20

Magnetic Effects of Current

IN THIS CHAPTER ....

In the year 1820, Oersted realised that electricity and magnetism were related to each other. He showed experimentally that the electric current through a straight wire causes noticeable deflection of the magnetic compass needle held near the wire.

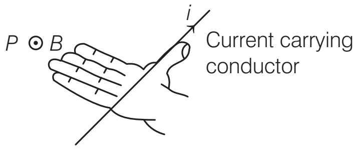
This shows that the magnetic field is associated with a moving charge or a current carrying conductor. The branch of physics which deals with the magnetism due to electric current is called **electromagnetism**.

Magnetic Field

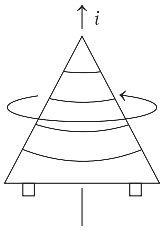
The space around a magnet, moving charges or current carrying conductor in which its magnetic effect can be experienced, is called magnetic field (**B**). It is a vector quantity. The SI unit for magnetic field is tesla or weber/m^2 and its CGS unit is gauss (1 tesla = 10^4 gauss) or maxwell/cm^2.

Rules to Find Direction of Magnetic Field

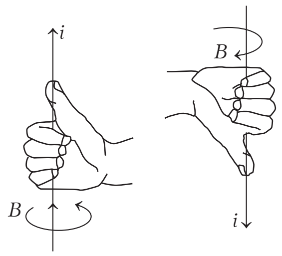
- **Right Hand Palm Rule** If we spread our right hand in such a way that thumb is towards the direction of current and fingers are towards that point where we have to find the direction of field, then the direction of field will be perpendicular to the palm.



- **Maxwell's Right Handed Screw Rule** If a right handed cork screw is rotated so that its tip moves in the direction of flow of current through the conductor, then the rotation of the head of the screw gives the direction of magnetic field.



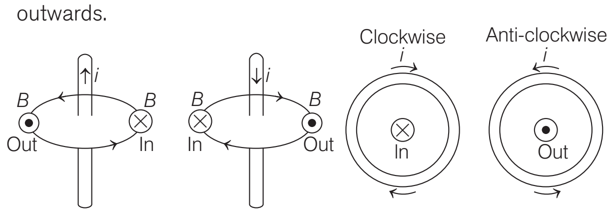
- **Right hand thumb rule** If a straight current carrying conductor is held in the right hand such that the thumb of the hand represents the direction of current flow, then the direction of the folding fingers will represent the direction of magnetic field lines of force.



Note (i) If magnetic field is directed perpendicular and into the plane of the paper, it is represented by ⊗(cross) whereas if magnetic field is directed perpendicular and out of the plane of the paper, it is represented by ⊙ (dot).

(ii) **In** Magnetic field is away from the observer or perpendicular inwards.

Out Magnetic field is towards the observer or perpendicular outwards.



Biot-Savart's Law

This law deals with the magnetic field produced at a point due to a small current element.

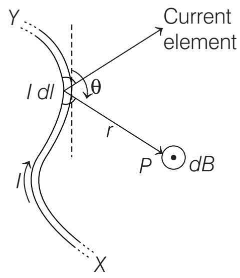
According to this law, the magnitude of the magnetic field $\mathbf{dB}$ at the point P due to the small current element of length $\mathbf{dl}$ is given by

$$|\mathbf{dB}| = \frac{\mu_0}{4\pi} \frac{idl \sin\theta}{r^2}$$

where, μ_0 is a constant and is called, *magnetic permeability of free space.*

$$\mu_0 = 4\pi \times 10^{-7} \text{ Wb/A-m}$$

The value of $\frac{\mu_0}{4\pi}$ in CGS is unity.



Its direction is perpendicular to the plane containing $d\mathbf{l}$ and $\mathbf{r}$.

In vector form, Biot-Savart's law can be written as

$$d\mathbf{B} \propto \frac{i\,(d\mathbf{l} \times \mathbf{r})}{|\,\mathbf{r}\,|^3}$$

$$= \frac{\mu_0}{4\pi} \cdot \frac{id\mathbf{l} \times \mathbf{r}}{r^3}$$

The direction of $d\mathbf{B}$ is represented by the right hand screw rule or right hand thumb rule.

Similarly, magnetic field induction at point P due to current through entire wire,

$$\mathbf{B} = \int \frac{\mu_0}{4\pi} \cdot \frac{i(d\mathbf{l} \times \mathbf{r})}{r^3}$$

or

$$\mathbf{B} = \int \frac{\mu_0}{4\pi} \cdot \frac{id\,l \sin\theta}{r^2}$$

Biot-Savart's Law in a Medium

If the conductor is placed in a medium, then vector form of magnetic field is given as

$$d\mathbf{B} = \frac{\mu}{4\pi} \frac{i(d\mathbf{l} \times \mathbf{r})}{|\,\mathbf{r}\,|^3}$$

$$= \frac{\mu_0\mu_r}{4\pi} \frac{i\,(d\mathbf{l} \times \mathbf{r})}{r^3}$$

where, μ_r = relative permeability $= \frac{\mu}{\mu_0}$

and μ = absolute permeability of the medium.

For air or vacuum $\mu_r = 1$.

Biot-Savart's Law in Terms of Current Density $\boldsymbol{J}$

$$d\mathbf{B} = \frac{\mu_0}{4\pi} \cdot \frac{(\mathbf{J} \times \mathbf{r})}{r^3} dV \qquad \left(\because J = \frac{i}{A} = \frac{idA}{Adl} = \frac{idl}{dV}\right)$$

Biot-Savart's Law in Terms of Charge $\boldsymbol{q}$ and its Velocity $\boldsymbol{v}$

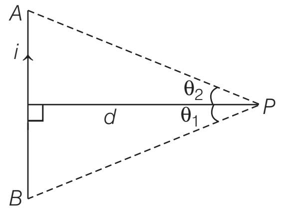
A moving charge constitutes current and hence, associated magnetic field is given as

$$d\mathbf{B} = \frac{\mu_0}{4\pi} \cdot \frac{q(\mathbf{v} \times \mathbf{r})}{r^3} \qquad \left(\because idl = \frac{q}{dt} dl = q\frac{dl}{dt} = qv\right)$$

Applications of Biot-Savart's Law

Let us consider few applications of Biot-Savart law

(i) **Magnetic field due to a straight current carrying conductor is**



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

- For an infinitely long straight wire,

$$\theta_1 = \theta_2 = 90^\circ$$

$$\Rightarrow \quad B = \frac{\mu_0 i}{2\pi d}$$

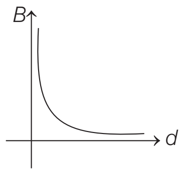
- When wire is semi-infinite (at the foot of long wire),

$$\theta_1 = 0^\circ \text{ and } \theta_2 = \frac{\pi}{2}$$

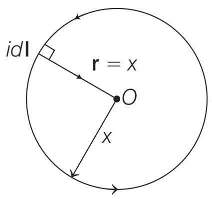
$$\Rightarrow \quad B = \frac{\mu_0 i}{4\pi d}$$

- For axial position of wire, *i.e.* point P lies on axial position of current carrying conductor, then B at P is zero.
- For an infinitely long straight wire, $B \propto \frac{1}{d}$

  $\Rightarrow$ B-d graph is a rectangular hyperbola as shown below



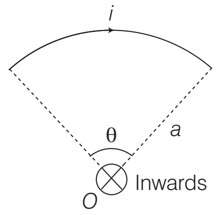
(ii) **Magnetic field at the centre of a circular current carrying coil**



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

- Due to whole circular loop, direction of this field is outward perpendicular to the plane of the paper. If the loop have N turns, then magnetic field, $B = \frac{\mu_0 Ni}{2\pi a}$.

- Magnetic field due to an arc of a circular current carrying coil at the centre is given by

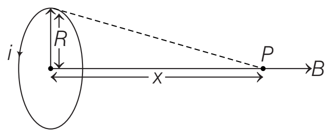


$$B = \left(\frac{\mu_0}{4\pi}\right)\left(\frac{i}{a}\right)\theta$$

Here, θ is to be substituted in radians.

(iii) **Magnetic field on the axis of a circular coil having N turns is**

$$B = \frac{\mu_0 NiR^2}{2(R^2 + x^2)^{3/2}}$$



Here, R = radius of the coil,

x = distance of point P from centre

and i = current in the coil.

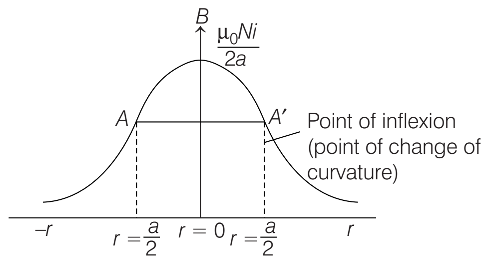
- At the centre of the loop, $x = 0$

$$\therefore \quad B = \frac{\mu_0 Ni}{2R}$$

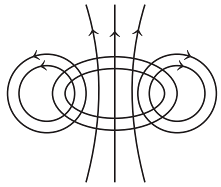
- For $x >> R$, $x^2 + R^2 = x^2$

$$\therefore \quad B = \frac{\mu_0 NiR^2}{2x^3} \Rightarrow B \propto \frac{1}{x^3}$$

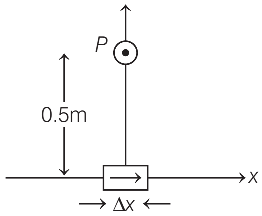
- B-r graph shows the variation of magnetic field at various position on the axis of circular current carrying coil. Magnetic field is maximum at the centre and decreases as we move away from the centre on the axis of the loop.



The magnetic field lines due to current carrying circular coil form closed loops and is shown as follows



Example 1. *An element $\Delta L = \Delta x \cdot \hat{\mathbf{i}}$ is placed at the origin and carries a large current $I = 10$ A. The magnetic field on the Y-axis at a distance of 0.5 m is ($\Delta x = 1$ cm)*



(a) 2×10^{-8} T (b) 6×10^{-8} T
(c) 8×10^{-8} T (d) 4×10^{-8} T

Sol. (d) According to Biot-Savart law,

$$|d\mathbf{B}| = \frac{\mu_0}{4\pi} \frac{idl \sin\theta}{r^2}$$

Given, $\Delta x = dl = 10^{-2}$ m, $I = 10$ A, $r = 0.5$ m $= y$

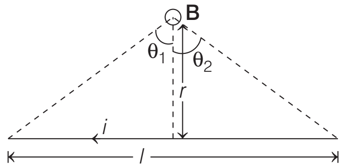
$$\theta = 90^\circ, \sin\theta = 1$$

$$\therefore \quad |d\mathbf{B}| = \frac{10^{-7} \times 10 \times 10^{-2}}{25 \times 10^{-2}} = 4 \times 10^{-8} \text{ T}$$

Example 2. *The magnitude of the magnetic field at the centre of an equilateral triangular loop of side 1 m which is carrying a current of 10 A is [Take, $\mu_0 = 4\pi \times 10^{-7}$ NA^{-2}]* **[JEE Main 2019]**

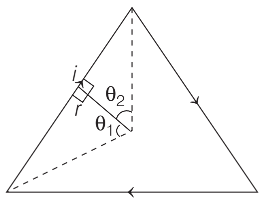
(a) $9\ \mu T$ (b) $1\ \mu T$
(c) $3\ \mu T$ (d) $18\ \mu T$

Sol. (d) For a current carrying wire, from result obtained by Biot-Savart's law, magnetic field at a distance r is given by



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

Now, in given case,



Due to symmetry of arrangement, net field at centre of triangle is

B_{net} = Sum of fields of all wires (sides)

$$= 3 \times \frac{\mu_0 i}{4\pi r}(\sin\theta_1 + \sin\theta_2)$$

Here, $\theta_1 = \theta_2 = 60^\circ$

$$\therefore \quad \sin\theta_1 = \sin\theta_2 = \frac{\sqrt{3}}{2}, i = 10\text{ A}, \frac{\mu_0}{4\pi} = 10^{-7}\text{NA}^{-2}$$

and
$$r = \frac{1}{3} \times \text{altitude} = \frac{1}{3} \times \frac{\sqrt{3}}{2} \times \text{side length} = \frac{1}{2\sqrt{3}} \times 1 = \frac{1}{2\sqrt{3}} \text{ m}$$

So,
$$B_{\text{net}} = \frac{3 \times 10^{-7} \times 10 \times 2\left(\frac{\sqrt{3}}{2}\right)}{\left(\frac{1}{2\sqrt{3}}\right)} = 18 \times 10^{-6} \text{ T}$$

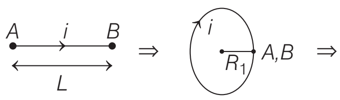
$$\Rightarrow \quad B_{\text{net}} = 18\ \mu\text{T}$$

Example 3. *One of the two identical conducting wires of length L is bent in the form of a circular loop and the other one into a circular coil of N identical turns. If the same current is passed in both, the ratio of the magnetic field at the centre of the loop B_L to that at the centre of the coil B_C, i.e. $\frac{B_L}{B_C}$ will be* **[JEE Main 2019]**

(a) $\frac{1}{N}$ (b) N
(c) $\frac{1}{N^2}$ (d) N^2

Sol. (c) Let consider the length of first wire is L, then according to question, if radius of loop formed is R_1, then

For first wire,

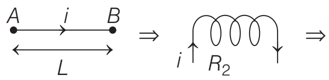


$$L = 2\pi R_1 \Rightarrow R_1 = \frac{L}{2\pi}$$

The magnetic field due to this loop at its centre,

$$B_L = \frac{\mu_0 i}{2R_1} = \frac{\mu_0 i}{2L} \times 2\pi \quad \text{...(i)}$$

Now, second wire is made into a coil of N turns.



(R_2=radius of coil having N loops)

Thin,
$$L = N(2\pi R_2) \Rightarrow R_2 = \frac{L}{2\pi N}$$

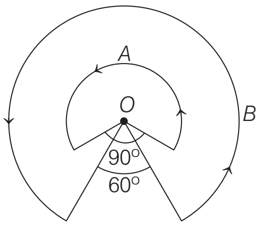
The magnetic field due to this circular coil of N turns,

$$B_C = \left(\frac{\mu_0 i}{2R_2}\right)N = N \cdot \frac{\mu_0 i \cdot (2\pi N)}{2L} \quad \text{...(ii)}$$

Using Eqs. (i) and (ii), the ratio of $\frac{B_L}{B_C}$ is

$$\Rightarrow \quad \frac{B_L}{B_C} = \frac{\frac{\mu_0 i}{2R_1}}{N\frac{\mu_0 i}{2R_2}} = \frac{\frac{\mu_0 i}{2L} \cdot (2\pi)}{\frac{\mu_0 i}{2L} \cdot (2\pi)N^2} = \frac{1}{N^2}$$

Example 4. *A wire A, bent in the shape of an arc of a circle, carrying a current of 2 A and having radius 2 cm and another wire B, also bent in the shape of arc of a circle, carrying a current of 3 A and having radius of 4 cm, are placed as shown in the figure. The ratio of the magnetic fields due to the wires A and B at the common centre O is*



[JEE Main 2020]

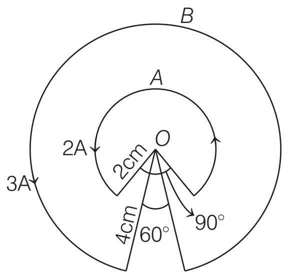
(a) 4 : 6 (b) 6 : 4 (c) 6 : 5 (d) 2 : 5

Sol. (c) For wire *A*,

$$\theta_A = 360° - 90° = 270° = \frac{3\pi}{2} \text{ rad}$$

$$i_A = 2 \text{ A}$$

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



For wire *B*,

$$\theta_B = 360° - 60° = 300° = \frac{5\pi}{3} \text{ rad}$$

$$i_B = 3 \text{ A}$$

$$R_B = 4 \text{ cm} = 4 \times 10^{-2} \text{ m}$$

So, the ratio of magnetic fields due to wires *A* and *B* at the common centre *O* is

$$\frac{B_A}{B_B} = \frac{\dfrac{\mu_0 \theta_A i_A}{4\pi R_A}}{\dfrac{\mu_0 \theta_B i_B}{4\pi R_B}} = \frac{\theta_A i_A R_B}{\theta_B i_B R_A}$$

$$= \frac{\dfrac{3\pi}{2} \times 2 \times 4 \times 10^{-2}}{\dfrac{5\pi}{3} \times 3 \times 2 \times 10^{-2}}$$

$$= \frac{12}{10} = \frac{6}{5}$$

So, $B_A : B_B = 6 : 5$

Example 5. *The magnetic field B due to a current carrying circular loop of radius* 12 cm *at its centre is* 0.5×10^{-4} *T. Find the magnetic field due to this loop at a point on the axis at a distance of* 5.0 cm *from the centre.*

(a) $3.9 \times 10^{-5} T$ (b) $0.5 \times 10^{-4} T$
(c) $3.9 \times 10^{4} T$ (c) $1.0 \times 10^{4} T$

Sol. (a) Magnetic field at the centre of a circular loop, $B_1 = \dfrac{\mu_0 i}{2R}$

and that at an axial point, $B_2 = \dfrac{\mu_0 i R^2}{2(R^2 + x^2)^{3/2}}$

Thus, $$\frac{B_2}{B_1} = \frac{R^3}{(R^2 + x^2)^{3/2}} \text{ or } B_2 = B_1 \left[\frac{R^3}{(R^2 + x^2)^{3/2}}\right]$$

Substituting the values, we have

$$B_2 = (0.5 \times 10^{-4}) \left[\frac{(12)^3}{(144 + 25)^{3/2}}\right]$$

$$= 3.9 \times 10^{-5} \text{ T}$$

Ampere's Circuital Law

It states that, the line integral of **B** around any closed path or circuit is equal to μ_0 times the total current bounded or threaded by that closed path provided the electric field inside the loop remains constant. Thus,

$$\int \mathbf{B} \cdot d\mathbf{l} = \mu_0 (i_{\text{net}})$$

Its simplified form is $Bl = \mu_0 i_{\text{net}}$

This simplified equation can be used under the following conditions

(i) At every point of the closed path, $\mathbf{B} \,||\, d\mathbf{l}$.

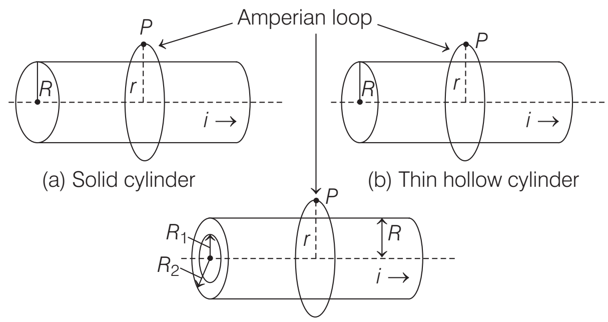
(ii) Magnetic field has the same magnitude B at all places on the closed path.

(iii) Ampere circuital law holds for steady currents which do not change with time.

Magnetic Field due to a Cylindrical Wire

- **Outside the cylinder** ($r > R$)

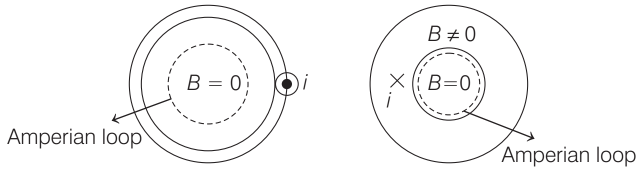
  In all the cases, $B_{\text{surface}} = \dfrac{\mu_0 i}{2\pi R}$



(a) Solid cylinder (b) Thin hollow cylinder

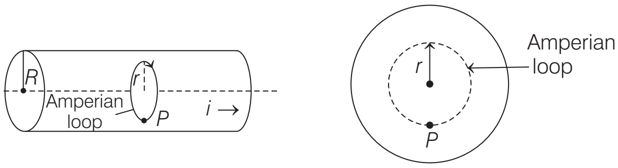
(c) Thick hollow cylinder

- **Inside the hollow cylinder** ($r < R$) Magnetic field inside the hollow cylinder is zero because no current is enclosed by Amperian loops as shown below



(a) Thin hollow cylinder (b) Thick hollow cylinder

- **Inside the solid cylinder** ($r < R$) Current i' enclosed by Amperian loop is lesser than the total current i.

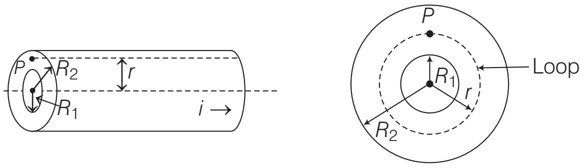


At inside point, $\oint \mathbf{B}_{\text{in}} \cdot d\mathbf{l} = \mu_0 i'$

$$\Rightarrow \qquad B_{\text{in}} = \frac{\mu_0}{2\pi} \cdot \frac{ir}{R^2}$$

- **Inside the thick portion of hollow cylinder** Current enclosed by the Amperian loop of radius r is given by

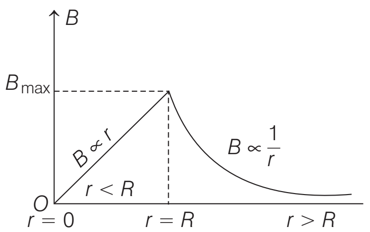
$$i' = i \times \frac{(r^2 - R_1^2)}{(R_2^2 - R_1^2)}$$



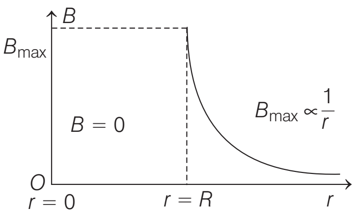
$$B_{\text{in}} = \frac{\mu_0 i}{2\pi r} \cdot \frac{(r^2 - R_1^2)}{(R_2^2 - R_1^2)}$$

Variation in Magnetic Field with Radius

- The variation in magnetic field due to infinite long solid cylindrical conductor along its radius is as shown in figure



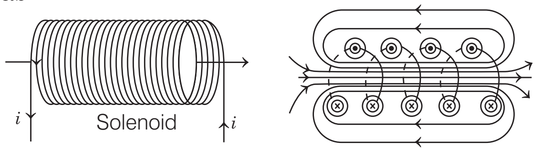
- The variation in magnetic field due to infinite long hollow cylindrical conductor along its radius is as shown in figure



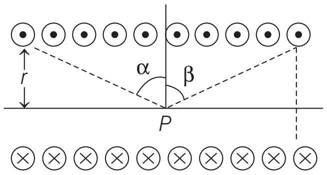
Solenoid

It consists of a long wire wound in the form of a helix, where the neighbouring turns are closely spaced. The net magnetic field is the vector sum of the fields due to all the turns.

Magnetic field due to a straight solenoid can be given as



- **Finite Length Solenoid** If N = total number of turns, l = length of the solenoid and n = number of turns per unit length = N/l, then



Magnetic field inside the solenoid at point P is given by

$$B = \frac{\mu_0 ni}{2} [\sin\alpha + \sin\beta]$$

- **Infinite Length Solenoid** If the solenoid is of infinite length and the point is well inside it,

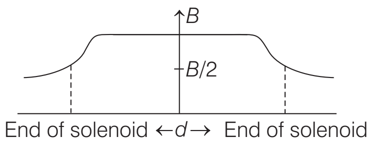
i.e. $\qquad \alpha = \beta = (\pi/2)$

So, $\qquad B_{\text{in}} = \mu_0 ni$

If the solenoid is of infinite length and the point is near one end, *i.e.* $\alpha = 0$ and $\beta = (\pi/2)$, so

$$B_{\text{end}} = \frac{1}{2}(\mu_0 ni) \qquad \left(\because B_{\text{end}} = \frac{1}{2} B_{\text{in}}\right)$$

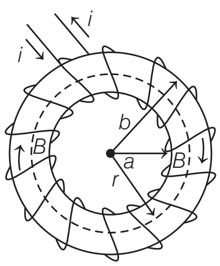
Variation in magnetic field with distance *d* from its centre



Toroid

It is a hollow circular ring in which a large number of turns of a wire are closely wound.

