.28 MHz

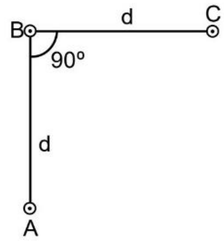
(3) 1 GHz (4) 100 MHz

17. A 250 - Turn rectangular coil of length 2.1 cm and width 1.25 cm carries a current of 85 μA and subjected to a magnetic field of strength 0.85 T. Work done for rotating the coil by 180º against the torque is : **[NEET - 2017]**

(1) 9.1 μ J (2) 4.55 μ J

(3) 2.3 μ J (4) 1.15 μ J

18. An arrangement of three parallel straight wires placed perpendicular to plane of paper carrying same current 'I' along the same direction is shown in Fig. Magnitude of force per unit length on the middle wire 'B' is given by : **[NEET - 2017]**



(1) $\frac{\mu_\circ i^2}{2\pi d}$ (2) $\frac{2\mu_\circ i^2}{\pi d}$

(3) $\frac{\sqrt{2}\mu_\circ i^2}{\pi d}$ (4) $\frac{\mu_\circ i^2}{\sqrt{2}\pi d}$

19. A metallic rod of mass per unit length 0.5 kg/m is lying horizontally on a smooth inclined plane which makes an angle of 30^0 with the horizontal. The rod is not allowed to slide down by flowing a current through it when a magnetic field of induction 0.25 T is acting on it in the vertical direction. The current flowing in the rod to keep is stationary is **[NEET- 2018]**

(1) 7.14 A (2) 5.98 A

(3) 14.76 A (4) 11.32 A

20. Current sensitivity of a moving coil galvanometer is 5 div/mA and its voltage sensitivity (angular deflection per unit voltage applied) is 20 div/V. The resistance of the galvanometer is: **[NEET-2018]**

(1) 40 Ω (2) 25 Ω

(3) 250 Ω (4) 500Ω

21. A long solenoid of 50 cm, length having 100 turns carries a current of 2.5 A. The magnetic field at the centre of the solenoid is : ($\mu_0 = 4\pi \times 10^{-7}$ Tm A^{-1}) **[NEET-2020]**

(1) 6.28×10^{-5} T (2) 3.14×10^{-5} T

(3) 6.28×10^{-4}T (4) 3.14×10^{-4} T

22. A wire of length L metre carrying a current of I ampere is bent in the form of a circle. Its magnetic moment is,

[NEET_Covid_2020]

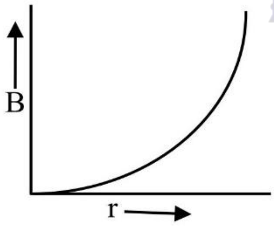
(1) $IL^2/4\ Am^2$

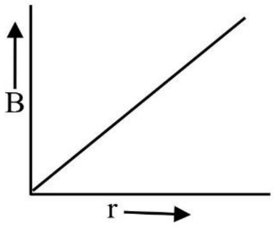
(2) $I\pi\ L^2/4\ Am^2$

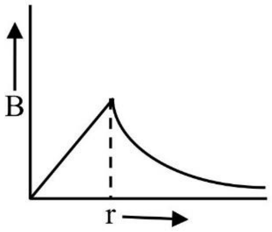
(3) $2\ IL^2/\pi\ Am^2$

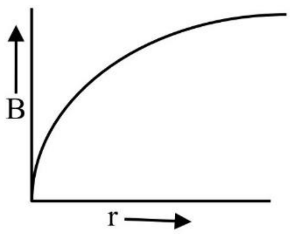
(4) $IL^2/4\pi\ Am^2$

23. A thick current carrying cable of radius 'R' carries current 'I' uniformly distributed across its cross-section. The variation of magnetic field B(r) due to the cable with the distance 'r' from the axis of the cable is represented by : **[NEET-2021]**

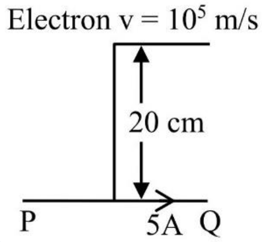
(1)


(2)


(3)


(4)


24. An infinitely long straight conductor carries a current of 5 A as shown. An electron is moving with a speed of 10^5 m/s parallel to the conductor. The perpendicular distance between the electron and the conductor is 20 cm at an instant. Calculate the magnitude of the force experienced by the electron at that instant. **[NEET-2021]**



(1) 4×10^{-20}N (2) $8\pi\times10^{-20}$N

(3) $4\pi\times10^{-20}$N (4) 8×10^{-20}N

25. In the product

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

$=q\vec{\upsilon}\times(B\hat{i}+B\hat{j}+B_0\hat{k})$

For q = 1 and $\vec{\upsilon}=2\hat{i}+4\hat{j}+6\hat{k}$

and $\vec{F}=4\hat{i}-20\hat{j}+12\hat{k}$

What will be the complete expression for $\vec{B}$? **[NEET-2021]**

(1) $-8\hat{i}-8\hat{j}-6\hat{k}$ (2) $-6\hat{i}-6\hat{j}-8\hat{k}$

(3) $8\hat{i}+8\hat{j}-6\hat{k}$ (4) $6\hat{i}+6\hat{j}-8\hat{k}$

26. A uniform conducting wire of length 12a and resistance 'R' is wound up as a current carrying coil in the shape of,

[NEET-2021]

(i) an equilateral triangle of side 'a'.

(ii) a square of side 'a'.

The magnetic dipole moments of the coil in each case respectively are:

(1) $\sqrt{3}\,Ia^2$ and $3\ Ia^2$ (2) $3\ Ia^2$ and Ia^2

(3) $3\ Ia^2$ and $4\ Ia^2$ (4) $4\ Ia^2$ and $3\ Ia^2$

27. Given below are two statements: **[NEET-2022]**

Statement I:

Biot-Savart's law gives us the expression for the magnetic field strength of an infinitesimal current element (Idl) of a current carrying conductor only.

Statement II:

Biot-Savart's law is analogous to Coulomb's inverse square law of charge q, with the former being related to the field produced by a scalar source, Idl while the latter being produced by a vector source, q.

In light of above statements choose the most appropriate answer from the options given below:

(1) Both statement I and statement II are correct

(2) Both statement I and statement II are incorrect

(3) Statement I is correct and Statement II is incorrect

(4) Statement I is incorrect and Statement II is correct

28. A long solenoid of radius 1 mm has 100 turns per mm. If 1 A current flows in the solenoid, the magnetic field strength at the centre of the solenoid is: **[NEET-2022]**

(1) 6.28×10^{-2} T (2) 12.56×10^{-2} T

(3) 12.56×10^{-4} T (4) 6.28×10^{-4} T

29. From Ampere's circuital law for a long straight wire of circular cross-section carrying a steady current, the variation of magnetic field in the inside and outside region of the wire is: **[NEET-2022]**

(1) Uniform and remains constant for both the regions

(2) A linearly increasing function of distance upto the boundary of the wire and then linearly decreasing for the outside region.

(3) A linearly increasing function of distance r upto the boundary of the wire and then decreasing one with 1/r dependence for the outside region.

(4) A linearly decreasing function of distance upto the boundary of the wire and then a linearly increasing one for the outside region.

ANSWER KEY

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ans.	2	2	3	1	4	1	3	2	1	3	3	2	1	3	4	3	1	4	2	3	3	4	3	4	2
Que.	26	27	28	29																					
Ans.	1	3	2	3																					