It can be viewed as a solenoid which has been bent into a circular shape to close on itself as shown below



Magnetic field due to toroidal solenoid can be given as

- In the open space, exterior of toroidal solenoid,

$$B = 0$$

- Inside the toroidal solenoid,

$$B = \frac{\mu_0 Ni}{2\pi r}$$

where, N = total number of turns = $2\pi rn$.

Then, $B = \mu_0\, ni$

Note Ampere's law is valid only for steady current. Further, it is useful only for calculating the magnetic fields of current configurations with high degrees of symmetry, just as Gauss's law is useful only for calculating the electric fields of highly symmetric charge distributions.

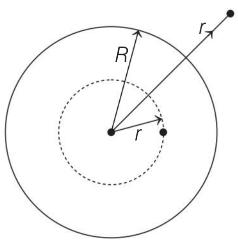
Example 6. *A long, straight wire of radius a carries a current distributed uniformly over its cross-section. The ratio of the magnetic fields due to the wire at distance* $\frac{a}{3}$ *and* $2a$ *respectively, from the axis of the wire is* **[JEE Main 2020]**

(a) $\frac{3}{2}$ (b) 2 (c) $\frac{2}{3}$ (d) $\frac{1}{2}$

Sol. (c) By Ampere's circuital law, magnetic field inside and outside a wire carrying a uniformly distributed current are

$$B_{\text{out}} = \frac{\mu_0 i}{2\pi r} \quad \ldots\text{(i)}$$

$$B_{\text{in}} = \frac{\mu_0}{2\pi}\cdot\frac{ir}{R^2} \quad \ldots\text{(ii)}$$



In given case, radius of wire is a. So, magnetic field due to wire at a distance $\frac{a}{3}$ from centre,

$$B_1 = \frac{\mu_0}{2\pi}\,\frac{i\left(\frac{a}{3}\right)}{a^2} = \frac{\mu_0 i}{6\pi a} \quad \text{[from Eq. (ii)]}$$

and magnetic field at a distance $2a$ from centre,

$$B_2 = \frac{\mu_0 i}{2\pi(2a)} = \frac{\mu_0 i}{4\pi a} \quad \text{[from Eq. (i)]}$$

Ratio of fields will be

$$\frac{B_1}{B_2} = \frac{\left(\frac{\mu_0 i}{6\pi a}\right)}{\left(\frac{\mu_0 i}{4\pi a}\right)} = \frac{2}{3}$$

Example 7. *A solenoid of length* 0.4 *m and diameter* 0.6 *m consists of a single layer of* 1000 *turns of fine wire carrying a current of* 5×10^{-3} *A. Calculate the magnetic field on the axis at the middle and at the end of the solenoid.*

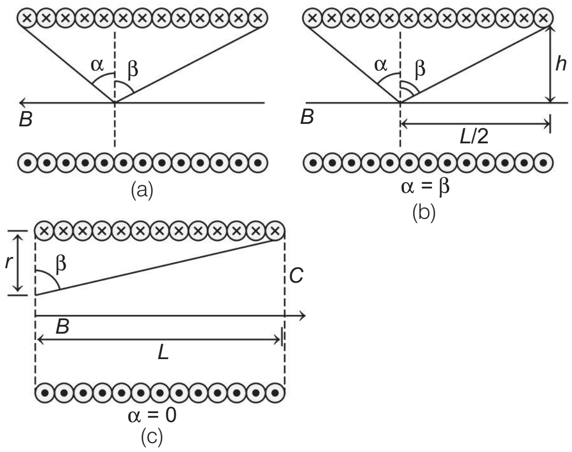
(a) $8.7\times10^{-6}T, 6.28\times10^{-6}T$

(b) $6.28\times10^{-6}T, 8.7\times10^{-6}T$

(c) $5.7\times10^{-6}\,T, 6.28\times10^{-6}T$

(d) $8.7\times10^{-6}T, 8.28\times10^{-6}T$

Sol. (a) In case of solenoid, the field at a point on the axis as shown in figure is given by $B = \frac{\mu_0}{4\pi}2\pi ni\,(\sin\alpha + \sin\beta)$



Here, $n = \frac{N}{L} = \frac{1000}{0.4} = 2.5\times10^3$ turns m^{-1}

So, $B = 10^{-7}\times 2\pi\times 2.5\times10^3\times5\times10^{-3}(\sin\alpha + \sin\beta)$

i.e. $B = 2.5\pi\times10^{-6}(\sin\alpha + \sin\beta)$

So, (a) when the point is at the middle on the axis $\alpha = \beta$ with

$$\sin\alpha = \sin\beta = \frac{L}{\sqrt{L^2 + 4r^2}}$$

$$= \frac{0.4}{\sqrt{(0.4)^2 + 4(0.3)^2}} = \frac{4}{7.2}$$

Then, $B = 2.5\pi\times10^{-6}\times2\times\frac{4}{7.2}$

$= 8.7\times10^{-6}$T

and (b) when the point is at the end on the axis $\alpha = 0$ with

$$\sin\beta = \frac{L}{\sqrt{L^2 + r^2}} = \frac{0.4}{\sqrt{(0.4)^2 + (0.3)^2}} = \frac{4}{5}$$

Then, $B = 2.5\pi\times10^{-6}\times\frac{4}{5} = 6.28\times10^{-6}$T

Example 8. *A coil wrapped around a toroid has inner radius of* 20.0 *cm and an outer radius of* 25.0 *cm. If the wire wrapping makes* 800 *turns and carries a current of* 12.0 *A. Find the ratio of maximum and minimum values of the magnetic field within the toroid.*

(a) 2 (b) 1.25 (c) 3 (d) 4.29

Sol. (b) Let a and b denote the inner and outer radii of the toroid, then maximum value of magnetic field,

$$B_{\max} = \mu_0 ni = \frac{\mu_0 N}{2\pi a}\,i = \frac{4\pi\times10^{-7}\times800\times12.0}{2\pi\times20.0\times10^{-2}} \quad \left(\because n = \frac{N}{2\pi r}\right)$$

$= 9.6\times10^{-3}$ T $= 9.6$ mT

Minimum value of magnetic field, $B_{\min} = \mu_0 ni = \mu_0\frac{Ni}{2\pi b}$

$$B_{\min} = \frac{4\pi\times10^{-7}\times800\times12.0}{2\pi\times25.0\times10^{-2}} = 7.68\times10^{-3}\text{ T} = 7.68\text{ mT}$$

$\Rightarrow$ $B_{\max}/B_{\min} = 9.6/7.68 = 1.25$

Force on a Moving Charge in a Uniform Magnetic Field

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

$$\mathbf{F}_m = q\,(\mathbf{v} \times \mathbf{B})$$

Motion of Charged Particle in a Uniform Magnetic Field

When a charged particle q is thrown in magnetic field $\mathbf{B}$ with a velocity $\mathbf{v}$. The magnetic force acting on the particle is given by $F = Bqv\sin\theta$, where θ is the angle between the velocity and the magnetic field.

Depending on the initial conditions, the charged particle can follow different trajectories in a region of uniform magnetic field.

***Case* I** When $\theta = 0°$ or $180°$

The magnetic force is $F = 0$.

Hence, path of the charged particle is a straight line (undeviated) when it enters parallel or antiparallel to magnetic field.

***Case* II** When $\theta = 90°$

The magnetic force is $F = Bqv$.

This magnetic force is perpendicular to the velocity at every instant. Hence, path is circle. Then,

- Radius of the circle, $r = \dfrac{mv}{Bq} = \dfrac{\sqrt{2qVm}}{Bq}$

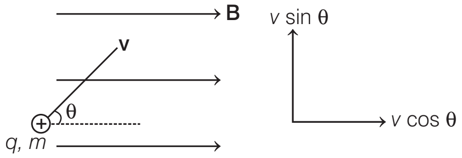
  Here, K = kinetic energy of particle $= \dfrac{p^2}{2m}$ or $p = \sqrt{2Km}$

  where, p = momentum of particle.
- Time period of the circular path, $T = \dfrac{2\pi m}{Bq}$
- Angular speed of the particle,

  $\therefore \quad \omega = \dfrac{Bq}{m}$
- Frequency of rotation, $f = \dfrac{Bq}{2\pi m}$

***Case* III** When θ is other than $0°$, $180°$ or $90°$,

then velocity of charged particle can be resolved in two components one along $\mathbf{B}$ and another perpendicular to $\mathbf{B}$.



$$v_{\parallel} = v\cos\theta \quad \text{and} \quad v_{\perp} = v\sin\theta$$

Hence, the resultant path will be helical. Then,

- The radius of this helical path,

$$r = \frac{mv_{\perp}}{Bq} = \frac{mv\sin\theta}{Bq}$$

- Time period, $T = \dfrac{2\pi m}{Bq}$
- Frequency, $f = \dfrac{Bq}{2\pi m}$
- **Pitch** is defined as the distance travelled along magnetic field in one complete cycle.

  i.e. $\quad P = v_{\parallel} T = \dfrac{2\pi m\, v\cos\theta}{Bq}$

***Example* 9.** *A charged particle carrying charge 1 μC is moving with velocity $(2\hat{\mathbf{i}} + 3\hat{\mathbf{j}} + 4\hat{\mathbf{k}})\ ms^{-1}$. If an external magnetic field of $(5\hat{\mathbf{i}} + 3\hat{\mathbf{j}} - 6\hat{\mathbf{k}}) \times 10^{-3}$ T exists in the region, where the particle is moving, then the force on the particle is $\mathbf{F} \times 10^{-9}$ N. The vector $\mathbf{F}$ is* **[JEE Main 2020]**

(a) $-0.30\hat{\mathbf{i}} + 0.32\hat{\mathbf{j}} - 0.09\hat{\mathbf{k}}$

(b) $-30\hat{\mathbf{i}} + 32\hat{\mathbf{j}} - 9\hat{\mathbf{k}}$

(c) $-300\hat{\mathbf{i}} + 320\hat{\mathbf{j}} - 90\hat{\mathbf{k}}$

(d) $-3.0\hat{\mathbf{i}} + 3.2\hat{\mathbf{j}} - 0.9\hat{\mathbf{k}}$

Sol. (b) Force on a charged particle moving in region of a magnetic field is given by

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

Here, $\quad q = 1\ \mu C = 1 \times 10^{-6}\ C$,

$$\mathbf{v} = (2\hat{\mathbf{i}} + 3\hat{\mathbf{j}} + 4\hat{\mathbf{k}})\ ms^{-1}$$

and $\quad \mathbf{B} = (5\hat{\mathbf{i}} + 3\hat{\mathbf{j}} - 6\hat{\mathbf{k}}) \times 10^{-3}\ T$

So, force on the particle is

$$\mathbf{F} \times 10^{-9} = 1 \times 10^{-6} \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ 2 & 3 & 4 \\ 5\times10^{-3} & 3\times10^{-3} & -6\times10^{-3} \end{vmatrix}$$

$$= 10^{-9} \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ 2 & 3 & 4 \\ 5 & 3 & -6 \end{vmatrix}$$

$$\Rightarrow \quad \mathbf{F} = -30\hat{\mathbf{i}} + 32\hat{\mathbf{j}} - 9\hat{\mathbf{k}}$$

***Example* 10.** *A proton, an electron and a helium nucleus, have the same energy. They are in circular orbits in a plane due to magnetic field perpendicular to the plane. Let r_p, r_e and r_{He} be their respective radii, then* **[JEE Main 2019]**

(a) $r_e < r_p = r_{He}$

(b) $r_e > r_p = r_{He}$

(c) $r_e < r_p < r_{He}$

(d) $r_e > r_p > r_{He}$

Sol. (c) When a moving charged particle is placed in a magnetic field B, then the net magnetic force acting on it is

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

$$\mathbf{F}_m = q\,vB\sin\theta$$

Here, $\quad \theta = 90°$

$$\mathbf{F}_m = q\,vB$$

Also, due to this net force, the particle transverses a circular path, whose necessary centripetal force is being provided by F_m, *i.e.*

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

$$\Rightarrow \qquad r = \frac{mv^2}{qvB} = \frac{mv}{qB} \Rightarrow r \propto m$$

So, **for electron** $\quad r_e = \dfrac{m_e v}{eB}$ or $r_e \propto m_e$

For proton $\quad r_p = \dfrac{m_p v}{eB}$ or $r_p \propto m_p$

For He-particle $\quad r_{He} = \dfrac{4m_p v}{2eB} = \dfrac{2m_p v}{eB}$

Clearly, $\quad r_{He} > r_p \qquad (\because r_{He} = 2r_p)$

and we know that, $m_p > m_e \qquad \left(\begin{array}{l}\because m_p \approx 10^{-27} \text{kg}, \\ m_e \approx 10^{-31} \text{ kg}\end{array}\right)$

$$\therefore \qquad r_p > r_e \Rightarrow r_{He} > r_p > r_e$$

Example 11. *A beam of protons with a velocity $4 \times 10^5 ms^{-1}$ enters a uniform magnetic field of 0.3 T at an angle of 60° to the magnetic field. Find the pitch of the helix. (Take, mass of the proton $= 1.67 \times 10^{-27}$ kg)*

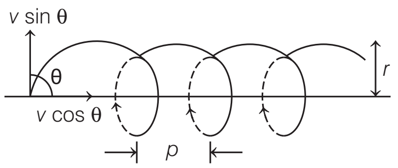
(a) 2.35 cm (b) 5.35 cm
(c) 4.35 cm (d) 6.35 cm

Sol. (c) When a charged particle is projected at an angle θ to a magnetic field, the component of velocity parallel to the field is $v \cos\theta$ while perpendicular to the field is $v \sin\theta$, so the particle will move in a circle of radius

$$r = \frac{mv \sin\theta}{qB}$$

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

$$= \frac{2}{\sqrt{3}} \times 10^{-2} \text{m} = 1.2 \text{ cm}$$



As, $\quad T = \dfrac{2\pi r}{v \sin\theta} = \dfrac{2\pi \times 1.2 \times 10^{-2}}{4 \times 10^5 \times (\sqrt{3}/2)} = 2.175 \times 10^{-7}$ s

So, pitch, $\quad P = v \cos\theta \times T = 4 \times 10^5 \times \dfrac{1}{2} \times 2.175 \times 10^{-7}$

i.e. $\quad P = 4.35 \times 10^{-2}$ m $= 4.35$ cm

Lorentz Force

Motion of a charged particle in combined electric and magnetic fields.

If a charge q is moving with velocity $\mathbf{v}$ enters in a region in which electric field $\mathbf{E}$ and magnetic field $\mathbf{B}$ both are present, it experiences force due to both fields simultaneously. The force experienced by the charged particle is given by the expression,

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B}) + q\mathbf{E} = \mathbf{F}_m + \mathbf{F}_e$$

Here, magnetic force $\mathbf{F}_m = q(\mathbf{v} \times \mathbf{B}) = Bqv \sin\theta$ and electric force $\mathbf{F}_e = q\mathbf{E}$.

This force is known as **Lorentz force**.

The direction of magnetic force is same as $\mathbf{v} \times \mathbf{B}$, if charge is positive and opposite to $\mathbf{v} \times \mathbf{B}$, if charge q is negative.

***Case* I** When **vB** and **B** are all collinear.

In this, magnetic force on the particle will be zero. So,

$$\mathbf{a} = \frac{q\mathbf{E}}{m}$$

The particle will pass through the field following a straight line path with change in its speed.

***Case* II** When **v**, **E** and **B** are mutually perpendicular.

In this, $\quad \mathbf{F} = \mathbf{F}_e + \mathbf{F}_m = 0$

or $\quad \mathbf{a} = 0$

The particle will pass through the field with same velocity without any deviation in it's path.

Thus, $\quad F_e = F_m$

or $\quad v = \dfrac{E}{B}$

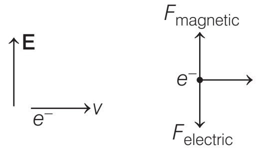
This principle is used in velocity selector to get a charged beam having a specific velocity.

Example 12. *An electron is moving along +x-direction with a velocity of 6×10^6 ms^{-1}. It enters a region of uniform electric field of 300 V/cm pointing along +y-direction. The magnitude and direction of the magnetic field set up in this region such that the electron keeps moving along the x-direction will be* ***[JEE Main 2020]***

(a) 3×10^{-4} *T, along + z-direction*
(b) 5×10^{-3} *T, along − z-direction*
(c) 5×10^{-3} *T, along + z-direction*
(d) 3×10^{-4} *T, along − z-direction*

Sol. (c) Given that, $\mathbf{v} = 6 \times 10^6 \,\hat{\mathbf{i}}$ m/s,

$$\mathbf{E} = 300\hat{\mathbf{j}} \text{ V/cm} = 3 \times 10^4 \,\hat{\mathbf{j}} \text{ V/m}$$



To keep the electron moving along x-direction,

$$\mathbf{F}_{net} = 0$$

or $\quad \mathbf{F}_{electric} + \mathbf{F}_{magnetic} = 0$

$$q\mathbf{E} + q(\mathbf{v} \times \mathbf{B}) = 0$$

or $\quad \mathbf{E} + \mathbf{v} \times \mathbf{B} = 0$

It is possible when magnetic field **B** must be along + z-direction and magnitude is

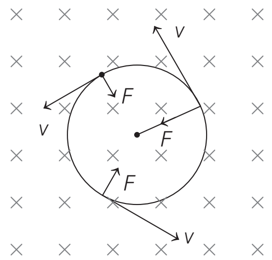
$$\mathbf{B} = \frac{\mathbf{E}}{\mathbf{v}} = \frac{3 \times 10^4 \hat{\mathbf{j}}}{6 \times 10^6 \hat{\mathbf{i}}} = 5 \times 10^{-3} \hat{\mathbf{k}} \text{T}$$

Example 13. *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 (Take, charge of electron $= 1.6 \times 10^{-19}$ C)*

[JEE Main 2019]

(a) 1.6×10^{-19} kg
(b) 1.6×10^{-27} kg
(c) 9.1×10^{-31} kg
(d) 2.0×10^{-24} kg

Sol. (*d*) According to given condition, when a particle having charge same as electron move in a magnetic field on circular path, then the force always acts towards the centre and perpendicular to the velocity.



Here, $B = 0.5$ T

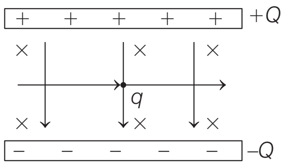
R = radius of circular path $= 0.5$ cm $= 0.5 \times 10^{-2}$ m

Now, the magnetic force is

$$F_m = q(v \times B) = q\,vB \sin 90°$$

$$F_m = qvB \quad \text{...(i)}$$

When the electric field applied, then the particle moves in a straight path, then this is the case of velocity selector.



Here, the electric force on charge,

$$F_e = qE \quad \text{...(ii)}$$

In velocity selector,

$$F_m = F_e$$

$$\Rightarrow \quad qvB = qE \Rightarrow v = E/B \quad \text{...(iii)}$$

Initially particle moves under the magnetic field, so the radius of circular path taken by the particle is

$$R = \frac{mv}{qB} \quad \text{...(iv)}$$

From Eqs. (iii) and (iv), we get

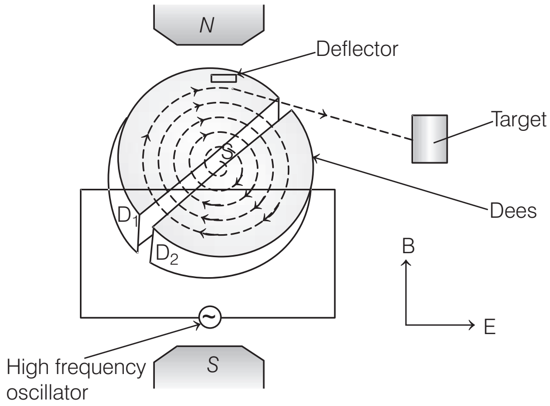
$$m = \frac{qB^2R}{E}$$

$$m = \frac{1.6 \times 10^{-19} \times 0.25 \times 0.5 \times 10^{-2}}{10^2}$$

$$m = 2 \times 10^{-24} \text{ kg}$$

Cyclotron

It is a device used for accelerating positively charged particle (like α-particles, deutrons, etc.) with the help of uniform magnetic field upto energy of the order of MeV.



The period of revolution is given by

$$T = \frac{1}{\nu_c} = \frac{2\pi m}{qB}$$

or

$$\nu_c = \frac{qB}{2\pi m}$$

This frequency is called the *cyclotron frequency*.

The frequency ν_a of the applied voltage is adjusted, so that the polarity of the dees is reversed in the same time that it takes the ions to complete one-half of the revolution. The requirement $\nu_a = \nu_c$ is called the *resonance condition*.

The velocity of the charged particle or ions when it leave the system *via* an exit slit,

$$v = \frac{qBR}{m}$$

where, R is the radius of the trajectory at exit and equals the radius of a dee.

The kinetic energy of the ions,

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

Maximum energy of charged particle is

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

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

Important Points Related to Cyclotron

- Cyclotron is suitable only for accelerating heavy particles like proton, deutron, α-particle, etc. Electrons cannot be accelerated by the cyclotron because the mass of the electron is small and a small increase in energy of the electron makes the electrons move with a very high speed. As a result of it, the electrons go quickly out of step with oscillating electric field.

- When a positive ion is accelerated by the cyclotron, it moves with greater and greater speed. As the speed of ion becomes comparable with that of light, the mass of the ion increase according to the relation

$$m = \frac{m_0}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}}$$

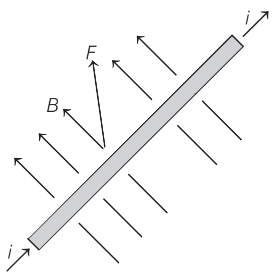
where m_0 = the rest mass of the ion,
m = the mass of the ion while moving velocity v
and c = velocity of light.
Now, the time taken by the ion to describe semicircular path is

$$t = \frac{\pi m}{qB} = \frac{\pi}{qB} \cdot \frac{m_0}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}}$$

From the above relation, we can conclude that, the ion cannot move with a speed beyond a certain limit in a cyclotron.

Force on a Current Carrying Conductor in a Magnetic Field

When a current carrying conductor is placed in a magnetic field, the conductor experience a force in a direction perpendicular to both the direction of magnetic field and the direction of current flowing in the conductor.



The magnetic force is

$$F = ilB \sin\theta$$

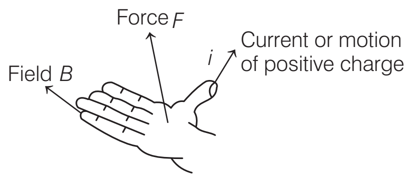
In vector form, $\mathbf{F} = i\,(\mathbf{l} \times \mathbf{B})$
where, B = intensity of magnetic field,
i = current in the conductor,
l = length of the conductor
and θ = angle between the length of conductor and direction of magnetic field.

There arises two cases

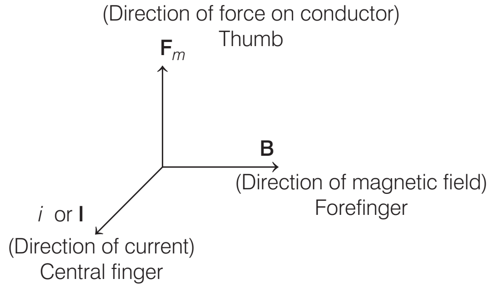
- If $\theta = 90^\circ$ or $\sin\theta = 1$, then $F = ilB$ (maximum).
  Therefore, force will be maximum when the conductor carrying current is perpendicular to magnetic field.
- If $\theta = 0^\circ$ or $\sin\theta = 0$, then $F = ilB \times 0 = 0$.
  Thus, the force will be zero, when the current carrying conductor is parallel to the field.
  The direction of this force can be found out either by Fleming's left hand rule or by right hand palm rule.

Rules to Find the Direction of Force

- **Right hand palm rule** If we stretch the right hand palm such that the fingers and the thumb are mutually perpendicular to each other and the fingers point in the direction of magnetic field and thumb points in the direction of motion of positive charge, then the direction of force will be along the outward normal on the palm.



- **Fleming's left hand rule** If we spread the forefinger, central finger and thumb of our left hand in such a way that all three are perpendicular to each other then, if forefinger is in the direction of magnetic field, central finger is in the direction of current, then thumb will represent the direction of force.



Note To learn this rule, remember the sequence of Father, Mother, Child.
Thumb → Father → Force
Forefinger → Mother → Magnetic field
Central finger → Child → Current of direction of positive charge

Magnetic Force on an Arbitrarily Shaped Wire

If the current carrying conductor in the form or a loop of any arbitrary shape is placed in a uniform field,

$$\mathbf{F} = \oint i d\mathbf{L} \times \mathbf{B} = i[\oint d\mathbf{L} \times \mathbf{B}]$$

and as for a closed loop, the vector sum of $d\mathbf{L}$ is always zero.

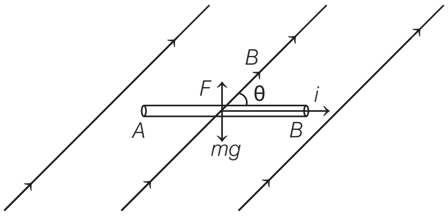
So, $$\mathbf{F} = \oint i d\mathbf{L} \times \mathbf{B} = i[\oint d\mathbf{L} \times \mathbf{B}]$$

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

Example 14. *A straight wire of length* 30 cm *and mass* 60 μg *lies in a direction* 30° *east of north. The earth's magnetic field at this site is horizontal and has a magnitude of* 0.8 G. *What current must be passed through the wire, so that it may float in air?*

(a) 10 A (b) 20 A
(c) 40 A (d) 50 A

Sol. (*d*) As shown in figure, if a current i is passed through the wire from end A towards B it will experience a force $BiL \sin\theta$ vertically up and hence will float, if

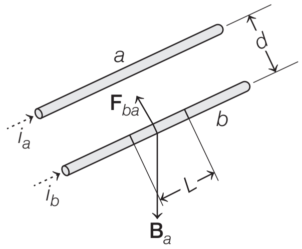


$$Bil \sin\theta = mg$$

i.e. $$i = \frac{mg}{Bl \sin\theta} = \frac{60 \times 10^{-6} \times 10}{0.8 \times 10^{-4} \times 30 \times 10^{-2} \times 1/2} = 50 \text{ A}$$

Force between the Two Parallel Carrying Current Conductors

If two infinitely long parallel conductors carrying the currents i_a and i_b respectively and are separated by a distance d, then magnetic force experienced by length L of any one conductor due to the other current carrying conductor is $\mathbf{F}_{ba} = \frac{\mu_0}{2\pi} \cdot \frac{i_a i_b}{d} \cdot L$.



The force $\mathbf{F}_{ba}$ per unit length, $f_{ba} = \frac{\mu_0 i_a i_b}{2\pi d}$

The direction of force depends on the direction of current in them as

(i) attractive, if current flow in same direction.
(ii) repulsive, if current flow in opposite direction.

Definition of Ampere

One ampere is the current which flows through each of the two parallel uniform long linear conductors, which are placed in free space at a distance of 1 m from each other and attract or repel each other with a force of 2×10^{-7} N/m.

Example 15. *The force between two parallel current carrying conductor is F. If the current in each conductor is doubled, then the force between them becomes*

(a) $4F$ (b) $2F$ (c) F (d) $F/4$

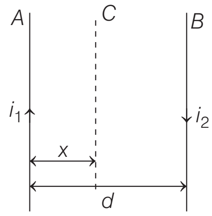
Sol. (*a*) The force between two parallel current carrying conductor is

$$F = \frac{\mu_0}{4\pi} \frac{I_1 I_2}{d} \times l$$

When currents in each conductor are doubled, then force will be

$$F' = \frac{\mu_0}{2\pi} \frac{2I_1 \times 2I_2}{d} \times l = 4 \frac{\mu_0}{2\pi} \frac{I_1 I_2}{d} \times l = 4F$$

Example 16. *Two wires A and B are carrying currents i_1 and i_2 as shown in the figure. The separation between them is d. A third wire C carrying a current i is to be kept parallel to them at a distance x from A such that the net force acting on it is zero. The possible values of x are*



[JEE Main 2019]

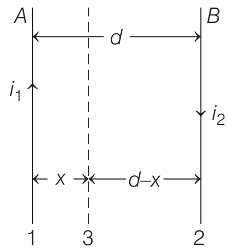
(a) $x = \left(\frac{i_2}{i_1 + i_2}\right) d$ and $x = \left(\frac{i_2}{i_1 - i_2}\right) d$

(b) $x = \left(\frac{i_1}{i_1 - i_2}\right) d$ and $x = \left(\frac{i_2}{i_1 + i_2}\right) d$

(c) $x = \left(\frac{i_1}{i_1 + i_2}\right) d$ and $x = \left(\frac{i_2}{i_1 - i_2}\right) d$

(d) $x = \pm \frac{i_1 d}{(i_1 - i_2)}$

Sol. (*d*) Net force on the third wire, carrying current i in the following first case is



$$F_{13} + F_{23} = 0$$

Using thumb rule, direction of **B** at inside region of wires A and B will be same.

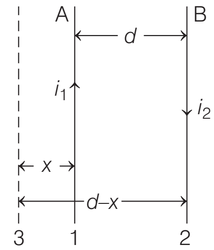
$$\therefore \quad \frac{\mu_0 i_1 i}{2\pi x} + \frac{\mu_0 i_2 i}{2\pi (d - x)} = 0$$

$$\Rightarrow \quad \frac{i_1}{x} + \frac{i_2}{d - x} = 0 \quad \Rightarrow \quad \frac{i_1}{x} = \frac{i_2}{x - d}$$

or $$(x - d)\, i_1 = x\, i_2 \quad \Rightarrow x\,(i_1 - i_2) = d i_1$$

$$\Rightarrow \quad x = \frac{i_1}{(i_1 - i_2)} \cdot d \quad \text{... (i)}$$

Second case of balanced force can be as shown



Using thumb rule, directions of B at any point on wires A and B will be opposite, so net force,

$$\frac{\mu_0 i_1 i}{2\pi x} - \frac{\mu_0 i_2 i}{2\pi (d + x)} = 0$$

or $\frac{i_1}{x} - \frac{i_2}{(d+x)} = 0 \Rightarrow \frac{i_1}{x} = \frac{i_2}{d+x}$

$\Rightarrow \quad (d+x)\, i_1 = x\, i_2$

$\Rightarrow \quad (i_2 - i_1)\, x = d i_1$

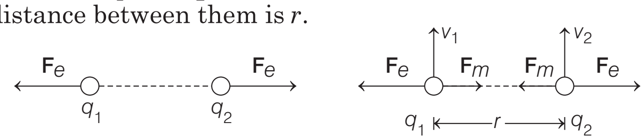
$$\Rightarrow \quad x = -\frac{i_1}{(i_1 - i_2)} \cdot d \quad \ldots \text{(ii)}$$

From Eqs. (i) and (ii), it is clear that

$$x = \pm \frac{i_1}{(i_1 - i_2)} d$$

Magnetic Force between Two Moving Charges

Consider two charges q_1 and q_2 are moving with velocities v_1 and v_2 respectively and at any instant, the distance between them is r.



A magnetic force F_m will appear between them alongwith the electric force.

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

Torque Acting on a Current Carrying Coil

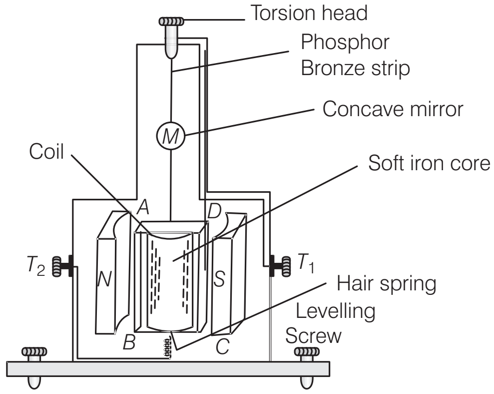
Torque acting on a current carrying coil placed inside a uniform magnetic field is given by

$$\tau = NBiA \sin\theta$$

where, N = number of turns in the coil,
B = magnetic field intensity,
i = current in the coil,
A = area of cross-section of the coil
and θ = angle between magnetic field and normal to the plane of the coil.

Moving Coil Galvanometer (MCG)

It is a device whose principle is based on the torque on a current carrying loop. When a current flows through the coil of a galvanometer, a torque acts on it. This torque is given by $\tau = NiAB$.



In equilibrium, deflecting torque = restoring force

$$k\phi = NiAB$$

where, k is the torsional constant of the spring.

Due to this torque, a deflection ϕ is indicated on the scale by the pointer attached to the spring as

$$\phi = \left(\frac{NAB}{k}\right) i$$

where, N = number of turns in the coil,
B = magnetic field intensity,
A = area of cross-section of the coil
and θ = angle of twist.

Current Sensitivity The deflection produced per unit current in galvanometer is called its current sensitivity.

Current sensitivity, $i_S = \frac{\theta}{i} = \frac{NBA}{k}$

Voltage Sensitivity The deflection produced per unit voltage applied across the ends of the galvanometer is called its voltage sensitivity.

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

where, R is the resistance of the galvanometer.

Therefore for a sensitive galvanometer

- N should be large,
- B should be large,
- A should be large
- and k should be small.

Example 17. *A moving coil galvanometer has a coil with 175 turns and area 1 cm^2. It uses a torsion band of torsion constant 10^{-6} N-m/rad. The coil is placed in a magnetic field B parallel to its plane. The coil deflects by 1° for a current of 1 mA. The value of B (in tesla) is approximately* **[JEE Main 2019]**

(a) 10^{-3} (b) 10^{-4}
(c) 10^{-1} (d) 10^{-2}

Sol. (a) In a moving coil galvanometer in equilibrium, torque on coil due to current is balanced by torque of torsion band.

As, torque on coil,

$C = NIAB \sin\alpha$

where, B = magnetic field strength,
i = current and N = number of turns of coil.

Since, plane of the coil is parallel to the field.

$\therefore \quad \alpha = 90° \Rightarrow \tau = NiBA$

Torque of torsion band, $T = k\theta$

where, k = torsion constant of torsion band
and θ = deflection of coil in radians or angle of twist of restoring torque.

$$\therefore \quad BiNA = k\theta \text{ or } B = \frac{k\theta}{iNA} \quad \ldots \text{(i)}$$

Here, $k = 10^{-6}$ N - m / rad,
$i = 1 \times 10^{-3}$ A,
$N = 175$,
$A = 1 \text{ cm}^2 = 1 \times 10^{-4} \text{ m}^2$
$\theta = 1° = \frac{\pi}{180}$ rad

Substituting values in Eq. (i), we get

$$B = \frac{10^{-6} \times 22}{1 \times 10^{-3} \times 175 \times 7 \times 180 \times 10^{-4}}$$

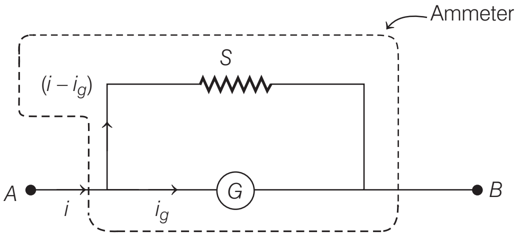
$$= 0.998 \times 10^{-3}$$

$$\simeq 10^{-3}\ \text{T}$$

Conversion of Galvanometer to Ammeter

A current measuring instrument is called an ammeter. A galvanometer can be converted into an ammeter by connecting a small resistance S (called shunt) in parallel with it.

If G is the resistance of a galvanometer and it give full scale deflection for current i_g, then required low resistance S, connected in its parallel for converting it into an ammeter of range i is given by



$$i_g \times G = (i - i_g) \times S$$

$$\Rightarrow \qquad S = \left(\frac{i_g}{i - i_g}\right) G$$

Note (i) Percentage error in measuring a current through an ammeter is

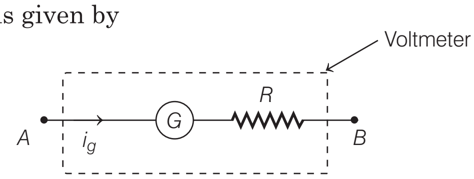
$$= \left(\frac{R_A}{R + R_A}\right) \times 100$$

(ii) Resistance of ammeter, $R_A = \dfrac{GS}{G + S}$

Conversion of Galvanometer to Voltmeter

A voltage measuring device is called a *voltmeter*. It measures the potential difference between two points. A galvanometer can be converted into voltmeter by connecting a high resistance R in series with it.

If a galvanometer of resistance G shows full scale deflection for current i_g, then required high resistance R, connected in series for converting it into a voltmeter of range V is given by



$$V = i_g\,(G + R)$$

$$\Rightarrow \qquad R = \frac{V}{i_g} - G$$

Note (i) Percentage error in measuring the potential difference by a

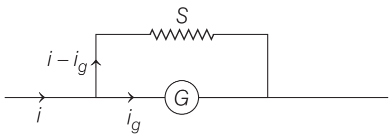
$$\text{voltmeter} = \left(\frac{1}{1 + \dfrac{r}{R_V}}\right) \times 100$$

(ii) Resistance of voltmeter, $R_V = R + G$

Example 18. *The resistance of a galvanometer is 50 Ω and the maximum current which can be passed through it is 0.002 A. What resistance must be connected to it in order to convert it into an ammeter of range 0-0.5 A?* ***[JEE Main 2019]***

(a) 0.2 Ω (b) 0.5 Ω
(c) 0.002 Ω (d) 0.02 Ω

Sol. (a) Ammeter circuit is shown in the figure below



So, $\quad i_g G = (i - i_g)\, S$

Here, $\quad i_g = 0.002$ A,

$i = 0.5$ A,

$G = 50\ \Omega$

So, shunt resistance required,

$$S = \frac{i_g G}{i - i_g} = \frac{0.002 \times 50}{(0.5 - 0.002)} \approx 0.2\ \Omega$$

Example 19. *A moving coil galvanometer has resistance 50 Ω and it indicates full deflection at 4 mA current. A voltmeter is made using this galvanometer and a 5 kΩ resistance. The maximum voltage, that can be measured using this voltmeter, will be close to* ***[JEE Main 2019]***

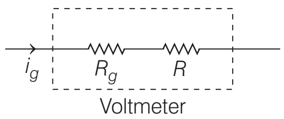
(a) 40 V (b) 10 V (c) 15 V (d) 20 V

Sol. (d) Given, resistance of galvanometer, $R_g = 50\ \Omega$

Current, $i_g = 4$ mA $= 4 \times 10^{-3}$ A

Resistance used in converting a galvanometer in voltmeter,

$$R = 5\ \text{k}\Omega = 5 \times 10^{3}\ \Omega$$



$\therefore$ Maximum current in galvanometer,

$$i_g = \frac{E}{R + R_g}$$

$$\therefore \qquad E = i_g (R + R_g)$$

$$= 4 \times 10^{-3} \times (5 \times 10^{3} + 50)$$

$$= 5050 \times 4 \times 10^{-3}$$

$$= 20.2\ \text{V}$$

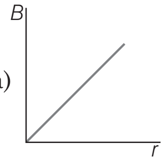
$$\simeq 20\ \text{V}$$

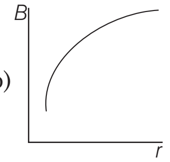
Practice Exercise

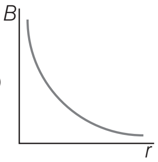
ROUND I Topically Divided Problems

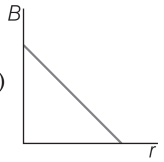
Magnetic Field, Biot-Savart's Law and its Applications

1. Which of the following graph represents the variation of magnetic flux density B with distance r for a straight long wire carrying an electric current?

(a) 

(b) 

(c) 

(d) 

2. Biot-Savart law indicates that the moving electrons (velocity $\mathbf{v}$) produce a magnetic field $\mathbf{B}$ such that **[NCERT Exemplar]**

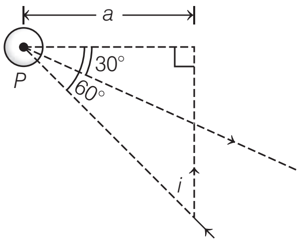
(a) $\mathbf{B} \perp \mathbf{v}$

(b) $\mathbf{B} \parallel \mathbf{v}$

(c) it obeys inverse cube law

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

3. Find the magnitude and direction of magnetic field at point P due to the current carrying wire as shown in figure.



(a) $\mathbf{B} = \frac{\mu_0 i}{4\pi a}[-1/2 - \sqrt{3}/2]$

(b) $\mathbf{B} = \frac{\mu_0 i}{4\pi a}[1/2 + \sqrt{3}/2]$

(c) $\mathbf{B} = \frac{\mu_0 i}{4\pi a}[-1/2 + \sqrt{3}/2]$

(d) $\mathbf{B} = \frac{\mu_0 i}{4\pi a}[-1/2 + \sqrt{5}/2]$

4. A horizontal overhead power line carries a current of 90 A in east to west direction. What are the magnitude and direction of the magnetic field due to the current 1.5 m below the line? **[NCERT]**

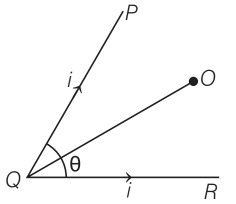
(a) 1.2×10^{-5} T, perpendicularly outward to the plane of paper

(b) 1.9×10^{-5} T, perpendicularly outward to the plane of paper

(c) 2.6×10^{-5} T, perpendicularly inward to the plane of paper

(d) 2.6×10^{-5} T, perpendicularly inward to the plane of paper

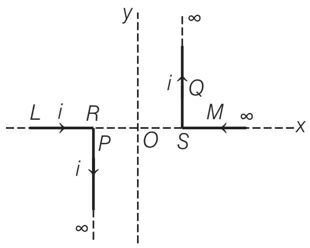
5. Two wires PQ and QR, carry equal currents i as shown in figure. One end of both the wires extends to infinity $\angle PQR = \theta$. The magnitude of the magnetic field at O on the bisector angle of these two wires at a distance r from point Q, is



(a) $\frac{\mu_0}{4\pi}\frac{i}{r}\sin\frac{\theta}{2}$ (b) $\frac{\mu_0}{4\pi}\frac{i}{r}\cot\theta$

(c) $\frac{\mu_0}{4\pi}\frac{i}{r}\tan\frac{\theta}{2}$ (d) $\frac{\mu_0}{2\pi}\frac{i}{r}\frac{(1+\cos\theta/2)}{(\sin\theta/2)}$

6. A pair of stationary and infinite long bent wires are placed in the xy-plane. The wires carrying currents of 10 A each are shown in figure. The segments L and M are parallel to X-axis. The segments P and Q are parallel to Y-axis, such that $OS = OR = 0.02$ m. The magnetic field induction at the origin O is

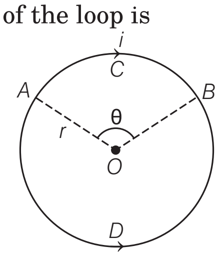


(a) 10^{-3} T (b) 4×10^{-3} T (c) 2×10^{-4} T (d) 10^{-4} T

7. A length l of wire carries a steady current i. It is bent first to form a circular plane coil of one turn. The same length is now bent more sharply to give three loops of smaller radius. The magnetic field at the centre caused by the same current is

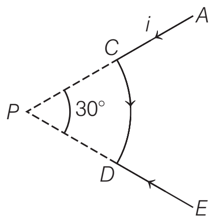
(a) one-third of its initial value
(b) unaltered
(c) three times of its initial value
(d) nine times of its initial value

8. Equal current i flows in two segments of a circular loop in the direction shown in figure. Radius of the loop is r. The magnitude of magnetic field induction at the centre of the loop is



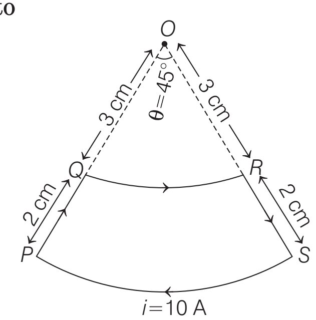
(a) zero
(b) $\frac{\mu_0 i\theta}{3\pi r}$
(c) $\frac{\mu_0}{2\pi}\frac{i}{r}(\pi-\theta)$
(d) $\frac{\mu_0}{2\pi}\frac{i}{r}(2\pi-\theta)$

9. A current path shaped as shown in figure produces a magnetic field at P, the centre of the arc. If the arc subtends an angle of 30° and the radius of the arc is 0.6 m. What is the magnitude of the field at P, if the current is 3.0 A?



(a) 2.62×10^{-6} T
(b) 2.62×10^{-7} T
(c) 3.62×10^{-7} T
(d) 2.62×10^{-8} T

10. A current loop, having two circular arcs joined by two radial lines as shown in the figure. It carries a current of 10 A. The magnetic field at point O will be close to **[JEE Main 2019]**



(a) 1.0×10^{-5} T
(b) 1.0×10^{-7} T
(c) 1.5×10^{-7} T
(d) 1.5×10^{-5} T

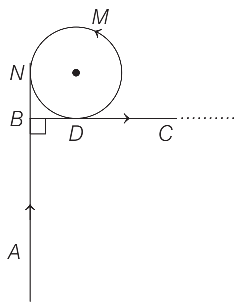
11. Magnitude of magnetic field (in SI unit) at the centre of a hexagonal shaped coil of side 10 cm, 50 turns and carrying current i ampere in units of $\frac{\mu_0 i}{\pi}$ is **[JEE Main 2020]**

(a) $250\sqrt{3}$
(b) $50\sqrt{3}$
(c) $500\sqrt{3}$
(d) $5\sqrt{3}$

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

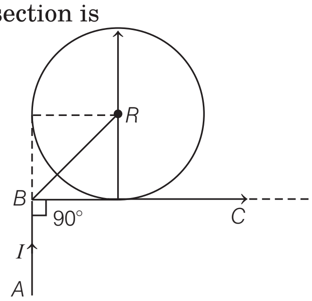
(a) $(2/3)r^2/h^2$
(b) $(3/2)r^2/h^2$
(c) $(2/3)h^2/r^2$
(d) $(3/2)h^2/r^2$

13. A very long wire $ABDMNDC$ is shown in figure carrying current i. AB and BC parts are straight, long and at right angle. At D, wire forms a circular turn $DMND$ of radius R. AB, BC parts are tangential to circular turn at N and D. Magnetic field at the centre of circle is **[JEE Main 2020]**



(a) $\frac{\mu_0 i}{2\pi R}\left(\pi+\frac{1}{\sqrt{2}}\right)$
(b) $\frac{\mu_0 i}{2R}$
(c) $\frac{\mu_0 i}{2\pi R}(\pi+1)$
(d) $\frac{\mu_0 i}{2\pi R}\left(\pi-\frac{1}{\sqrt{2}}\right)$

14. The magnetic field at the centre of the circular loop as shown in figure, when a single wire is bent to form a circular loop and also extends to form straight section is

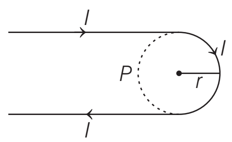


(a) $\frac{\mu_0 i}{2R}$
(b) $\frac{\mu_0 i}{2R}\left(1+\frac{1}{\pi\sqrt{2}}\right)$
(c) $\frac{\mu_0 i}{2R}\left(1-\frac{1}{\pi\sqrt{2}}\right)$
(d) $\frac{\mu_0 i}{R}\left(1-\frac{1}{\pi\sqrt{2}}\right)$

15. Two concentric coils, each of radius equal to 2π cm, are placed at right angle to each other. Currents of 3 A and 4 A respectively, are flowing through the two coils. The magnetic induction (in Wbm^{-2} or T) at the centre of the coils will be
(Take, $\mu_0 = 4\pi \times 10^{-7}$ Wb $(Am)^{-1}$)

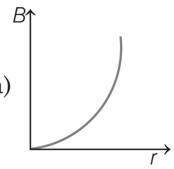
(a) 5×10^{-5} (b) 7×10^{-5}
(c) 12×10^{-5} (d) 10^{-5}

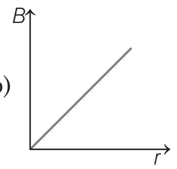
16. A hair pin like shape as shown in figure is made by bending a long current carrying wire. What is the magnitude of a magnetic field at point P which lies on the centre of the semi-circle? **[JEE Main 2021]**

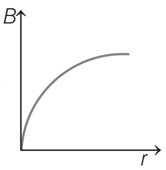


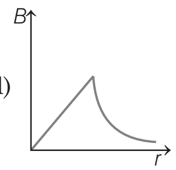
(a) $\frac{\mu_0 I}{4\pi r}(2 - \pi)$ (b) $\frac{\mu_0 I}{4\pi r}(2 + \pi)$
(c) $\frac{\mu_0 I}{2\pi r}(2 + \pi)$ (d) $\frac{\mu_0 I}{2\pi r}(2 - \pi)$

17. The magnetic flux density B at a distance r from a long straight rod carrying a steady current varies with r as shown in figure.

(a)


(b)


(c)


(d)


Ampere's Circuital Law and Solenoid

18. A current of i ampere flows along an infinitely long straight thin walled tube, then the magnetic induction at any point inside the tube is

(a) infinite (b) zero
(c) $\frac{\mu_0 2i}{4\pi r}$ T (d) $\frac{\mu_0 i}{2r}$ T

19. A solenoid of 1000 turns per metre has a core with relative permeability 500. Insulated windings of the solenoid carry an electric current of 5A. The magnetic flux density produced by the solenoid is (Take, permeability of free space $= 4\pi \times 10^{-7}$ H/m) **[JEE Main 2021]**

(a) πT (b) $2 \times 10^{-3}\pi$T
(c) $\frac{\pi}{5}$ T (d) $10^{-4}\pi$T

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

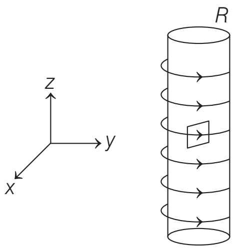
(a) 1.5×10^{-2}T, opposite to the axis of solenoid
(b) 2.5×10^{-2}T, along the axis of solenoid
(c) 3.5×10^{-2}T, along the axis of solenoid
(d) 1.5×10^{-2}T, opposite to the axis of solenoid

Force on Charged Particle in Electric and Magnetic Fields

21. An electron is projected with uniform velocity along the axis of a current carrying long solenoid. Which of the following is true? **[NCERT Exemplar]**

(a) The electron will be accelerated along the axis
(b) The electron path will be circular about the axis
(c) The electron will experience a force at 45° to the axis and hence execute a helical path
(d) The electron will continue to move with uniform velocity along the axis of the solenoid

22. An electron gun is placed inside a long solenoid of radius R on its axis. The solenoid has n turns/length and carries a current I. The electron gun shoots an electron along the radius of the solenoid with speed v. If the electron does not hit the surface of the solenoid, maximum possible value of v is (all symbols have their standard meaning) **[JEE Main 2020]**



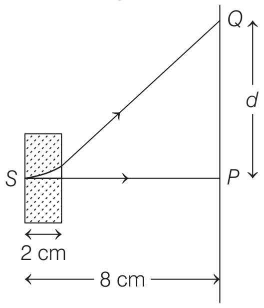
(a) $\frac{2e\mu_0 nIR}{m}$
(b) $\frac{e\mu_0 nIR}{4m}$
(c) $\frac{e\mu_0 nIR}{2m}$
(d) $\frac{e\mu_0 nIR}{m}$

23. A particle of charge q and mass m is moving with a velocity $-v\hat{\mathbf{i}} (v \neq 0)$ towards a large screen placed in the YZ-plane at a distance d. If there is a magnetic field $\mathbf{B} = B_0\hat{\mathbf{k}}$, the minimum value of v for which the particle will not hit the screen is **[JEE Main 2020]**

(a) $\frac{qdB_0}{3m}$ (b) $\frac{2qdB_0}{m}$
(c) $\frac{qdB_0}{m}$ (d) $\frac{qdB_0}{2m}$

24. An electron moving along the X-axis with an initial energy of 100 eV, enters a region of magnetic field $\mathbf{B} = (1.5 \times 10^{-3}\ \mathrm{T})\ \hat{\mathbf{k}}$ at S (see figure). The field extends between $x = 0$ and $x = 2$ cm. The electron is detected at the point Q on a screen placed 8 cm away from the point S. The distance d between P and Q (on the screen) is

(Take, electron's charge $= 1.6 \times 10^{-19}$ C, mass of electron $= 9.1 \times 10^{-31}$ kg) **[JEE Main 2019]**



(a) 11.65 cm (b) 12.87 cm
(c) 1.22 cm (d) 2.25 cm

25. In an experiment, electrons 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. (Take, charge of the electron $= 1.6 \times 10^{-19}$ C and mass of the electron $= 9.1 \times 10^{-31}$ kg) **[JEE Main 2019]**

(a) 7.5×10^{-2} m (b) 7.5×10^{-4} m
(c) 7.5×10^{-3} m (d) 7.5 m

26. A proton and an α-particle (with their masses in the ratio of 1 : 4 and charges in the ratio of 1 : 2) are accelerated from rest through a potential difference V. If a uniform magnetic field B is set up perpendicular to their velocities, the ratio of the radii $r_p : r_\alpha$ of the circular paths described by them will be **[JEE Main 2019]**

(a) $1 : \sqrt{2}$ (b) $1 : \sqrt{3}$
(c) $1 : 3$ (d) $1 : 2$

27. A deuteron of kinetic energy 50 keV is describing a circular orbit of radius 0.5 m, is plane perpendicular to magnetic field B. The kinetic energy of proton that describes a circular orbit of radius 0.5 m in the same plane with the same magnetic field B, is

(a) 200 keV (b) 50 keV
(c) 100 keV (d) 25 keV

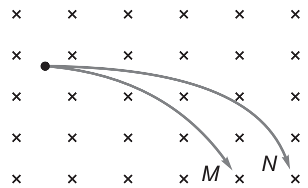
28. An electron and a proton enter a magnetic field perpendicularly. Both have same kinetic energy, which of the following statement is true ?

(a) Trajectory of electron is less curved.
(b) Trajectory of proton is less curved.
(c) Both trajectories are equally curved.
(d) Both move on straight line path.

29. A charge Q is moving $d\mathbf{l}$ distance in the magnetic field $\mathbf{B}$. Find the value of work done by $\mathbf{B}$. **[JEE Main 2021]**

(a) 1 (b) Infinite (c) Zero (d) −1

30. Two charged particles M and N enter a space of uniform magnetic field, with velocities perpendicular to the magnetic field. The paths are as shown in figure. The possible reason (s) is/are



(a) the charge of M is greater than that of N
(b) the momentum of M is greater than that of N
(c) specific charge of M is greater than that of N
(d) the speed of M is greater than that of N

31. An electron, a proton and an alpha particle having the same kinetic energy are moving in circular orbits of radii r_e, r_p, r_α respectively, in a uniform magnetic field B. The relation between r_e, r_p, r_α is **[JEE Main 2018]**

(a) $r_e > r_p = r_\alpha$ (b) $r_e < r_p = r_\alpha$
(c) $r_e < r_p < r_\alpha$ (d) $r_e < r_\alpha < r_p$

32. A proton of mass 1.67×10^{-27} kg and charge 1.6×10^{-19}C is projected with a speed of $2 \times 10^6\ \mathrm{ms}^{-1}$ at an angle of 60° to the x-axis. If a uniform magnetic field of 0.104 T is applied along y-axis, the path of proton is

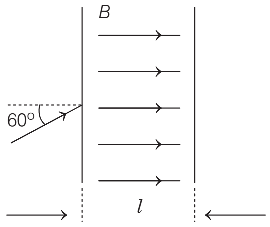
(a) a circle of radius = 0.2 m and time period $= 2\pi \times 10^{-7}$ s
(b) a circle of radius = 0.1 m and time period $= 2\pi \times 10^{-7}$ s
(c) a helix of radius 0.1 m and time period $= 2\pi \times 10^{-7}$ s
(d) a helix of radius 0.2 m and time period $= 2\pi \times 10^{-7}$ s

33. A beam of protons with speed $4 \times 10^5\ \mathrm{ms}^{-1}$ enters a uniform magnetic field of 0.3 T at an angle of 60° to the magnetic field. The pitch of the resulting helical path of protons is close to

(Take, mass of the proton $= 1.67 \times 10^{-27}$ kg and charge of the proton $= 1.69 \times 10^{-19}$ C) **[JEE Main 2020]**

(a) 2 cm (b) 4 cm
(c) 5 cm (d) 12 cm

34. The figure shows a region of length l with a uniform magnetic field of 0.3 T in it and a proton entering the region with velocity $4 \times 10^5\ \mathrm{ms}^{-1}$ making an angle 60° with the field. If the proton completes 10 revolutions by the time it cross the region shown, l is close to (Take, mass of proton $= 1.67 \times 10^{-27}$ kg, charge of the proton $= 1.6 \times 10^{-19}$ C) **[JEE Main 2020]**



(a) 0.11 m (b) 0.88 m
(c) 0.44 m (d) 0.22 m

35. A particle of mass m and charge q is in an electric and magnetic field is given by

$$\mathbf{E} = 2\hat{\mathbf{i}} + 3\hat{\mathbf{j}},\ \mathbf{B} = 4\hat{\mathbf{j}} + 6\hat{\mathbf{k}}.$$

The charged particle is shifted from the origin to the point $P(x = 1;\ y = 1)$ along a straight path. The magnitude of the total work done is **[JEE Main 2019]**

(a) $0.35\ q$ (b) $(0.15)\ q$
(c) $2.5\ q$ (d) $5\ q$

36. A particle of charge q and mass m starts moving from the origin under the action of an electric field, $E = E_0\ \hat{\mathbf{i}}$ and $B = B_0\ \hat{\mathbf{i}}$ with a velocity, $v = v_0\ \hat{\mathbf{j}}$. The speed of the particle will become $\frac{\sqrt{5}}{2} v_0$ after a time

(a) $\frac{mv_0}{qE}$ (b) $\frac{mv_0}{2qE}$
(c) $\frac{\sqrt{3}mv_0}{2qE}$ (d) $\frac{\sqrt{5}mv_0}{2qE}$

Force on a Current Carrying Conductor/Coil in a Magnetic Field

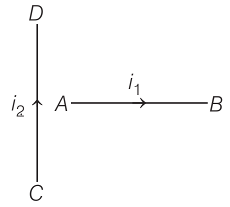
37. A long horizontal wire P carries a current of 50 A. It is rigidly fixed. Another fine wire Q is placed directly above and parallel to P. The weight of wire Q is 0.075 Nm^{-1} and carries a current of 25 A. Find the position of wire Q from P, so that wire Q remains suspended due to the magnetic repulsion.

(a) $\frac{1}{2} \times 10^{-2}$ m (b) $\frac{1}{3} \times 10^{-2}$ m
(c) $\frac{1}{4} \times 10^{-2}$ m (d) $\frac{1}{5} \times 10^{-2}$ m

38. A metal wire of mass m slides without friction on two rails placed at a distance l apart. The track lies in a uniform vertical magnetic field B. A constant current i flows along the rails across the wire and breakdown the other rail. The acceleration of the wire is

(a) $\frac{Bmi}{l}$ (b) $mBil$
(c) $\frac{Bil}{m}$ (d) $\frac{mil}{B}$

39. A current i_1 carrying wire AB is placed near an another long wire CD carrying current i_2 as shown in figure. If free to move, wire AB will have

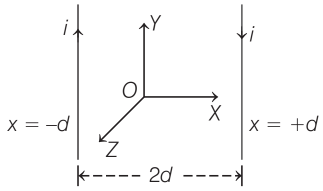


(a) rotational motion only
(b) translational motion only
(c) rotational as well as translational motion
(d) neither rotational nor translational motion

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

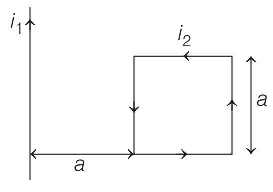
(a) 1.5×10^{-5} N (b) 2×10^{-5} N
(c) 4×10^{-5} N (d) 3.2×10^{-5} N

41. In the given diagram, two long parallel wires carry equal currents in opposite direction. Point O is situated mid-way between the wires and the XY-plane contains the two wires and the positive Z-axis comes normally out of the plane of paper. The magnetic field B at O is non-zero along



(a) X, Y and Z-axes (b) X-axis (positive)
(c) Y-axis (negative) (d) Z-axis (negative)

42. A rigid square loop of side a and carrying current i_2 is lying on a horizontal surface near a long current i_1 carrying wire in the same plane as shown in figure. The net force on the loop due to the wire will be **[JEE Main 2019]**



(a) repulsive and equal to $\frac{\mu_0 i_1 i_2}{2\pi}$
(b) attractive and equal to $\frac{\mu_0 i_1 i_2}{3\pi}$
(c) zero
(d) repulsive and equal to $\frac{\mu_0 i_1 i_2}{4\pi}$

43. Two very long straight parallel wires carry currents i and $2i$ in opposite directions. The distance between the wires is r. 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 v is perpendicular to this plane. The magnitude of the force due to the magnetic field acting on the charge at this instant is

(a) zero (b) $\frac{3\mu_0}{2\pi}\frac{iqv}{r}$

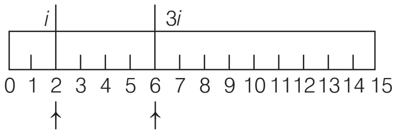
(c) $\frac{\mu_0}{\pi}\frac{iqv}{r}$ (d) $\frac{\mu_0}{2\pi}\frac{iqv}{r}$

44. Two parallel long wires A and B carry currents i_1 and i_2 ($< i_1$). When i_1 and i_2 are in the same direction, the magnetic field at a point mid-way between the wires is $10\mu T$. If i_2 is reversed, the field becomes $30\,\mu T$. The ratio, i_1/i_2 is

(a) 1 (b) 2

(c) 3 (d) 4

45. Two parallel long straight conductors are placed at right angle to the meter scale at the 2 cm and 6 cm marks as shown in the figure. If they carry currents i and $3i$ respectively in the same direction, then they will produce zero magnetic field at



(a) zero mark
(b) 9 cm mark
(c) 3 cm mark
(d) 7 cm mark

46. A square coil of side 10 cm consists of 20 turns and carries a current of 12 A. The coil is suspended vertically and the normal to the plane of the coil makes an angle of 30° with the direction of a uniform horizontal magnetic field of magnitude 0.80 T. What is the magnitude of torque experienced by the coil? **[NCERT Exemplar]**

(a) 0.96 N-m (b) 2.06 N-m

(c) 0.23 N-m (d) 1.36 N-m

Moving Coil Galvanometer, Its Conversion into Ammeter and Voltmeter

47. A galvanometer having a coil resistance of 100 Ω gives a full scale deflection when a current of 1 mA is passed through it. The value of the resistance which can convert this galvanometer into ammeter giving a full scale deflection for a current of 10 A, is **[JEE Main 2016]**

(a) 0.01 Ω (b) 2 Ω

(c) 0.1 Ω (d) 3 Ω

48. An ammeter has resistance R_0 and range I. What resistance should be connected in parallel with it to increase its range by nI ?

(a) $R_0/(n-1)$ (b) $R_0/(n+1)$

(c) R_0/n (d) None of these

49. A moving coil galvanometer allows a full scale current of 10^{-4} A. A series resistance of 2 MΩ is required to convert the above galvanometer into a voltmeter of range 0-5 V. Therefore, the value of shunt resistance required to convert the above galvanometer into an ammeter of range 0.10 mA is **[JEE Main 2019]**

(a) 100 Ω (b) 500 Ω

(c) 200 Ω (d) 10 Ω

50. A galvanometer having a coil resistance 100 Ω gives a full scale deflection when a current of 1 mA is passed through it. What is the value of the resistance which can convert this galvanometer into a voltmeter giving full scale deflection for a potential difference of 10 V? **[JEE Main 2020]**

(a) 8.9 kΩ (b) 10 kΩ

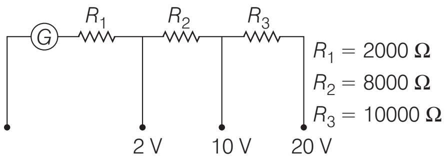
(c) 9.9 kΩ (d) 7.9 kΩ

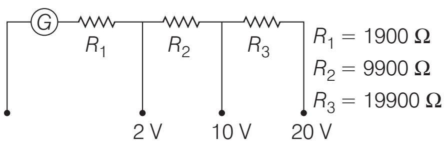
51. A voltmeter has resistance of 2000 Ω and it can measure upto 2 V. If we want to increase its range by 8 V, then required resistance in series will be

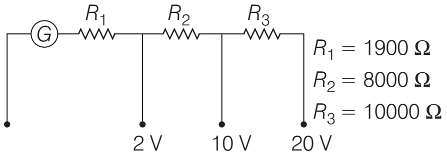
(a) 4000 Ω (b) 6000 Ω

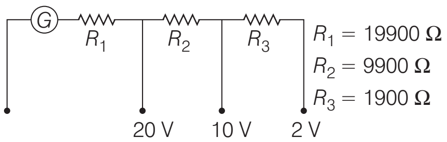
(c) 7000 Ω (d) 8000 Ω

52. A galvanometer of resistance 100 Ω has 50 divisions on its scale and has sensitivity of $20\,\mu A$/division. It is to be converted to a voltmeter with three ranges of 0-2 V, 0-10 V and 0-20 V. The appropriate circuit to do so is **[JEE Main 2019]**

(a)


(b)


(c)


(d)


53. A microammeter has a resistance of 100 Ω and full scale range of $50\mu A$. It can be used as a voltmeter or as a higher range ammeter provided a resistance is added to it. Pick the correct range and resistance combinations

(a) 50 V range with 10 kΩ resistance in series
(b) 10 V range with 200 kΩ resistance in series
(c) 10 mA range with 1 Ω resistance in parallel
(d) 10 mA range with 0.1 Ω resistance in parallel

54. A moving coil galvanometer, having a resistance G, produces full scale deflection when a current i_g flows through it. This galvanometer can be converted into (i) an ammeter of range 0 to $i_0 (i_0 > i_g)$ by connecting a shunt resistance R_A to it and (ii) into a voltmeter of range 0 to V ($V = Gi_0$) by connecting a series resistance R_V to it. Then, **[JEE Main 2019]**

(a) $R_A R_V = G^2 \left(\frac{i_0 - i_g}{I_g}\right)$ and $\frac{R_A}{R_V} = \left(\frac{i_g}{(i_0 - i_g)}\right)^2$

(b) $R_A R_V = G^2$ and $\frac{R_A}{R_V} = \left(\frac{i_g}{i_0 - i_g}\right)^2$

(c) $R_A R_V = G^2 \left(\frac{i_g}{i_0 - i_g}\right)$ and $\frac{R_A}{R_V} = \left(\frac{i_0 - i_g}{i_g}\right)^2$

(d) $R_A R_V = G^2$ and $\frac{R_A}{R_V} = \frac{i_g}{(i_0 - i_g)}$

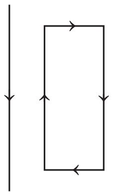
ROUND II Mixed Bag

Only One Correct Option

1. A current i flows along the length of an infinitely long, straight and thin-walled pipe, then

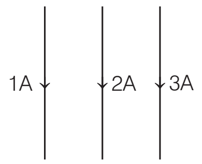
(a) the magnetic field at all points inside the pipe is the same, but not zero
(b) the magnetic field at any point inside the pipe is zero
(c) the magnetic field as zero only on the axis of the pipe
(d) the magnetic field at different at different points inside the pipe

2. A rectangular loop carrying current is placed near a long straight fixed wire carrying strong current such that long sides are parallel to wire. If the current in the nearer long side of loop is parallel to current in the wire. Then the loop



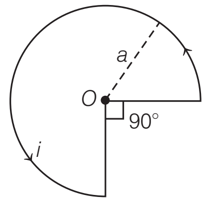
(a) experiences no force
(b) experiences a force towards wire
(c) experiences a force away from wire
(d) experiences a torque but no force

3. Three infinite straight wires A, B and C carry currents as shown in figure. The net force on the wire B is directed



(a) towards A
(b) towards C
(c) normal to plane of paper
(d) zero

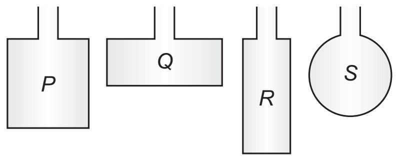
4. For the arrangement as shown in the figure, the magnetic induction at the centre is



(a) $\frac{3\mu_0 i\pi}{4a}$ (b) $\frac{\mu_0 i}{4\pi a}(1 + \pi)$

(c) $\frac{\mu_0 i}{4\pi a}$ (d) $\frac{3\mu_0 i}{8a}$

5. Four wires each of length 2.0 m are bent into four P, Q, R and S and then suspended into a uniform magnetic field. If same current is passed in each loop, then



(a) couple on loop P will be maximum
(b) couple on loop Q will be maximum
(c) couple on loop R will be maximum
(d) couple on loop S will be maximum

6. An electron is revolving around a proton in a circular path of diameter 0.1 nm. It produces a magnetic field 14 T at a proton. Then the angular speed of the electron is

(a) 8.8×10^6 rad s^{-1}
(b) 4.4×10^{16} rad s^{-1}
(c) 2.2×10^{16} rad s^{-1}
(d) 1.1×10^{16} rad s^{-1}

7. A pulsar is a neutron star having magnetic field at 10^{12} G at its surface. The maximum magnetic force experienced by an electron moving with velocity 0.9 c is

(a) 43.2 N (b) 4.32×10^{-3} N
(c) 4.32×10^{3} N (d) zero

8. An electron is shot in steady electric and magnetic fields such that its velocity v, electric field E and magnetic field B are mutually perpendicular. The magnitude of E is 1 Vcm^{-1} and that of B is 2 T. Now if it so happens that the Lorentz (magnetic) force cancels the electrostatic force on the electron, then the velocity of the electron is

(a) 50 ms^{-1} (b) 2 cms^{-1}
(c) 0.5 cms^{-1} (d) 200 cms^{-1}

9. An electron having kinetic energy E is moving in a circular orbit of radius R perpendicular to a uniform magnetic field induction B. If kinetic energy is doubled and magnetic field induction is tripled, the radius will become

(a) $R\sqrt{9/4}$ (b) $R\sqrt{3/2}$
(c) $R\sqrt{2/9}$ (d) $R\sqrt{4/3}$

10. Two coaxial solenoids of different radii carry current i in the same direction. Let $\mathbf{F}_1$ be the magnetic force on the inner solenoid due to the outer one and $\mathbf{F}_2$ be the magnetic force on the outer solenoid due to the inner one. Then, **[JEE Main 2015]**

(a) $\mathbf{F}_1 = \mathbf{F}_2 = 0$
(b) $\mathbf{F}_1$ is radially inwards and $\mathbf{F}_2$ is radially outwards
(c) $\mathbf{F}_1$ is radially inwards and $\mathbf{F}_2 = 0$
(d) $\mathbf{F}_1$ is radially outwards and $\mathbf{F}_2 = 0$

11. Two identical current carrying coaxial loops, carry current i in an opposite sense. A simple amperian loop passes through both of them once. Calling the loop as C, **[NCERT Exemplar]**

(a) $\int_C \mathbf{B} \cdot d\mathbf{l} = 2\mu_0 i$
(b) the value of $\int_C \mathbf{B} \cdot d\mathbf{l}$ is not independent of sense of C
(c) there may be a point on C where $\mathbf{B}$ and $d\mathbf{l}$ are perpendicular.
(d) $\mathbf{B}$ vanishes everywhere on C

12. A particle of mass m and charge q released from the origin in a region occupied by electric field E and magnetic field B,

$$B = -B_0\,\hat{\mathbf{j}},\ E = E_0\,\hat{\mathbf{i}}$$

The velocity of the particle will be

(a) $\sqrt{\dfrac{2qE_0}{m}}$ (b) $\sqrt{\dfrac{qE_0}{m}}$
(c) $\sqrt{\dfrac{qE_0}{2m}}$ (d) None of these

13. Consider the following statements regarding a charged particle in a magnetic field

(i) starting with zero velocity, it accelerates in a direction perpendicular to the magnetic field.
(ii) while deflecting in the magnetic field, its energy gradually increases.
(iii) only the component of magnetic field perpendicular to the direction of motion of the charged particle is effective in deflecting it.
(iv) direction of deflecting force on the moving charged particle is perpendicular to its velocity.

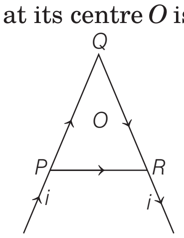
Amongst these statements,

(a) (ii) and (iii) are correct
(b) (iii) and (iv) are correct
(c) (i), (iii) and (iv) are correct
(d) (i), (ii) and (iii) are correct

14. When a current of 5 mA is passed through a galvanometer having a coil of resistance 15 Ω, it shows full scale deflection. The value of the resistance to be put in series with the galvanometer to convert it into a voltmeter of range 0-10 V is **[JEE Main 2017]**

(a) 2.045×10^3 Ω (b) 2.535×10^3 Ω
(c) 4.005×10^3 Ω (d) 1.985×10^3 Ω

15. An equilateral triangle of side l is formed from a piece of wire of uniform resistance. The current i is fed as shown in the figure. The magnitude of the magnetic field at its centre O is

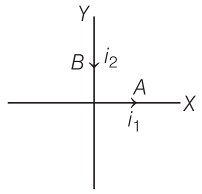


(a) $\dfrac{\sqrt{3}\mu_0 i}{2\pi l}$ (b) $\dfrac{3\sqrt{3}\mu_0 i}{2\pi l}$
(c) $\dfrac{\mu_0 i}{2\pi l}$ (d) zero

16. Consider a wire carrying a steady current, i placed in a uniform magnetic field $\mathbf{B}$ perpendicular to its length. Consider the charges inside the wire. It is known that magnetic forces do no work. This implies that, **[NCERT Exemplar]**

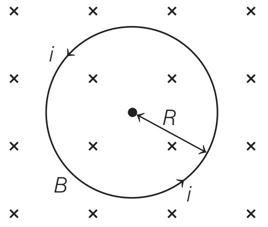
(a) motion of charges inside the conductor is unaffected by $\mathbf{B}$ since they do not absorb energy
(b) some charges inside the wire move to the surface as a result of $\mathbf{B}$
(c) if the wire moves under the influence of $\mathbf{B}$, no work is done by the force
(d) if the wire moves under the influence of $\mathbf{B}$, then work is done by the magnetic force on the ions, assumed fixed within the wire

17. Two wires A and B carry currents as shown in figure. The magnetic interactions



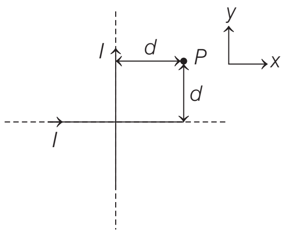
(a) push i_2 away from i_1 (b) pull i_2 closer to i_1
(c) turn i_2 clockwise (d) turn i_2 counter-clockwise

18. A current i carrying circular wire of radius R is placed in a magnetic field B perpendicular to its plane. The tension T along the circumference of wire is



(a) BiR (b) $2\pi BiR$
(c) πBiR (d) $2BiR$

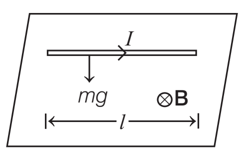
19. Two very long, straight and insulated wires are kept at 90° angle from each other in XY-plane as shown in the figure.



These wires carry currents of equal magnitude i, whose directions are shown in the figure. The net magnetic field at point P will be **[JEE Main 2019]**

(a) zero (b) $\frac{+\mu_0 i}{\pi d}(\hat{\mathbf{z}})$
(c) $-\frac{\mu_0 i}{2\pi d}(\hat{\mathbf{x}}+\hat{\mathbf{y}})$ (d) $\frac{\mu_0 i}{2\pi d}(\hat{\mathbf{x}}+\hat{\mathbf{y}})$

20. A straight wire of mass 200g and length 1.5 m carries a current of 2 A. It is suspended in mid-air by a uniform horizontal magnetic field B. The magnitude of the magnetic field is **[NCERT]**



(a) 0.35 T (b) 0.65 T (c) 0.25 T (d) 0.88 T

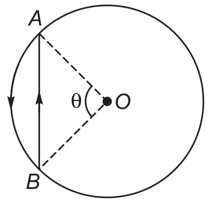
21. A galvanometer of resistance G is converted into a voltmeter of range 0-1V by connecting a resistance R_1 in series with it. The additional resistance that should be connected in series with R_1 to increase the range of the voltmeter to 0-2V will be **[JEE Main 2020]**

(a) $R_1 + G$ (b) R_1 (c) G (d) $R_1 - G$

22. A uniform electric and magnetic fields are produced pointing in the same direction. If an electron is projected with its velocity pointing in the same direction, **[NCERT Exemplar]**

(a) the electron velocity will decrease in magnitude
(b) the electron velocity will increase in magnitude
(c) neither (a) nor (b)
(d) None of the above

23. Net magnetic field at the centre of the circle O due to a current through a loop as shown in figure ($\theta < 180°$)

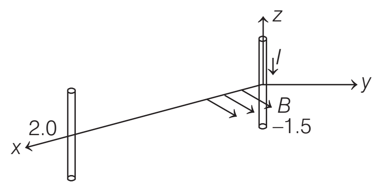


(a) zero
(b) perpendicular to paper inwards
(c) perpendicular to paper outwards
(d) perpendicular to paper outwards if $90° \le \theta < 180°$

24. A particle of mass m and charge q has an initial velocity $\mathbf{v} = v_0\hat{\mathbf{j}}$. If an electric field $\mathbf{E} = E_0\hat{\mathbf{i}}$ and magnetic field $\mathbf{B} = B_0\hat{\mathbf{i}}$ act on the particle, its speed will double after a time **[JEE Main 2020]**

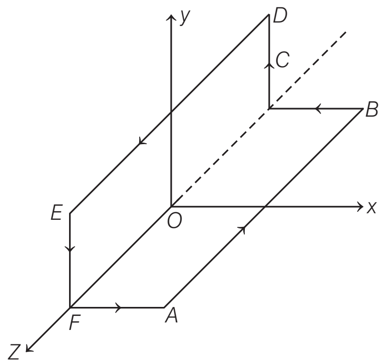
(a) $\frac{3mv_0}{qE_0}$ (b) $\frac{\sqrt{3}mv_0}{qE_0}$
(c) $\frac{2mv_0}{qE_0}$ (d) $\frac{\sqrt{2}mv_0}{qE_0}$

25. A conductor lies along the Z-axis at $-1.5 \le z < 1.5$ m and carries a fixed current of 10.0 A in $-a_z$ direction (see figure). For a field $B = 3.0 \times 10^{-4} e^{-0.2x} a_y$ T, find the power required to move the conductor at constant speed to $x = 2.0$ m, $y = -0$ in 5×10^{-3} s. Assume, parallel motion along the X-axis. **[JEE Main 2014]**



(a) 1.57 W (b) 2.97 W
(c) 14.85 W (d) 29.7 W

26. In the figure, $ABCDEFA$ was a square loop of side l, but is folded in two equal parts so that half of it lies in the XZ-plane. The origin O is centre of the frame also. The loop carries current i, the magnetic field at the centre is



(a) $\frac{\mu_0 i}{2\sqrt{2}\,\pi l}(\hat{\mathbf{i}}-\hat{\mathbf{j}})$ (b) $\frac{\mu_0 i}{4\pi l}(-\hat{\mathbf{i}}+\hat{\mathbf{j}})$

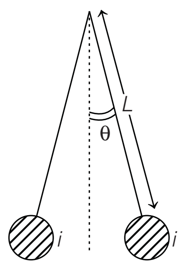
(c) $\frac{\sqrt{2}\,\mu_0 i}{\pi l}(\hat{\mathbf{i}}+\hat{\mathbf{j}})$ (d) $\frac{\mu_0 i}{\sqrt{2}\,\pi l}(\hat{\mathbf{i}}+\hat{\mathbf{j}})$

27. A thin ring of 10 cm radius carries a uniformly distributed charge. The ring rotates at a constant angular speed of 40π rad s^{-1} about its axis, perpendicular to its plane. If the magnetic field at its centre is 3.8×10^{-9} T, then the charge carried by the ring is close to $(\mu_0 = 4\pi\times10^{-7}\ \text{N/A}^2)$.

[JEE Main 2019]

(a) 2×10^{-6} C
(b) 3×10^{-5} C
(c) 4×10^{-5} C
(d) 7×10^{-6} C

28. Two long current carrying thin wires, both with current i, are held by insulating threads of length L and are in equilibrium as shown in the figure, with threads making an angle θ with the vertical. If wires have mass λ per unit length, then the value of i is (g = gravitational acceleration)

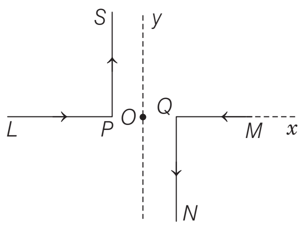


[JEE Main 2015]

(a) $\sin\theta\sqrt{\frac{\pi\lambda gL}{\mu_0\cos\theta}}$ (b) $2\sin\theta\sqrt{\frac{\pi\lambda gL}{\mu_0\cos\theta}}$

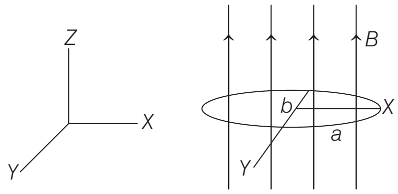
(c) $2\sqrt{\frac{\pi gL}{\mu_0}}\tan\theta$ (d) $\sqrt{\frac{\pi\lambda gL}{\mu_0}}\tan\theta$

29. As shown in the figure, two infinitely long, identical wires are bent by 90° and placed in such a way that the segments LP and QM are along the X-axis, while segments PS and QN are parallel to the Y-axis. If $OP = OQ = 4$ cm and the magnitude of the magnetic field at O is 10^{-4} T and the two wires carry equal currents (see figure), the magnitude of the current in each wire and the direction of the magnetic field at O will be
(Take, $\mu_0 = 4\pi\times10^{-7}\ \text{NA}^{-2}$) **[JEE Main 2019]**



(a) 40 A, perpendicular out of the page
(b) 20 A, perpendicular into the page
(c) 20 A, perpendicular out of the page
(d) 40 A, perpendicular into the page

30. An elliptical loop having resistance R, of semi-major axis a and semi-minor axis b is placed in a magnetic field as shown in the figure. If the loop is rotated about the X-axis with angular frequency ω, then the average power loss in the loop due to joule's heating is **[JEE Main 2020]**



(a) $\frac{\pi^2a^2b^2B^2\omega^2}{2R}$
(b) zero
(c) $\frac{\pi abB\omega}{R}$
(d) $\frac{\pi^2a^2b^2B^2\omega^2}{R}$

31. A square loop of side $2a$ and carrying current i is kept in XY-plane with its centre at origin. A long wire carrying the same current i is placed parallel to the Z-axis and passing through the point $(0, b, 0)$, $(b >> a)$. The magnitude of the torque on the loop about Z-axis is given by **[JEE Main 2020]**

(a) $\frac{2\mu_0I^2a^3}{\pi b^2}$ (b) $\frac{2\mu_0I^2a^2}{\pi b}$

(c) $\frac{\mu_0I^2a^3}{2\pi b^2}$ (d) $\frac{\mu_0I^2a^2}{2\pi b}$

32. Two identical wires A and B, each of length l, carry the same current i. Wire A is bent into a circle of radius R and wire B is bent to form a square of side a. If B_A and B_B are the values of magnetic field at the centres of the circle and square respectively, then the ratio $\frac{B_A}{B_B}$ is **[JEE Main 2016]**

(a) $\frac{\pi^2}{8}$ (b) $\frac{\pi^2}{16\sqrt{2}}$

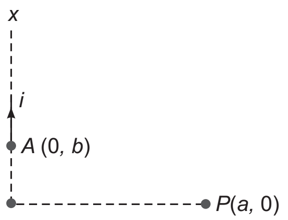
(c) $\frac{\pi^2}{16}$ (d) $\frac{\pi^2}{8\sqrt{2}}$

33. Proton with kinetic energy of 1 MeV moves from south to north. It gets an acceleration of 10^{12} m/s^2 by an applied magnetic field (west to east). The value of magnetic field (rest mass of proton is 1.6×10^{-27} kg) **[JEE Main 2020]**

(a) 71 mT (b) 0.071 mT

(c) 0.71 mT (d) 7.1 mT

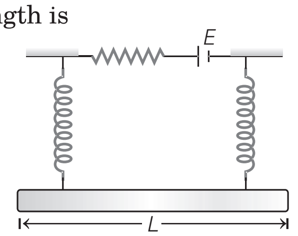
34. An infinitely long wire carrying current i is along Y-axis such that its one end is at point $(0, b)$ while the wire extends upto ∞. The magnitude of magnetic field strength at point $P(a, 0)$ is



(a) $\frac{\mu_0 i}{4\pi a}\left(1+\frac{b}{\sqrt{a^2+b^2}}\right)$ (b) $\frac{\mu_0 i}{4\pi a}\left(1-\frac{b}{\sqrt{a^2+b^2}}\right)$

(c) $\frac{\mu_0 i}{4\pi a}\left(1-\frac{a}{\sqrt{a^2+b^2}}\right)$ (d) $\frac{\mu_0 i}{4\pi a}\left(1+\frac{a}{\sqrt{a^2+b^2}}\right)$

35. A straight rod of mass m and length L is suspended from the identical springs as shown in figure. The spring is stretched a distance x_0 due to the weight of the wire. The circuit has total resistance R. When the magnetic field perpendicular to the plane of paper is switched ON, springs are observed to extend further by the same distance. The magnetic field strength is

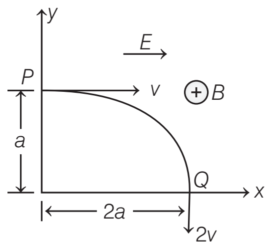


(a) $\frac{2mgR}{LE}$ (b) $\frac{mgR}{LE}$ (c) $\frac{mgR}{2LE}$ (d) $\frac{mgR}{E}$

36. A thin disc having radius r and charge q distributed uniformly over the disc is rotated n rotations per second about its axis. The magnetic field at the centre of the disc is

(a) $\frac{\mu_0 qn}{2r}$ (b) $\frac{\mu_0 qn}{r}$ (c) $\frac{\mu_0 qn}{4r}$ (d) $\frac{3\mu_0 qn}{4r}$

37. A particle of charge $+q$ and mass m moving under the influence of a uniform electric field $E\hat{\mathbf{i}}$ and a uniform magnetic field $B\hat{\mathbf{k}}$ follows a trajectory from P to Q as shown in figure. The velocities at P and Q are $v\hat{\mathbf{i}}$ and $-2v\hat{\mathbf{i}}$, respectively. Which of the following statement(s) is/are correct?



(a) $E = \frac{1}{4}\left(\frac{\mu v^2}{qa}\right)$

(b) Rate of work done by the electric field at P is $= \frac{1}{4}\left(\frac{mv^2}{a}\right)$.

(c) Rate of work done by the electric field at P is zero.

(d) Rate of work done by both the fields at Q is zero.

38. A cubical region of space is filled with some uniform electric and magnetic fields. An electron enters, the cube across one of its faces with velocity $\mathbf{v}$ and a positron enters *via* opposite face with velocity $-\mathbf{v}$. At this instant, **[NCERT Exemplar]**

(a) the electric forces on both the particles cause identical accelerations

(b) the magnetic forces on both the particles cause unequal accelerations

(c) Both particles gain or loose energy at the same rate

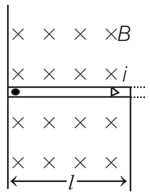
(d) the motion of the centre of mass (CM) is determined by $\mathbf{E}$ alone

39. A square loop of side $2a$ and carrying current i is kept in XZ-plane with its centre at origin. A long wire carrying the same current i is placed parallel to Z-axis and passing through point $(0, b, 0)$, $(b >> a)$. The magnitude of torque on the loop about Z-axis will be **[JEE Main 2020]**

(a) $\frac{2\mu_0 i^2 a^2}{\pi b}$ (b) $\frac{2\mu_0 i^2 a^2 b}{\pi(a^2+b^2)}$

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

40. A straight conductor of mass m and carrying a current i is hinged at one end and placed in a plane perpendicular to the magentic field of intensity B as shown in the figure. At any moment if the conductor is left free, then the angular acceleration of the conductor will be (Assume gravity free region) will be



(a) $\dfrac{iB}{m}$ (b) $\dfrac{3iB}{2m}$

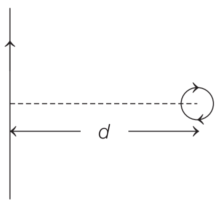
(c) $\dfrac{2m}{iB}$ (d) $\dfrac{2m}{3iB}$

41. The region between $y = 0$ and $y = d$ contains a magnetic field $\mathbf{B} = B\hat{\mathbf{k}}$. A particle of mass m and charge q enters the region with a velocity $\mathbf{v} = v\hat{\mathbf{i}}$. If $d = \dfrac{mv}{2qB}$ then the acceleration of the charged particle at the point of its emergence at the other side is **[JEE Main 2019]**

(a) $\dfrac{qvB}{m}\left(\dfrac{\sqrt{3}}{2}\hat{\mathbf{i}} + \dfrac{1}{2}\hat{\mathbf{j}}\right)$ (b) $\dfrac{qvB}{m}\left(\dfrac{1}{2}\hat{\mathbf{i}} - \dfrac{\sqrt{3}}{2}\hat{\mathbf{j}}\right)$

(c) $\dfrac{qvB}{m}\left(\dfrac{-\hat{\mathbf{j}} + \hat{\mathbf{i}}}{\sqrt{2}}\right)$ (d) $\dfrac{qvB}{m}\left(\dfrac{\hat{\mathbf{i}} + \hat{\mathbf{j}}}{\sqrt{2}}\right)$

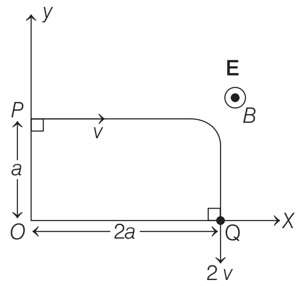
42. An infinitely long current-carrying wire and a small current carrying loop are in the plane of the paper as shown in figure. The radius of the loop is a and distance of its centre from the wire is $d (d >> a)$. If the loop applies a force F on the wire, then **[JEE Main 2019]**



(a) $F \propto \left(\dfrac{a^2}{d^3}\right)$ (b) $F = 0$

(c) $F \propto \left(\dfrac{a}{d}\right)$ (d) $F \propto \left(\dfrac{a}{d}\right)^2$

43. A charged particle of mass m and charge q moving under the influence of uniform electric field $E\hat{\mathbf{i}}$ and a uniform magnetic field $B\hat{\mathbf{k}}$ follows a trajectory from point P to Q as shown in the figure. The velocities at P and Q are respectively, $v\hat{\mathbf{i}}$ and $-2v\hat{\mathbf{j}}$. Then, which of the following statements (A, B, C, D) are the correct? (Trajectory shown is schematic and not to scale)



I. $E = \dfrac{3}{4}\left(\dfrac{mv^2}{qa}\right)$

II. Rate of work done by the electric field at P is $\dfrac{3}{4}\left(\dfrac{mv^3}{a}\right)$.

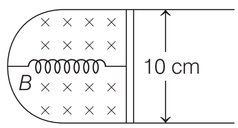
III. Rate of work done by both the fields at Q is zero.

IV. The difference between the magnitude of angular momentum of the particle at P and Q is $2\,mav$. **[JEE Main 2020]**

(a) I, III,IV (b) I, II, III

(c) I, II, III, IV (d) II, III, IV

44. A thin strip 10 cm long is on an U-shaped wire of negligible resistance and it is connected to a spring of spring constant $0.5\ \text{Nm}^{-1}$ (see figure). The assembly is kept in a uniform magnetic field of 0.1 T. If the strip is pulled from its equilibrium position and released, the number of oscillations it performs before its amplitude decreases by a factor of e is N. If the mass of the strip is 50 g, its resistance $10\ \Omega$ and air drag negligible, N will be close to



[JEE Main 2019]

(a) 1000 (b) 50000

(c) 5000 (d) 10000

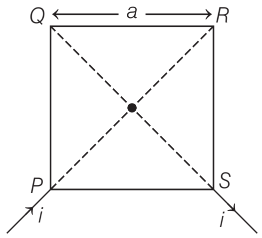
Numerical Value Questions

45. 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 magnitude of the force due to the magnetic field acting on the charge at this instant is ……… .

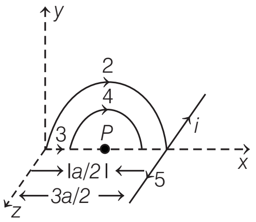
46. A galvanometer coil has 500 turns and each turn has an average area of $3 \times 10^{-4}\ \text{m}^2$. If a torque of 1.5 N-m is required to keep this coil parallel to a magnetic field when a current of 0.5 A is flowing through it, the strength of the field (in T) is ....

[JEE Main 2020]

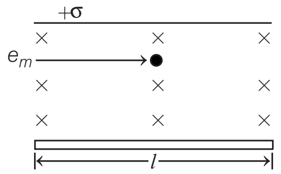
47. In a square loop *PQRS* made with a wire of cross-section current i enters from point P and leaves from point S. The magnitude of magnetic field induction at the centre O of the square is ....



48. In the following figure, the magnetic field at the point P will be $\frac{\mu_0 i}{P\pi a}\sqrt{\pi^2 + 4}$, where the value of P is ....



49. An electron moves straight inside a charged parallel plate capacitor of uniform surface charge density σ. The space between the plates is filled with constant magenetic field of induction **B**, as shown in the figure. If the gravity is neglected, then the time of straight line motion of the electron in the capacitor will be $\frac{\varepsilon_0 lB}{x\sigma}$, where the value of x is



Answers

Round I

1. (c)	**2.** (a)	**3.** (c)	**4.** (a)	**5.** (d)	**6.** (c)	**7.** (d)	**8.** (c)	**9.** (b)	**10.** (a)
11. (c)	**12.** (d)	**13.** (a)	**14.** (b)	**15.** (a)	**16.** (b)	**17.** (d)	**18.** (b)	**19.** (a)	**20.** (b)
21. (d)	**22.** (c)	**23.** (c)	**24.** (*)	**25.** (b)	**26.** (a)	**27.** (c)	**28.** (b)	**29.** (c)	**30.** (c)
31. (b)	**32.** (c)	**33.** (b)	**34.** (c)	**35.** (d)	**36.** (b)	**37.** (b)	**38.** (c)	**39.** (c)	**40.** (b)
41. (d)	**42.** (d)	**43.** (a)	**44.** (b)	**45.** (c)	**46.** (a)	**47.** (a)	**48.** (c)	**49.** (*)	**50.** (c)
51. (d)	**52.** (c)	**53.** (b)	**54.** (b)						

Round II

1. (b)	**2.** (b)	**3.** (a)	**4.** (d)	**5.** (d)	**6.** (b)	**7.** (b)	**8.** (a)	**9.** (c)	**10.** (a)
11. (c)	**12.** (a)	**13.** (c)	**14.** (d)	**15.** (d)	**16.** (b)	**17.** (d)	**18.** (a)	**19.** (a)	**20.** (b)
21. (a)	**22.** (a)	**23.** (b)	**24.** (b)	**25.** (b)	**26.** (c)	**27.** (b)	**28.** (b)	**29.** (b)	**30.** (a)
31. (b)	**32.** (d)	**33.** (c)	**34.** (b)	**35.** (b)	**36.** (b)	**37.** (d)	**38.** (c)	**39.** (a)	**40.** (b)
41. (*)	**42.** (d)	**43.** (b)	**44.** (c)	**45.** 0	**46.** 20	**47.** 0	**48.** 3	**49.** 1	

Solutions

Round I

1. Magnetic field induction at a point due to a long current carrying wire is related with distance r by relation $B \propto \frac{1}{r}$.

Therefore, graph given in option (c) is correct.

2. According to Biot Savart's law, the magnetic field $\mathbf{B}$ at a point distance r from a charge q moving with a velocity $\mathbf{v}$ is given by

$$\mathbf{B} = \frac{\mu_0}{4\pi} \frac{q\,(\mathbf{v} \times \mathbf{r})}{r^3}$$

or
$$B = \frac{\mu_0}{4\pi} \frac{qv \sin\theta}{r^2}$$

The direction of $\mathbf{B}$ is along $(\mathbf{v} \times \mathbf{r})$, *i.e.* perpendicular to the plane containing $\mathbf{v}$ and $\mathbf{r}$. $\mathbf{B}$ at a point obeys inverse square law and not inverse cube law.

3. As, $\mathbf{B} = \frac{\mu_0 i}{4\pi a} [\sin\theta_1 + \sin\theta_2]$

Here, $\theta_1 = -30°, \theta_2 = 60°$

$$\sin\theta_1 = -\frac{1}{2} \text{ and } \sin\theta_2 = \frac{\sqrt{3}}{2}$$

Putting these values, we get

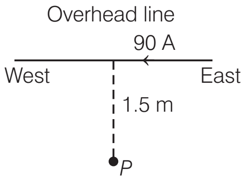
$$\mathbf{B} = \frac{\mu_0 i}{4\pi a} [-1/2 + \sqrt{3}/2]$$

4. Given, $i = 90$ A and $r = 1.5$ m

Here, point P is below the power line, where we have to find the magnetic field and its direction.

The magnitude of magnetic field,

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2i}{r}$$



$$= \frac{10^{-7} \times 2 \times 90}{1.5} = 1.2 \times 10^{-5} \text{ T}$$

The direction of magnetic field is given by Maxwell's right hand rule, so the direction of magnetic field at point P due to the flowing current is perpendicularly outwards to the plane of paper.

5. Perpendicular to O from PQ or QR,

$$a = r \sin\frac{\theta}{2}$$

Magnetic field induction at O due to current through PQ and QR,

$$B = \frac{\mu_0}{4\pi} \frac{i}{a} [\sin(90° - \theta/2) + \sin 90°] \times 2$$

$$= \frac{\mu_0}{2\pi} \frac{i}{r \sin\frac{\theta}{2}} \left(\cos\frac{\theta}{2} + 1\right) = \frac{\mu_0}{2\pi} \frac{i}{r} \frac{\left(1 + \cos\frac{\theta}{2}\right)}{\sin\frac{\theta}{2}}$$

6. Total magnetic field induction at O,

$$\mathbf{B} = \mathbf{B}_{LR} + \mathbf{B}_{RP} + \mathbf{B}_{MS} + \mathbf{B}_{SQ}$$
$$= 0 + \frac{\mu_0}{2\pi} \frac{i}{r} + 0 + \frac{\mu_0}{2\pi} \frac{i}{r} = \frac{\mu_0}{2\pi} \frac{2i}{r}$$
$$= \frac{2 \times 10^{-7} \times 2 \times 10}{0.02} = 2 \times 10^{-4} \text{ T}$$

7. Magnetic field induction at the centre of circular coil carrying current, $B = \frac{\mu_0}{4\pi} \frac{2\pi n i}{r}$, *i.e.* $B \propto n/r$

But, $2\pi r = 3 \times 2\pi r_1$ or $r_1 = \frac{r}{3}$

So, $$\frac{B_1}{B} = \frac{n_1}{r_1} \times \frac{r}{n} = \frac{3 \times r}{\left(\frac{r}{3}\right) \times 1} = 9$$

$$B_1 = 9B$$

The magnetic field at the centre caused by the same current is nine times of its initial value.

8. Magnetic field induction at O due to current through ACB is $B_1 = \frac{\mu_0 i\theta}{4\pi r}$

It is acting perpendicular to the paper downwards. Magnetic field induction at O due to current through ABD is

$$B_2 = \frac{\mu_0}{4\pi} \frac{i(2\pi - \theta)}{r}$$

It is acting perpendicular to paper upwards.

$\therefore$ Total magnetic field at O due to current loop is

$$B = B_2 - B_1 = \frac{\mu_0}{4\pi} \frac{i}{r} (2\pi - \theta) - \frac{\mu_0}{4\pi} \frac{i}{r} \theta$$
$$= \frac{\mu_0}{2\pi} \frac{i}{r} (\pi - \theta)$$

9. Magnetic field at centre of the circular loop,

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

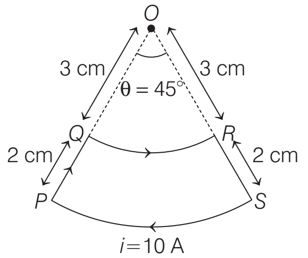
Magnetic field due to an arc of a circle at the centre,

$$B = \left(\frac{\theta}{2\pi}\right) \frac{\mu_0 i}{2R} = \left(\frac{\mu_0}{4\pi}\right)\left(\frac{i}{R}\right)\theta$$

Here, $\theta = 30°$ and $i = 3$ A, $R = 0.6$ m

$$B = \left(\frac{\mu_0}{4\pi}\right)\left(\frac{3}{0.6}\right)\left(\frac{\pi}{6}\right)$$
$$= \frac{10^{-7} \times 3 \times \pi}{0.6 \times 6} = 2.6 \times 10^{-7} \text{ T}$$

10. From the given figure as shown below



The magnetic field at point O due to wires PQ and RS will be zero.

Magnetic field due to arc QR at point O will be

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

Here, $\theta = 45° = \dfrac{\pi}{4}$ rad, $i = 10$ A

and $a = 3$ cm $= 3 \times 10^{-2}$ m

$$\Rightarrow \quad B_1 = \frac{\pi}{2\pi \times 4}\left(\frac{\mu_0 \times 10}{2 \times 3 \times 10^{-2}}\right)$$

$$= \frac{\mu_0 \times 5}{2 \times 12 \times 10^{-2}} = \frac{5 \times \mu_0 \times 10^2}{24}$$

Direction of field B_1 will be coming out of the plane of figure.

Similarly, field at point O due to arc SP will be

$$B_2 = \frac{\pi}{4}\left(\frac{1}{2\pi}\right)\left[\frac{\mu_0 \times 10}{2 \times (2+3) \times 10^{-2}}\right]$$

$$= \frac{\mu_0 \times 10^2}{8}$$

Direction of B_2 is going into the plane of the figure.

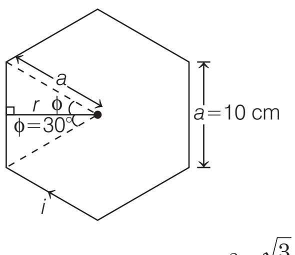
$\therefore$ The resultant field at O is

$$B = B_1 - B_2 = \frac{1}{2}\left(\frac{5 \times \mu_0}{12 \times 10^{-2}} - \frac{\mu_0}{4 \times 10^{-2}}\right)$$

$$= \frac{4\pi \times 10^{-7}}{12 \times 10^{-2}} \cong 1 \times 10^{-5} \text{ T}$$

11. Magnitude of magnetic field due to one side of hexagonal loop at the centre is

$$B_1 = \frac{\mu_0 i}{4\pi r} \cdot 2 \sin\phi$$



Here, $r = 10 \cos 30°$ cm $= 10 \times 10^{-2} \times \dfrac{\sqrt{3}}{2}$ m

$$= 5\sqrt{3} \times 10^{-2} \text{ m}$$

So, $\quad B_1 = \dfrac{\mu_0 i \times 2 \sin 30°}{4\pi(5\sqrt{3} \times 10^{-2})} \qquad (\because \phi = 30°)$

So, magnetic field due to complete 1 turn of loop of six sides is

$$B_2 = 6B_1 = \frac{6\,\mu_0 i \times 2 \sin 30°}{4\pi(5\sqrt{3} \times 10^{-2})}$$

Magnetic field of 50 such turns at centre is

$$B_3 = 50B_2 = \frac{50 \times 6 \times \mu_0 i \times 2 \sin 30°}{4\pi(5\sqrt{3} \times 10^{-2})}$$

$$= 500\sqrt{3}\left(\frac{\mu_0 i}{\pi}\right) \text{T}$$

$$= 500\sqrt{3} \text{ in units of } \frac{\mu_0 i}{\pi}$$

12. $B_1 = \dfrac{\mu_0}{4\pi}\dfrac{2\pi n i}{r}$ and $B_2 = \dfrac{\mu_0}{4\pi}\dfrac{2\pi n i r^2}{(r^2 + h^2)^{3/2}}$

So, $$\frac{B_2}{B_1} = \frac{r^3}{(r^2 + h^2)^{3/2}} = \left(1 + \frac{h^2}{r^2}\right)^{-3/2}$$

Fractional decrease in the magnetic field will be

$$= \frac{B_1 - B_2}{B_1} = \left(1 - \frac{B_2}{B_1}\right)$$

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

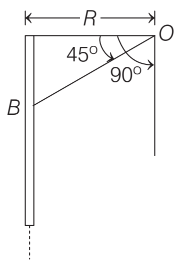
$$= 1 - \left(1 - \frac{3h^2}{2r^2}\right) = \frac{3h^2}{2r^2}$$

13. Given arrangement consists of two current carrying wires and one current loop as shown in the question figure.

For wire ABN, magnetic field at O is given by

$$B_1 = \frac{\mu_0}{4\pi} \times \frac{i}{R}(\sin\phi_1 + \sin\phi_2)$$

Here, $\phi_1 = +90°$ and $\phi_2 = -45°$.

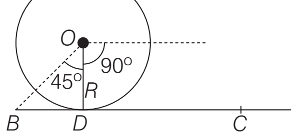


Hence, magnetic field of wire,

$$B_1 = \frac{\mu_0}{4\pi} \times \frac{i}{R}[\sin 90° + \sin(-45°)]$$

$$= \frac{\mu_0 i}{4\pi R}\left(1 - \frac{1}{\sqrt{2}}\right) \otimes$$

Also, field of wire BDC at O,



$$B_2 = \frac{\mu_0 i}{4\pi R}(\sin\phi_1 + \sin\phi_2)$$

Here, $\phi_1 = 45°$ and $\phi_2 = 90°$.

$$\therefore \quad B_2 = \frac{\mu_0 i}{4\pi R}\left(\frac{1}{\sqrt{2}} + 1\right) \odot$$

Magnetic field of circular coil at O,

$$B_3 = \frac{\mu_0 i}{2R} \odot$$

Hence, net field at O,

$$\begin{aligned} B_{\text{net}} &= B_1 \otimes + B_2 \odot + B_3 \odot \\ &= \frac{\mu_0 i}{4\pi R}\left(1 - \frac{1}{\sqrt{2}}\right) - \frac{\mu_0 i}{4\pi R}\left(\frac{1}{\sqrt{2}} + 1\right) - \frac{\mu_0 i}{2R} \\ &= \frac{\mu_0 i}{2R}\left(\frac{1}{2\pi} - \frac{1}{\sqrt{2}\cdot 2\pi} - \frac{1}{\sqrt{2}\cdot 2\pi} - \frac{1}{2\pi} - 1\right) \\ &= \frac{-\mu_0 i}{2\pi R}\left(\pi + \frac{1}{\sqrt{2}}\right) = \frac{\mu_0 i}{2\pi R}\left(\pi + \frac{1}{\sqrt{2}}\right). \end{aligned}$$

Negative sign is taken for outward field.

14. From the figure, magnetic field due to AB,

$$\mathbf{B}_1 = \frac{\mu_0 i}{4\pi R}\left[\sin\frac{\pi}{2} - \sin\frac{\pi}{4}\right] = \frac{\mu_0 i}{4\pi R}\left[1 - \frac{1}{\sqrt{2}}\right]$$

Magnetic field due to circular loop,

$$\mathbf{B}_2 = \frac{\mu_0 i}{2R}$$

Magnetic field due to straight wire BC,

$$\begin{aligned} \mathbf{B}_3 &= \frac{\mu_0 i}{4\pi R}\left[\sin\frac{\pi}{2} + \sin\frac{\pi}{4}\right] \\ &= \frac{\mu_0 i}{4\pi R}\left[1 + \frac{1}{\sqrt{2}}\right] \end{aligned}$$

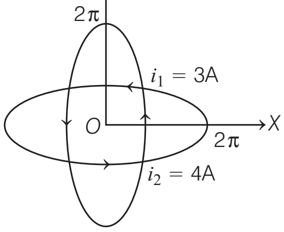
$\therefore$ Resultant magnetic field, $\mathbf{B} = \mathbf{B}_1 + \mathbf{B}_2 + \mathbf{B}_3$

$$\begin{aligned} &= \left(\frac{\mu_0 i}{2R} + \frac{2\mu_0 i}{4\pi R}\frac{1}{\sqrt{2}}\right) \\ &= \frac{\mu_0 i}{2R}\left[1 + \frac{1}{\sqrt{2}\,\pi}\right] \end{aligned}$$

15. Field at the centre of the loop is given by

$$B = \frac{\mu_0 i}{2R}$$

where, R is radius given, $R = 2\pi\,\text{cm} = 2\pi \times 10^{-2}$ m



$$B_x = \frac{\mu_0}{2}\,\frac{i_1}{2\pi \times 10^{-2}}$$

$$i_1 = 3\,\text{A}$$

$$\therefore \quad B_x = \frac{\mu_0}{2}\cdot\frac{3 \times 10^2}{2\pi} = 3 \times 10^{-5}\ \text{T}$$

$$B_y = \frac{\mu_0}{2}\cdot\frac{i_2}{2\pi \times 10^{-2}},\ i_2 = 4\,\text{A}$$

$$B_y = 4 \times 10^{-5}\ \text{T}$$

$$\therefore \quad B_{\text{net}} = \sqrt{B_x^2 + B_y^2} = \sqrt{(3^2 + 4^2) \times 10^{-10}}$$

$$B_{\text{net}} = 5 \times 10^{-5}\ \text{T}$$

16. As, total magnetic field is due to two straight paths and the circular loop.

$$\begin{aligned} B_{\text{total}} &= 2 \times B_{\text{st}} + B_{\text{loop}} \\ &= \frac{2\mu_0 I}{4\pi r} + \frac{\mu_0 I}{2r}\left(\frac{\pi}{2\pi}\right) \\ &= \frac{\mu_0 I}{4\pi r}(2 + \pi) \end{aligned}$$

17. Magnetic flux inside rod, $B \propto r$ and outside the rod, $B \propto \frac{i}{r}\cdot$ Therefore, the graph shown in option (d) is correct.

18. For a point inside the tube, using Ampere law, $\int B \cdot dl = \mu_0 i$. Here, we have $i = 0$ for inside the tube.

$$\therefore \quad B = 0$$

19. Magnetic field inside solenoid is

$$B = \mu n I = \mu_0 \mu_r n I = 4\pi \times 10^{-7} \times 500 \times 1000 \times 5 = \pi\text{T}$$

20. The length of solenoid, $l = 80$ cm $= 0.8$ m

Number of layers $= 5$

Number of turns per layer $= 400$

Diameter of solenoid $= 1.8$ cm

Current in solenoid, $i = 8$ A

$\therefore$ The total number of turns, $N = 400 \times 5 = 2000$

and number of turns/length, $n = \frac{2000}{0.8} = 2500$

The magnitude of magnetic field inside the solenoid

$$B = \mu_0 n i = 4 \times 3.14 \times 10^{-7} \times 2500 \times 8 = 2.5 \times 10^{-2}\,\text{T}$$

The direction of magnetic field is along the axis of solenoid.

21. There is a uniform magnetic field $\mathbf{B}$ inside the current carrying long solenoid acting along the axis of solenoid. The magnitude of force on the electron of charge $(-e)$ moving with velocity $\mathbf{v}$ in a magnetic field $\mathbf{B}$ is

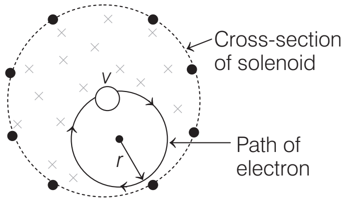
$$|\mathbf{F}| = -e\,|\mathbf{v} \times \mathbf{B}| = -evB\sin\theta$$

Here angle θ between $\mathbf{v}$ and $\mathbf{B}$ is zero, *i.e.* $\theta = 0°$ and $\sin\theta = 0$. Therefore, $F = 0$.

It means the electron will continue to move with a uniform velocity along the axis of the solenoid.

22. In given arrangement, electron gun shoots electron perpendicularly to the direction of magnetic field.

Here, we are showing cross-section of solenoid.



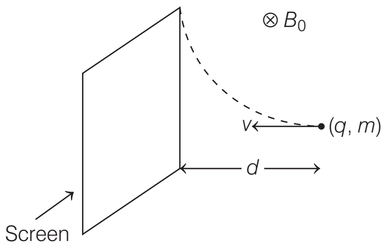
As electron is moving at 90° to magnetic field, its path is a circle. Maximum value of radius of path taken by electron, such that it does not collide with solenoid wall is $\frac{R}{2}$.

So, $\quad r_{\max} = \frac{R}{2} = \frac{mv_{\max}}{eB}$

Here, $\quad B = \mu_0 nI$

So, $\quad v_{\max} = \frac{ReB}{2m} = \frac{e\mu_0 nIR}{2m}$

23. As we know that, if a charge particle moves in a uniform magnetic field, then its path is always circular. Considering the charge positive,the direction of magnetic force acting on it, has been shown by dotted line.



As, charge particle should not hit the screen this means radius of circular path must be less than screen distance d.

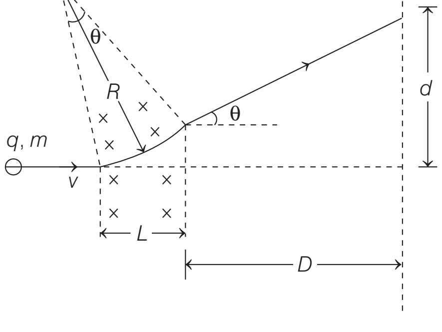
i.e. $\quad R \le d$

$\Rightarrow \quad \frac{mv}{qB_0} \le d \quad \left(\because R = \frac{mv}{qB_0}\right)$

or $\quad v \le \frac{qB_0 d}{m}$

Maximum value of $v = \frac{qB_0 d}{m}$

24.



When electron enters the region of magnetic field, it experiences a magnetic force which rotates electron in a circular path of radius R.

So, magnetic force acts like a centripetal force and we have

$$\frac{mv^2}{R} = Bqv$$

where, m = mass of electron, q = charge of electron, v = speed of electron, R = radius of path and B = magnetic field intensity.

Radius of path of electron,

$$R = \frac{mv}{Bq}$$

Now, from geometry of given arrangement, comparing values of $\tan\theta$, we have

$$\tan\theta = \frac{L}{R} = \frac{d}{D}$$

$$\Rightarrow \quad d = \frac{LD}{R} = \frac{Bq\,LD}{mv}$$

$$\Rightarrow \quad d = \frac{BqLD}{\sqrt{2mK}} \quad (\because mv = \sqrt{2mK})$$

where, K = kinetic energy of electron

Here, $B = 1.5 \times 10^{-3}$ T,

$q = 1.6 \times 10^{-19}$ C, $L = 2 \times 10^{-2}$ m, $D = 6 \times 10^{-2}$ m,

$m = 9.1 \times 10^{-31}$ kg, $K = 100 \times 1.6 \times 10^{-19}$ J

So, $\quad d = \frac{(1.5 \times 10^{-3} \times 1.6 \times 10^{-19} \times 2 \times 10^{-2} \times 6 \times 10^{-2})}{\sqrt{(2 \times 9.1 \times 10^{-31} \times 100 \times 1.6 \times 10^{-19})}}$

$= 5.34$ cm

No option is matching.

25. During the circular motion of accelerated electron in the presence of magnetic field, its radius is given by

$$r = \frac{mv}{Be} = \frac{\sqrt{2meV}}{eB}$$

where, v is velocity and V is voltage.

After substituting the given values, we get

$$= \frac{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 500}}{1.6 \times 10^{-19} \times 100 \times 10^{-3}}$$

$$= 10\left[\frac{2 \times 9.1 \times 500}{1.6} \times 10^{-12}\right]^{1/2},$$

$$r = 7.5 \times 10^{-4} \text{ m}$$

26. Radius of path of charged particle q in a uniform magnetic field B of mass m moving with velocity v is

$$r = \frac{mv}{Bq} = \frac{m\sqrt{(2qV/m)}}{Bq}$$

$$\Rightarrow \quad r \propto \frac{\sqrt{m}}{\sqrt{q}}$$

So, required ratio is

$$\frac{r_p}{r_\alpha} = \sqrt{\frac{m_p}{m_\alpha}} \times \sqrt{\frac{q_\alpha}{q_p}} = \sqrt{\frac{1}{4}} \times \sqrt{\frac{2}{1}} = \frac{\sqrt{2}}{2} = \frac{1}{\sqrt{2}}$$

27. As, $r = \dfrac{\sqrt{2mE}}{Bq} = \dfrac{\sqrt{2m_1E_1}}{Bq}$

or $\quad E_1 = \dfrac{mE}{m_1} = \dfrac{(2m_1)}{m_1} \times 50 \text{ keV} = 100 \text{ keV}$

28. As, $E = \dfrac{1}{2}mv^2$ or $v = \sqrt{\dfrac{2E}{m}}$

and $\quad r = \dfrac{mv}{Bq} = \dfrac{m}{Bq}\sqrt{2E/m}$

or $\quad r = \dfrac{\sqrt{2\,Em}}{Bq}$ or $r \propto \sqrt{m}$

Now, $m_e < m_p$, so $r_e < r_p$.

Therefore, trajectory of proton is less curved.

29. The force on a point charge Q in a magnetic field is

$$\mathbf{F} = Q(\mathbf{v} \times \mathbf{B})$$

Its direction is perpendicular to direction of motion of charge, so work done,

$$W = \mathbf{F} \cdot \mathbf{s} = Fs \cos 90° = 0$$

30. In magnetic field, the radius of circular path,

$$r = \frac{mv}{Bq} = \frac{v}{B\left(\dfrac{q}{m}\right)}, \text{ i.e. } r \propto 1/(q/m)$$

As, $r_M < r_N$

So, the specific charge of M is greater than that of N.

31. From $Bqv = \dfrac{mv^2}{r}$, we have

$$r = \frac{mv}{Bq} = \frac{\sqrt{2mK}}{Bq}$$

where, K is the kinetic energy.

As, kinetic energies of particles are same.

$$r \propto \frac{\sqrt{m}}{q}$$

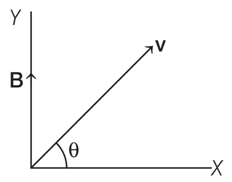
$\Rightarrow \quad r_e : r_p : r_\alpha = \dfrac{\sqrt{m_e}}{e} : \dfrac{\sqrt{m_p}}{e} : \dfrac{\sqrt{4m_p}}{2e}$

Clearly, $r_p = r_\alpha$ and r_e is least $\quad (\because m_e < m_p)$

So, $\quad r_p = r_\alpha > r_e$

32. Since, the proton is entering the magnetic field at some angle other than 90°, its path is helix. Component velocity of proton along X-axis,

$$v_x = v\cos 60° = 2 \times 10^6 \times \frac{1}{2} = 10^6 \text{ ms}^{-1}$$



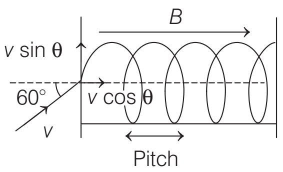
Due to component of velocity v_x, the radius of the helix described is given by the relation,

$$r = \frac{mv_x}{qB} = \frac{1.67 \times 10^{-27} \times 10^6}{1.6 \times 10^{-19} \times 0.104} = 0.1 \text{ m}$$

Now, $\quad T = \dfrac{2\pi r}{v_x} = \dfrac{2\pi \times 0.1}{10^6} = 2\pi \times 10^{-7}$ s

33. Pitch of helical path shown below is given by

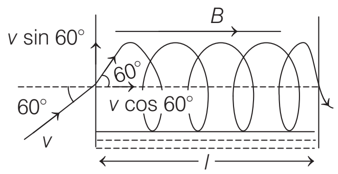
$$\text{Pitch} = T \cdot v\cos\theta = \frac{2\pi m}{Bq} \cdot v\cos\theta$$



$$\Rightarrow \text{Pitch} = \frac{2 \times 3.14 \times 1.67 \times 10^{-27} \times 4 \times 10^5 \times \cos 60°}{(0.3)(1.69 \times 10^{-19})}$$

$= 0.04 \text{ m} = 4 \text{ cm}$

34. As $\mathbf{v}$ is not perpendicular to $\mathbf{B}$, so path of particle is helical in magnetic field as shown in figure,



Let T be the time to complete 1 round, then

$$T = \frac{2\pi m}{Bq}$$

So, total time to cross the length l of region of magnetic field is

$$t = 10\,T = 10 \times \frac{2\pi m}{Bq}$$

Hence, length of path,

$$l = \text{speed} \times \text{time} = v\cos\theta \times t$$

$$= v\cos 60° \times 10 \times \frac{2\pi m}{Bq}$$

$$\Rightarrow \quad l = \frac{4 \times 10^5 \times \dfrac{1}{2} \times 10 \times 2\pi \times 1.67 \times 10^{-27}}{0.3 \times 1.6 \times 10^{-19}}$$

$= 0.437 \approx 0.44$ m

35. Here,

$$\mathbf{E} = 2\hat{\mathbf{i}} + 3\hat{\mathbf{j}},\ \mathbf{B} = 4\hat{\mathbf{j}} + 6\,\hat{\mathbf{k}}, \text{ where}$$

q = charge on a particle.

Initial position, $r_1 = (0,0)$

Final position, $r_2 = (1, 1)$

Net force experienced by charge particle inside electromagnetic field is

$$\mathbf{F}_{\text{net}} = q\mathbf{E} + q(\mathbf{v} \times \mathbf{B}) = q(2\hat{\mathbf{i}} + 3\hat{\mathbf{j}}) \text{ [here, } \mathbf{v} \times \mathbf{B} = 0]$$

$$= (2q\,\hat{\mathbf{i}} + 3q\,\hat{\mathbf{j}})$$

$\therefore \quad dW = \mathbf{F}_{net} \cdot d\mathbf{r}$

$$\Rightarrow \quad \int dW = \int_{r_1}^{r_2} (2q\,\hat{\mathbf{i}} + 3q\,\hat{\mathbf{j}}) \cdot (dx\,\hat{\mathbf{i}} + dy\,\hat{\mathbf{j}})$$

[here $d\mathbf{r} = dx\,\hat{\mathbf{i}} + dy\,\hat{\mathbf{j}}$]

$$\Rightarrow \quad W = 2q\int_0^1 dx + 3q\int_0^1 dy$$

or $\quad W = 2q + 3q$ or $W = 5q$

36. Here, E and B are acting along X-axis and v is acting along Y-axis, *i.e.* perpendicular to both E and B. Therefore, the path of charged particle is a helix with increasing speed. Speed of particle at time t is

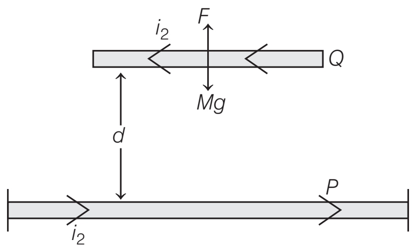
$$v = \sqrt{v_x^2 + v_y^2} \quad \ldots\text{(i)}$$

Here, $v_y = v_0$; $v_x = \frac{qE}{m} t$ and $v = \frac{\sqrt{5}}{2} v_0$

Putting values in Eq. (i), we get $t = \frac{mv_0}{2qE}$

37. As force per unit length between two parallel current carrying wires separated by a distance d is given by

$$\frac{dF}{dL} = \frac{\mu_0}{4\pi} \frac{2i_1 i_2}{d}$$



and is repulsive if the current in the wires is in opposite direction (otherwise attractive).

So, in order that wire Q may remain suspended, the force F on it must be repulsive and equal to its weight, *i.e.* the current in the two wires must be opposite directions and

$$F = Mg, \text{ i.e. } \frac{F}{L} = \frac{Mg}{L}$$

or $$\frac{\mu_0}{4\pi} \frac{2i_1 i_2}{d} = \frac{Mg}{L} \left[\text{as, } \frac{dF}{dL} = \frac{\mu_0}{4\pi} \frac{2i_1 i_2}{d}\right]$$

or $$d = 10^{-7} \times \frac{2 \times 50 \times 25}{0.075} = \frac{1}{3} \times 10^{-2} \text{ m}$$

$$\left[\text{as, } \frac{Mg}{L} = 0.075 \text{ Nm}^{-1}\right]$$

38. Force on wire, $F = Bil \sin 90° = Bil$. It acts perpendicular to the magnetic field as well as the length of wire. The acceleration in the wire,

$$a = \frac{F}{m} = \frac{Bil}{m}$$

39. Since, the magnetic field due to current through wire CD at various locations on wire AB is not uniform. Therefore, the wire AB, carrying current i_1 is subjected to variable magnetic field. Due to which, neither the force nor the torque on the wire AB will be zero. As a result of which, the wire AB will have both translational and rotational motion.

40. Given, $i_1 = 8$ A, $i_2 = 5$ A and $r = 4$ cm $= 0.04$ m

Force per unit length on two parallel wire carrying current,

$$F = \frac{\mu_0}{4\pi} \cdot \frac{2i_1 \cdot i_2}{r}$$
$$= \frac{10^{-7} \times 2 \times 8 \times 5}{0.04}$$
$$= 2 \times 10^{-4} \text{ N}$$

The force on A of length 10 cm, $F' = F \times 0.1$

($\because$ 1m = 100 cm)

$$\Rightarrow \quad F' = 2 \times 10^{-4} \times 0.1 = 2 \times 10^{-5} \text{ N}$$

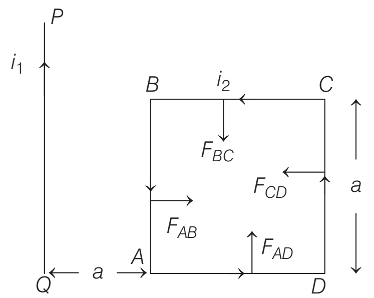
41. As the currents are in opposite directions, the magnetic field induction due to current in each wire will add up at O. The direction of magnetic field is perpendicular to XY-plane and is directed inward, *i.e.* along negative Z-axis.

42. Force on a wire 1 in which current i_1 is flowing due to another wire 2 which are separated by a distance r is given as

$$\mathbf{F} = i_1 (l \times \mathbf{B}_2)$$

or $$F = \frac{\mu_0 i_1 i_2}{2\pi r} \cdot l \sin\theta \qquad \left(\because \mathbf{B}_2 = \frac{\mu_0 i_2}{2\pi r}\right)$$

Thus, the given square loop can be drawn as shown below



$$F_{AB} = \frac{\mu_0 i_1}{2\pi a} \cdot i_2 a \text{ (away from wire } PQ) \quad (\because \theta = 90°)$$

$$F_{BC} = F_{AD} = 0 \quad (\because \theta = 0°)$$

$$F_{CD} = \frac{\mu_0 i_1}{2\pi (2a)} \cdot i_2 a \quad (\because \theta = 90°)$$

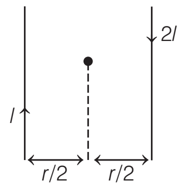
$$= \frac{\mu_0 i_1}{4\pi a} \cdot i_2 a \text{ (towards the wire } PQ)$$

$$\therefore \quad F_{net} = F_{AB} - F_{CD}$$

$$= \frac{\mu_0 i_1 i_2}{2\pi} - \frac{\mu_0 i_1 i_2}{4\pi} \text{ (away from wire)}$$

$$= \frac{\mu_0 i_1 i_2}{4\pi} \text{ (repulsive in nature)}$$

43. The magnetic field induction at P due to currents through both the wires is



$$B = \frac{\mu_0}{4\pi}\frac{2i}{r/2} + \frac{\mu_0}{4\pi}\frac{2(2i)}{r/2} = \frac{\mu_0}{4\pi}\cdot\frac{12i}{r}$$

$= \dfrac{\mu_0}{4\pi} \times \dfrac{12i}{r}$ acting perpendicular to plane of wire inwards. Now, B and v are acting in the same direction, *i.e.* $\theta = 0°$.

Force on charged particle is $F = qvB\sin\theta = qvB \times 0 = 0$.

44.
$$\frac{\mu_0 i}{4\pi}\frac{2i_i}{r} - \frac{\mu_0}{4\pi}\frac{2i_2}{r} = 10\,\mu T \qquad \ldots(i)$$
$$\frac{\mu_0}{4\pi}\frac{2i_1}{r} + \frac{\mu_0}{4\pi}\frac{2i_2}{r} = 30\,\mu T \qquad \ldots(ii)$$

On solving Eqs. (i) and (ii), we get

$$i_1 = 20\text{ A and } i_2 = 10\text{ A, so } \frac{i_1}{i_2} = 2$$

45. Distance between two linear conductors $= 6 - 2 = 4$ cm.

Let the distance of the point on scale from conductor carrying current i be x cm, where resultant magnetic field is zero. Then, the distance of this point from other conductor is $(4 - x)$ cm. As per question,

$$\frac{\mu_0}{4\pi}\frac{2i}{x \times 10^{-2}} = \frac{\mu_0}{4\pi}\frac{2(3i)}{(4-x)\,10^{-2}}$$

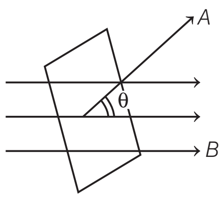
or $\quad 3x = 4 - x$

or $\quad x = 1$ cm

$\therefore$ Location of point on scale $= 2 + 1 = 3$ cm mark.

46. Given, side of square coil $= 10$ cm $= 0.1$ m

Number of turns, $N = 20$



Current in square coil, $I = 12$ A

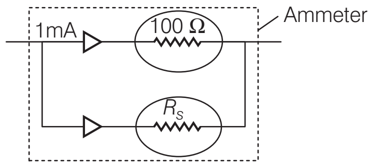
Angle made by coil, $\theta = 30°$

Magnetic field, $B = 0.80$ T

The magnitude of torque experienced by the coil,

$$\tau = NIAB\sin\theta$$
$$= 20 \times 12 \times (10 \times 10^{-2})^2 \times 0.80 \times \sin 30°$$
$$\tau = 2.4 \times 0.80\,\sin 30° = \frac{2.4 \times 0.80}{2} = 0.96\text{ N-m}$$

47. Maximum voltage that can be applied across the galvanometer coil $= 100\,\Omega \times 10^{-3}$ A $= 0.1$ V.



If R_s is the shunt resistance, then

$$R_s \times 10\text{ A} = 0.1\text{ V}$$
$$\Rightarrow \quad R_s = 0.01\,\Omega$$

48. Given, $i_g = i, G = R_0$

$$I = n\,i + i = (n+1)\,i$$
$$\therefore \quad S = \frac{i_g G}{I - i_g} = \frac{iR_0}{(n+1)i - i} = \frac{R_0}{n}$$

49. Given data,

$$i = 10^{-4}\text{ A},$$
$$R_S = 2\text{ M}\Omega = 2 \times 10^6\,\Omega,$$
$$V_{\max} = 5\text{ V}$$

Let internal resistance of galvanometer is R_G.

Voltmeter

Then, $\quad i \times R_S + i \times R_G = V_{\max}$

$\Rightarrow \quad 2 \times 10^6 \times 10^{-4} + 10^{-4} \times R_G = 5$

$\Rightarrow \quad 10^{-4}\,R_G = 5 - 200 = -195$

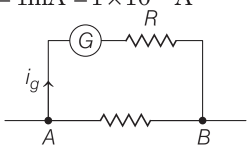
or $\quad R_G = -195 \times 10^4\,\Omega$

Resistance cannot be negative.

$\therefore$ No option is correct.

50. Here, $i_g =$ full scale deflection current

$$= 1\text{mA} = 1 \times 10^{-3}\text{ A}$$



$V_{AB} =$ full scale deflection potential $= 10$ V

$G =$ Galvanometer resistance $= 100\,\Omega$

If $R =$ resistance used in series for converting galvanometer into voltmeter, then from above circuit diagram,

$$i_g\,(G + R) = V$$
$$\Rightarrow \quad 10^{-3}(100 + R) = 10$$
$$\Rightarrow \quad R = 10000 - 100 = 9900\,\Omega = 9.9\text{k}\Omega$$

51. As, $i_g = \dfrac{2}{2000} = \dfrac{1}{1000}$ A;

Now for range, $V = 8\text{V} + 2\text{V} = 10\text{V}$

$$\therefore \quad R = \frac{V}{i_g} - G = \frac{10}{\left(\frac{1}{1000}\right)} - 2000 = 8000\,\Omega$$

52. Given, divisions in scale of galvanometer,

$$n = 50$$

Sensitivity of galvanometer,

$$\frac{i_g}{n} = 20\,\mu\text{A}/\text{division}$$

$\therefore$ Current in galvanometer,

$$I_g = \frac{I_g}{n} \times n = 20\mu\text{A} \times 50$$

$$\Rightarrow \quad I_g = 1000\,\mu\text{A} = 1\text{ mA}$$

Now, for R, it should be converted into 2V voltmeter.

$$\therefore \quad V_1 = i_g\,(R_1 + G)$$

$$2 = 10^{-3}\,(R_1 + 100)$$

$$\Rightarrow \quad 2000 = R_1 + 100$$

$$\therefore \quad R_1 = 1900\,\Omega \qquad \ldots\text{(i)}$$

For R_2, it should be converted into 10V voltmeter.

$$\therefore \quad V_2 = i_g\,[(R_1 + R_2) + G]$$

$$\Rightarrow \quad 10 = 10^{-3}\,[(R_1 + R_2) + 100]$$

$$\Rightarrow \quad 10000 = R_1 + R_2 + 100 = 2000 + R_2$$

$$\therefore \quad R_2 = 8000\,\Omega \qquad \ldots\text{(ii)}$$

For R_3, it should be converted into 20V voltmeter.

$$\therefore \quad V_3 = I_g[(R_1 + R_2 + R_3 + G]$$

$$\Rightarrow \quad 20 = 10^{-3}\,[1900 + 8000 + R_3 + 100]$$

$$\Rightarrow \quad 20000 = R_3 + 10000$$

$$\therefore \quad R_3 = 10000\,\Omega \qquad \ldots\text{(iii)}$$

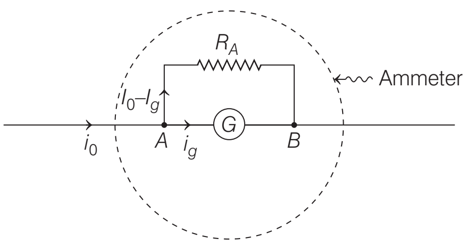
From Eqs. (i), (ii) and (iii), it is clear that option (c) is correct.

53. To convert a glavanometer into a voltmeter, a resistance $R = \frac{V}{i_g} - G$ is connected in series with it.

To convert galvanometer into an ammeter, a resistance, $S = i_g G/(i - i_g)$ is to be connected in parallel with galvanometer.

Therefore, the combination should have a range of 10 V with connection of resistance 200 kΩ in series.

54. To use galvanometer as an ammeter, a low resistance in parallel is used.



In ammeter, if $i_g =$ full scale deflection current, then equating potential drops across points marked AB, we have

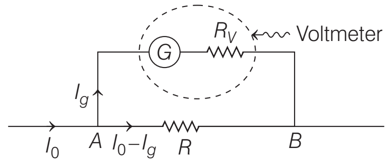
$$V_{AB} = i_g G$$

$$= (i_0 - i_g)R_A$$

$$\Rightarrow \quad R_A = \frac{i_g\,G}{i_0 - i_g} \qquad \ldots\text{(i)}$$

Here, G = resistance of galvanometer coil.

When a galvanometer is used as a voltmeter, a high resistance (R_V) in series is used.



Equating potential across point AB,

$$V_{AB} = (G + R_V)\,i_g$$

But $\quad V_{AB} = i_0 G \qquad$ (given)

So, $\quad i_0 G = (G + R_V)\,i_g$

$$\Rightarrow \quad R_V = \frac{(i_0 - i_g)G}{i_g} \qquad \ldots\text{(ii)}$$

From Eqs. (i) and (ii), we have

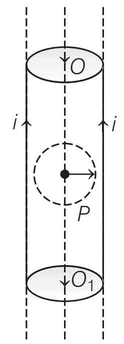
$$\frac{R_A}{R_V} = \frac{\left(\dfrac{i_g G}{i_0 - i_g}\right)}{\dfrac{(i_0 - i_g)G}{i_g}}$$

$$= \frac{i_g^2}{(i_0 - i_g)^2}$$

and $\quad R_A \times R_V = \dfrac{i_g G}{(i_0 - i_g)} \times \dfrac{(i_0 - i_g)\,G}{i_g} = G^2$

Round II

1. Figure shows infinitely long straight thin walled pipe carrying current I.

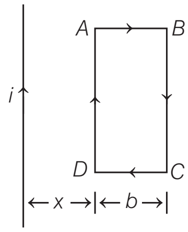


Let P be any point at a distance r from the axis OO_1 of the pipe. Let B be magnetic field at P. Consider a closed circular path passing through point P as shown in figure. From Ampere's circuital law $\oint B \cdot dl = \mu_0 i$

i = current through the closed path. Obviously, $i = 0$

$\therefore \qquad 2\pi RB = 0$ or $B = 0$

2. The magnetic force on AB and CD are equal and opposite due to symmetry and opposite currents in these sides. The magnetic force on AD,



$$F_1 = \frac{\mu_0 i}{2\pi x}, \text{ attractive}$$

Magnetic force on BC

$$F_2 = \frac{\mu_0 i}{2\pi (x + b)}, \text{ repulsive}$$

As $F_1 > F_2$, so magnetic force will be experienced towards wire.

3. Force on wire B due to A,

$$F_{BA} = \frac{\mu_0 \times 1 \times 2}{2\pi r} = \frac{\mu_0}{\pi r} \text{ towards } C$$

Force on wire B due to C,

$$F_{BC} = \frac{\mu_0 \times 2 \times 2}{2\pi r} = \frac{3\mu_0}{\pi r} \text{ towards } A$$

Clearly, $F_{BC} > F_{BA}$, therefore net force on B is directed towards A.

4. Magnetic field at the centre, $B = \dfrac{\mu_0 i\theta}{4\pi a} = \dfrac{\mu_0 i}{4\pi a} \cdot \dfrac{3\pi}{2} = \dfrac{3\mu_0 i}{8a}$

5. Torque on the loop, $\tau = NiAB \propto A$

For a given periphery, circle has maximum area.

6. Here, $2r = 0.1 \text{ nm} = 0.1 \times 10^{-9} \text{m} = 10^{-10} \text{m}$;

$i = \dfrac{e}{T} = \dfrac{e\omega}{2\pi}$ where, ω = angular speed.

Now, $\qquad B = \dfrac{\mu_0}{4\pi} \dfrac{2\pi ni}{r} = \dfrac{\mu_0}{4\pi} \dfrac{ne\omega}{r}$

or $\qquad \omega = B \cdot \dfrac{4\pi}{\mu_0} \cdot \dfrac{r}{ne}$

$$= 14 \times \frac{1}{10^{-7}} \times \frac{(10^{-10})/2}{1.6 \times 10^{-19}}$$

$$= 4.4 \times 10^{16} \text{ rad/s}$$

7. Maximum value of force, $F_{\max} = evB$

$$= (1.6 \times 10^{-19}) \times (0.9 \times 3 \times 10^8) \times (10^8)$$

$$= 4.32 \times 10^{-3} \text{ N}$$

8. As, $eE = evB \Rightarrow v = \dfrac{E}{B}$

Here, $\qquad E = 1 \text{ Vcm}^{-1} = 100 \text{ Vm}^{-1}, B = 2\text{T}$

$\therefore \qquad v = \dfrac{100}{2} = 50 \text{ ms}^{-1}$

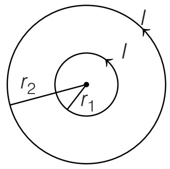
9. As, $E = \dfrac{B^2 q^2 r^2}{2m}$ or $r = \dfrac{\sqrt{2mE}}{Bq}$

So, $\qquad r \propto \sqrt{E}/B$

$\therefore \qquad \dfrac{r_2}{r_1} = \sqrt{\dfrac{2E}{E} \cdot \dfrac{B}{3B}} = \sqrt{\dfrac{2}{9}}$

$\therefore \qquad r_2 = \sqrt{\dfrac{2}{9}} = \sqrt{\dfrac{2}{9}} R$

10. Consider the two coaxial solenoids. Due to one of the solenoids, magnetic field at the centre of the other can be assumed to be constant.



Due to symmetry, forces on upper and lower part of a solenoid will be equal and opposite and hence resultant is zero.

Therefore, $\mathbf{F}_1 = \mathbf{F}_2 = 0$.

11. Consider a simple amperian loop passing once through both the identical current carrying coaxial loops.

(i) According to Ampere circuital law, $\oint_C \mathbf{B} \cdot d\mathbf{l} = \mu_0 (i - i) = 0$.

(ii) As $\oint_C \mathbf{B} \cdot d\mathbf{l} = 0$, therefore $\oint_C \mathbf{B} \cdot d\mathbf{l}$ is independent of sense of C.

(iii) The value of $\mathbf{B}$ does not vanish on various points of C.

12. Since, the magnetic field does not perform any work, therefore whatever has been gain in kinetic energy, it is only because of the work done by electric field. Applying work-energy theorem,

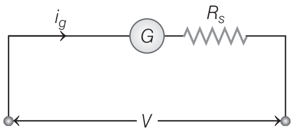
$$W = \Delta E$$

$$qE_0 = \frac{1}{2} mv^2 - 0$$

or $\qquad v = \sqrt{\dfrac{2qE_0}{m}}$

13. In magnetic field, the force on charged particle $F = q(v \times B)$. When particle accelerates from rest, its acceleration is perpendicular to the direction of magnetic field. When charged particle is deflected by the magnetic field, its speed does not change but direction of velocity changes because the deflecting force acts perpendicular to v and B. Only the component of magnetic field perpendicular to the direction of motion is effective in deflecting the particle. Also, while deflecting in the magnetic field, its energy gradually decreases.

14. Suppose a resistance R_s is connected in series with galvanometer to convert it into voltmeter.



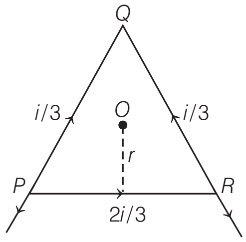
$$i_g\,(G + R_s) = V$$

$$\Rightarrow \qquad R = \frac{V}{i_g} - G$$

$$\Rightarrow \qquad R = 1985 = 1.985\ \text{k}\Omega$$

or $\qquad R = 1.985 \times 10^3\ \Omega$

15. Magnetic field at O due to PR,



$$B_1 = \frac{\mu_0}{4\pi}\frac{2i/3}{r}[\sin 30° + \sin 30°]$$

$$= \frac{\mu_0}{4\pi}\frac{2i}{3r}$$

It is directed outside the paper. Magnetic field at O, due to PQR (*i.e.*, for the wire PQ and QR)

$$B_2 = 2 \times \frac{\mu_0}{4\pi}\frac{\left(\frac{i}{3}\right)}{\mu}[\sin 30° + \sin 30°]$$

$$= \frac{\mu_0}{4\pi}\frac{2i}{3r}$$

It is directed inside the paper.

$\therefore$ Resultant magnetic field at O

$$B = B_1 - B_2 = 0$$

16. (a) Motion of charges inside the conductor is affected by magnetic field **B**, due to magnetic force **F** given by

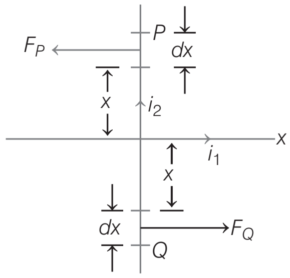
$$\mathbf{F} = q\,(\mathbf{v} \times \mathbf{B})$$

(b) Due to magnetic force, some charges inside the wire move to the surface of wire.

(c) The force on wire of length l, carrying current I when subjected to magnetic field **B** is, $\mathbf{F} = I\,(\mathbf{l} \times \mathbf{B})$. It acts perpendicular to the plane containing **l** and **B** and is directed as given by Right Hand rule. If the wire moves under the influence of **B** at an angle θ, where $\theta \neq 90°$, then work done, $W = Fs\cos\theta$, can not be zero.

(d) When wire moves under the influence of **B**, then displacement of the ions is perpendicular to the magnetic force **F**. Therefore **work done is zero.**

17. Magnetic field at point P due to i_1, $B_1 = \frac{\mu_0 i_1}{2\pi x}$ upward perpendicular to plane of paper. Therefore, magnetic force on element P



$$F_P = B_1 i_2 dx = \frac{\mu_0 i_1 i_2}{2\pi x}\,dx, \text{ along } X\text{-axis}$$

Magnetic field at point Q due to i_1,

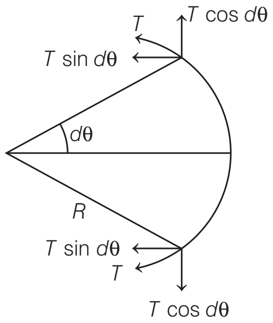
$B_2 = \frac{\mu_0 i_1}{2\pi x}$ downward perpendicular to plane to paper.

Magnetic force on element Q,

$$F_Q = B_2\, i_2\, dx = \frac{\mu_0 i_1 i_2}{2\pi x}\,dx, \text{ along } (+)\,X\text{-axis}$$

So, wire i_2 will turn counter-clockwise.

18. For small element of wire,

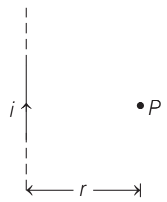


$$2T\sin d\theta = 2R\,d\theta\,iB$$

$$2Td\theta = 2RiBd\theta$$

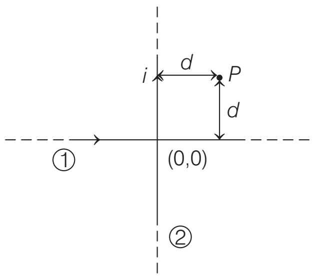
$$T = iRB$$

19. Magnetic field due to an infinitely long straight wire at point P is given as



$$|\mathbf{B}| = \frac{\mu_0\, i}{2\pi\, r}$$

Thus, in the given situation, magnetic field due to wire 1 at point P is



$$\mathbf{B}_1 = \frac{\mu_0}{2\pi}\frac{i}{d}, \otimes$$

Similarly, magnetic field due to wire 2 at point P is

$$\mathbf{B}_2 = \frac{\mu_0}{2\pi}\frac{i}{d}, \odot$$

Resultant field at point P is

$$\mathbf{B}_{\text{net}} = \mathbf{B}_1 + \mathbf{B}_2$$

Since, $|\mathbf{B}_1| = |\mathbf{B}_2|$, but they are opposite in direction.

Thus, $\mathbf{B}_{\text{net}} = 0$

$\therefore$ Net magnetic field at point P will be zero.

20. Applying Fleming's rule, we find that upward force F of magnitude IlB acts. For mid-air suspension, this must be balanced by the force due to gravity.

$$\therefore \quad mg = i\,lB$$

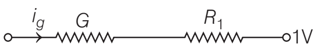
$$\Rightarrow \quad B = \frac{mg}{i\,l}$$

Given, $\quad m = 200\text{ g} = 0.2\text{ kg},\ g = 9.8\text{ m/s}^2$

$$I = 2A,\ l = 1.5\text{ m}$$

we have, $\quad B = \dfrac{0.2 \times 9.8}{2 \times 1.5} = 0.65\text{ T}$

21. According to question,

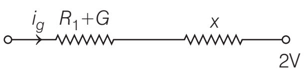


From Ohm's law, $V = IR$

$$\therefore \quad i_g(R_1 + G) = 1\text{V} \quad \ldots\text{(i)}$$

Let x be the required resistance.

Now, $\quad i_g(R_1 + G + x) = 2\text{V}$



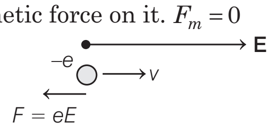
Using Eq. (i) in above equation, we get

$$\frac{1}{(R_1 + G)}(R_1 + G + x) = 2$$

$$R_1 + x + G = 2(R_1 + G)$$

$$x = R_1 + G$$

22. Since election is moving parallel to the magnetic field, hence magnetic force on it. $F_m = 0$



So, the only force which is acting on electron in the direction, is electric force which reduces its speed.

23. The current through loop is in anticlockwise direction. Hence, magnetic field at the points within the loop acts perpendicularly outward to the plane. The magnetic field lines form a closed path. A tangent to the field lines gives the directions of forces at same point. Thus, magnetic field at O is perpendicularly inward to the paper.

24. Acceleration produced by electric field,

$$\mathbf{a} = \frac{qE_0}{m}\hat{\mathbf{i}}$$

After time t, velocity of the particle,

$$\mathbf{v} = \mathbf{u} + \mathbf{a}t$$

$$\Rightarrow \quad \mathbf{v} = v_0\hat{\mathbf{j}} + \left(\frac{qE_0t}{m}\right)\hat{\mathbf{i}} \quad [\because u = \mathbf{v} = v_0\hat{\mathbf{j}}]$$

So, speed of the particle,

$$|\mathbf{v}| = \sqrt{v_0^2 + \left(\frac{qE_0t}{m}\right)^2}$$

Now, given $|\mathbf{v}| = 2v_0$ after time t, so

$$2v_0 = \sqrt{v_0^2 + \left(\frac{qE_0t}{m}\right)^2}$$

$$\Rightarrow \quad 4v_0^2 = v_0^2 + \left(\frac{qE_0t}{m}\right)^2$$

$$\Rightarrow \quad 3v_0^2 = \left(\frac{qE_0t}{m}\right)^2$$

So, time interval, $t = \dfrac{\sqrt{3}\,mv_0}{qE_0}$

Here, we must note that no change in magnitude of velocity is caused by a perpendicular magnetic field. So, we are not taking effect of magnetic field while calculating change in speed.

25. Force exerted on a current carrying conductor,

$$F_{\text{ext}} = B(x)\,iL$$

Average power $= \dfrac{\text{Work done}}{\text{Time taken}}$

$$P = \frac{1}{t}\int_0^2 F_{\text{ext}} \cdot dx$$

$$= \frac{1}{t}\int_0^2 B(x)\,iL\,dx$$

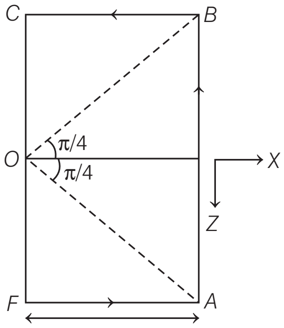
$$= \frac{1}{5 \times 10^{-3}}\int_0^2 3 \times 10^{-4} e^{-0.2x} \times 10 \times 3\,dx$$

$$= 9\,[1 - e^{-0.4}]$$

$$= 9\left[1 - \frac{1}{e^{0.4}}\right]$$

$$= 2.967 \approx 2.97\text{ W}$$

26. From the figure, due to *FABC*, the magnetic field at *O* is along *Y*-axis and due to *CDEF*, the magnetic field is along axis. Hence, the field will be of the form $A(\hat{\mathbf{i}}+\hat{\mathbf{j}})$.



Calculating the field due to *FABC*

Due to *AB*,

$$\mathbf{B}_{AB}=\frac{\mu_0 i}{4\pi\left(\frac{l}{2}\right)}(\sin 45^\circ+\sin 45^\circ)\hat{\mathbf{i}}=\sqrt{2}\,\frac{\mu_0 i}{2\pi l}$$

Due to *BC*, $\mathbf{B}_{AB}=\dfrac{\mu_0 i}{4\pi l\left(\frac{l}{2}\right)}(\sin 0^\circ+\sin 45^\circ)=\dfrac{\mu_0 i}{2\sqrt{2}\,\pi l}$

$$\mathbf{B}_{AB}=\frac{\mu_0 i}{2\sqrt{2}\,\pi l}\,\hat{\mathbf{i}}$$

Hence, the field due to *FABC*,

$$\mathbf{B}_{FABC}=\frac{\mu_0 i}{\pi l}\left[\frac{1}{2\sqrt{2}}+\frac{1}{2\sqrt{2}}+\frac{\sqrt{2}}{2}\right]\hat{\mathbf{i}}$$

$$\Rightarrow\qquad \mathbf{B}_{FABC}=\frac{\sqrt{2}\,\mu_0 i}{\pi l}\,\hat{\mathbf{i}}$$

Similarly, due to *CDEP*, we have

$$\mathbf{B}_{CDEF}=\frac{\sqrt{2}\,\mu_0 i}{\pi l}\,\hat{\mathbf{j}}$$

$$\therefore\qquad \mathbf{B}_{\text{net}}=\mathbf{B}_{FABC}+\mathbf{B}_{CDEF}=\frac{\sqrt{2}\,\mu_0 i}{\pi l}(\hat{\mathbf{i}}+\hat{\mathbf{j}})$$

27. Given, $\mu_0=4\pi\times10^{-7}\ \text{N/A}^2$,

$$\omega=40\pi\ \text{rad/s}$$

$$B_{\text{at centre}}=3.8\times10^{-9}\ \text{T}$$

and $\qquad R=10\ \text{cm}=0.1\ \text{m}$

Now, we know that, magnetic field at the centre of a current carrying ring is given by

$$B=\frac{\mu_0 i}{2R}\qquad \ldots\text{(i)}$$

Here, i can be determined by flow of charge per rotation, *i.e.*

$$i=\frac{Q}{T}\qquad \ldots\text{(ii)}$$

Here, $\qquad T=\dfrac{2\pi}{\omega}$

$$\Rightarrow\qquad i=\frac{Q\omega}{2\pi}\qquad \ldots\text{(iii)}$$

By putting value of i from Eq. (iii) to Eq. (i), we get

$$B=\frac{\mu_0 Q\omega}{2R\times2\pi}\ \text{ or }\ Q=\frac{2BR\times2\pi}{\mu_0\omega}$$

$$=\frac{2\times3.8\times10^{-9}\times0.1\times2\pi}{4\pi\times10^{-7}\times40\pi}$$

$$=\frac{2\times3.8\times0.1}{2\times40\pi}\times10^{-2}$$

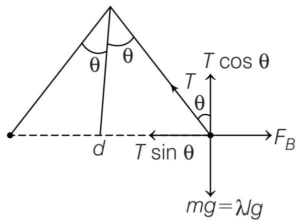
$$=0.003022\times10^{-2}\ \text{C}$$

$$=3.022\times10^{-5}\ \text{C}$$

or $\qquad Q=3\times10^{-5}\ \text{C}$

28. Consider free body diagram of the wire.

As the wires are in equilibrium, they must carry current in opposite direction.



Here, $F_B=\dfrac{\mu_0 i^2 l}{2\pi d}$, where l is length of each wire and d is separation between wires.

From figure, $d=2L\sin\theta$

$$T=\cos\theta=mg=\lambda lg\qquad\text{(in vertical direction)}\ldots\text{(i)}$$

$$T\sin\theta=F_B=\frac{\mu_0 i^2 l}{4\pi L\sin\theta}\text{(in horizontal direction)}\ldots\text{(ii)}$$

From Eqs. (i) and (ii),

$$\frac{T\sin\theta}{T\cos\theta}=\frac{\mu_0 i^2 l}{4\pi L\sin\theta\times\lambda\, lg}$$

$$\therefore\qquad i=\sqrt{\frac{4\pi\lambda Lg\sin^2\theta}{\mu_0\cos\theta}}=2\sin\theta\sqrt{\frac{\pi\lambda Lg}{\mu_0\cos\theta}}$$

29. There is no magnetic field along axis of a current-carrying wire.

Also, magnetic field near one of end of an infinitely long wire is $\dfrac{\mu_0 i}{4\pi r}$ tesla.

Hence, magnetic field due to segments *LP* and *MQ* at '*O*' is zero. Using right hand rule, we can check that magnetic field due to segments *PS* and *QN* at *O* is in same direction perpendicularly into the plane of page.

Hence, $B_O=B_{PS}+B_{QN}=\dfrac{\mu_0 i}{4\pi r}+\dfrac{\mu_0 i}{4\pi r}=\dfrac{\mu_0 i}{2\pi r}$

So, $\qquad i=\dfrac{2\pi rB_0}{\mu_0}$

Here, $r=OP=OQ=4$ cm and $B_0=10^{-4}$ T.

Substituting values, we get

$$\Rightarrow\qquad i=\frac{2\pi\times4\times10^{-2}\times10^{-4}}{4\pi\times10^{-7}}$$

$$\Rightarrow\qquad i=20\ \text{A}$$

Also, magnetic field points perpendicular to the plane of page.

30. Average power developed which eventually gets lost as heat due to resistance of loop is given by

$$P_{avg} = \frac{V_{rms}^2}{R} = \frac{(V_{max}/\sqrt{2})^2}{R} = \frac{V_{max}^2}{2R}$$

Also, $V_{max} = NBA\,\omega$

In given loop, $N = 1, A = \pi ab$

So, $$P_{avg} = \frac{(BA\omega)^2}{2R} = \frac{B^2\pi^2a^2b^2\omega^2}{2R}$$

31. Torque $(\tau) = \mathbf{M} \times \mathbf{B}$

Here, $\mathbf{M} = (2a)^2 \times I = 4a^2I\hat{\mathbf{j}}$

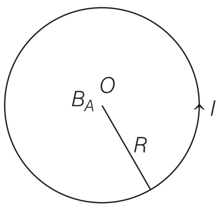
and $\mathbf{B} = \frac{\mu_0 I}{2\pi b}\hat{\mathbf{i}}$

$\therefore$ $$\tau = 4a^2I \times \frac{\mu_0 I}{2\pi b}(\hat{\mathbf{j}} \times \hat{\mathbf{i}})$$

$\Rightarrow$ $$|\tau| = \frac{2\mu_0 I^2 a^2}{\pi b}$$

32. Magnetic field in case of circle of radius R, we have

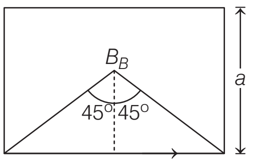
$$B_A = \frac{\mu_0 i}{2R}$$



As, $2\pi R = l$, (where l is length of a wire)

$$R = \frac{l}{2\pi}$$

$\Rightarrow$ $$B_A = \frac{\mu_0 i}{2 \times \frac{l}{2\pi}} = \frac{\mu_0 i\pi}{l} \quad \text{...(i)}$$



Magnetic field in case of square of side a, we get

$$B_B = 4 \times \frac{\mu_0}{4\pi} \times \frac{i}{\left(\frac{a}{2}\right)}\left(\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}\right)$$

$\Rightarrow$ $$B_B = \frac{4i\mu_0}{\pi a\sqrt{2}} = \frac{\mu_0 2\sqrt{2}i}{a\pi}$$

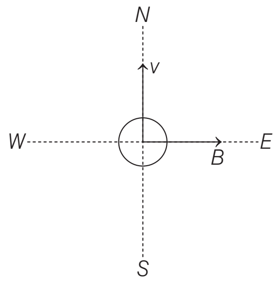
As, $4a = l$, $a = \frac{l}{4}$

$\Rightarrow$ $$B_B = \frac{8\sqrt{2}\,\mu_0 i}{\pi l} \quad \text{... (ii)}$$

Dividing Eq. (i) by Eq. (ii), we get

$$\frac{B_A}{B_B} = \frac{\pi^2}{8\sqrt{2}}$$

33. Given, proton is moving from south to north and magnetic field is directed from west to east.



As $\mathbf{v} \perp \mathbf{B}$, force on the charged particle,

$$F = Bqv$$

If m = mass and a = acceleration of the particle, then

$$F = ma$$

So, $$ma = Bqv$$

or $$B = \frac{ma}{qv} \quad \text{...(i)}$$

If K = kinetic energy of the particle,

then $$K = \frac{1}{2}mv^2$$

$\Rightarrow$ $$v = \sqrt{\frac{2K}{m}} \quad \text{...(ii)}$$

From Eqs. (i) and (ii), we get

$$B = \frac{ma}{q\sqrt{\frac{2K}{m}}} = \frac{m^{3/2} \cdot a}{q \times \sqrt{2K}} \quad \text{...(iii)}$$

Here, $m = 1.6 \times 10^{-27}$ kg,

$a = 10^{12}\ \text{ms}^{-2}$,

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

$K = 1$ MeV

$= 1 \times 10^6 \times 1.6 \times 10^{-19}$J

$= 1.6 \times 10^{-13}$ J

Substituting these given values in Eq. (iii), we get

$$B = \frac{(1.6 \times 10^{-27})^{3/2} \times 10^{12}}{1.6 \times 10^{-19} \times (2 \times 1.6 \times 10^{-13})^{1/2}}$$

$$= \frac{(1.6)^{3/2} \times 10^{-27 \times \frac{3}{2}} \times 10^{12}}{(1.6)^{3/2} \times 2^{1/2} \times 10^{-19} \times 10^{-13/2}}$$

$$= \frac{1}{\sqrt{2}} \times 10^{-3}$$

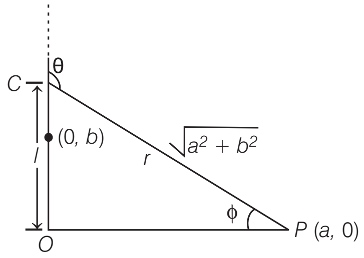
$= 0.71$ mT

34. As shown in the figure, consider an element dl at C of wire, where $OC = l$.

Let $PC = r$

and $\Delta OPC = \phi$.

According to Biot-Savart's law, magnitude of magnetic field induction at P due to current element at C is



$$dB = \frac{\mu_0}{4\pi}\frac{idl\sin\theta}{r^2}$$

Here, $\theta = 90° + \phi;\ r = a\sec\phi$

and $l = a\tan\phi$

$\therefore$ $dl = a\sec^2\phi\,d\phi$ (after differentiating)

$$\therefore \quad dB = \frac{\mu_0}{4\pi}\frac{i\,a(\sec^2\phi\,d\phi)\sin(90°+\phi)}{a^2\sec^2\phi}$$

$$= \frac{\mu_0}{4\pi}\frac{i}{a}\cos\phi\,d\phi$$

The magnetic field induction at P is

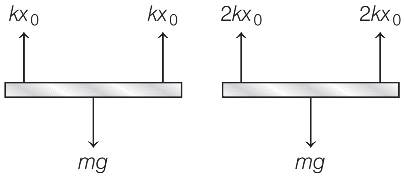
$$B = \int dB = \int_{90°}^{\phi}\frac{\mu_0}{4\pi}\frac{i}{a}\cos\phi\,d\phi = \frac{\mu_0}{4\pi}\frac{i}{a}[-\sin\phi]_{90°}^{\phi}$$

$$= \frac{\mu_0}{4\pi}\frac{i}{a}(1-\sin\phi) = \frac{\mu_0 i}{4\pi a}\left(1 - \frac{b}{\sqrt{a^2+b^2}}\right)$$

35. In the absence of magnetic field,

$$mg = 2kx_0 \qquad \text{...(i)}$$

$\therefore$ Magnetic force on the rod is $F_m = BiL = \dfrac{BLE}{R}$



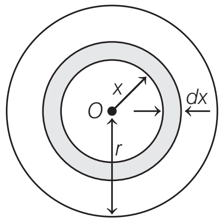
In downward direction,

$$\therefore \quad 2kx_0 = mg + \frac{BLE}{R} \qquad \text{...(ii)}$$

From Eqs. (i) and (ii); we get, $4kx_0 = 2kx_0 + \dfrac{BLE}{R}$

$$B = \frac{2kx_0R}{EL} = \frac{mgR}{LE}$$

36. Consider a hypothetical ring of radius x and thickness dx of a disc as shown in figure.



Charge on the ring, $dq = \dfrac{q}{\pi r^2}x\,(2\pi x\,dx)$

Current due to rotation of charge on ring,

$$di = \frac{dq}{T} = \frac{dq}{1/n} = ndq = \frac{nq2x\,dx}{r^2}$$

Magnetic field at the centre O due to current of ring element is

$$dB = \frac{\mu_0 di}{2x} = \frac{\mu_0 nq2x\,dx}{r^2(2x)} = \frac{\mu_0 n\,dx}{r^2} \qquad \text{... (i)}$$

Integrating Eq. (i), we get

$$\int_0^B dB = \int_0^r \frac{\mu_0 n dx}{r^2}$$

$$\Rightarrow \quad B = \frac{\mu_0 n}{r^2}\int_0^r dx \Rightarrow B = \frac{\mu_0 nr}{r^2}$$

Therefore, total magnetic field induction due to current of whole disc is

$$B = \frac{\mu_0 nq}{r^2}r = \frac{\mu_0 nq}{r}.$$

37. Increase in kinetic energy of particle

$$= \frac{1}{2}m(2v)^2 - \frac{1}{2}mv^2 = \frac{3}{2}mv^2$$

Work done by the uniform electric field, E in going from P to $Q = (qE)\times 2a = 2qEa$

Hence, $2qEa = \dfrac{3}{2}mv^2$ (by work-energy theorem)

or $$E = \frac{3mv^2}{4qa}$$

Rate of work done (*i.e.* power by the electric field),

$$P = F\cdot v = qE\cdot v = qE\hat{\mathbf{i}}\cdot v\hat{\mathbf{i}} = qEv$$

$$= q\cdot\frac{3mv^2}{4qa}\cdot v = \frac{3}{4}\frac{mv^2}{a}$$

$\therefore$ Power at $Q = qE\,\hat{\mathbf{i}}\cdot(-2v\hat{\mathbf{j}}) = 0$

At Q, rate of work done by both the fields is zero.

38. Acceleration of electron due to electric field is $\mathbf{a}_E = -e\mathbf{E}/m$.

Its direction is opposite to the direction of $\mathbf{E}$.

Acceleration of positron due to electric field is $\mathbf{a}'_E = e\mathbf{E}/m$. Its direction is along the direction of $\mathbf{E}$.

Thus $\mathbf{a}'_E \neq \mathbf{a}_E$.

Magnetic force on electron, $\mathbf{F} = -e\,(\mathbf{v}\times\mathbf{B})$

Acceleration of electron, $\mathbf{a}_m = \dfrac{\mathbf{F}}{m} = -\dfrac{e\,(\mathbf{v}\times\mathbf{B})}{m}$

Magnetic force on positron, $\mathbf{F}' = e\,(-\mathbf{v}\times\mathbf{B}) = -e\,(\mathbf{v}\times\mathbf{B})$

Acceleration of positron, $\mathbf{a}'_m = \dfrac{\mathbf{F}'}{m} = -\dfrac{-e\,(\mathbf{v}\times\mathbf{B})}{m}$

$$\therefore \quad \mathbf{a}_m = \mathbf{a}'_m.$$

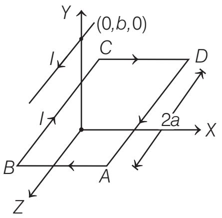
As both the particles (electron and positron) are of same mass and same charge in magnitude having same acceleration due to magnetic field, hence they gain or loose the energy at the same rate.

Due to electric field, net electric force on electron-positron pair, $= -e\mathbf{E} + e\mathbf{E} = 0$.

Net magnetic force on electron-positron pair $= -e(\mathbf{v}\times\mathbf{B}) + [-e(\mathbf{v}\times\mathbf{B})] = -2e(\mathbf{v}\times\mathbf{B})$

Therefore, the motion of the centre of mass (CM) is determined by magnetic field alone.

39. According to question, the situation can be drawn as



Force of a current carrying conducting wire,

$$F = Bil\sin\theta$$

So, force acting on wire AB and CD are zero

($\because \theta = 0°$ and $\sin 0° = 0$).

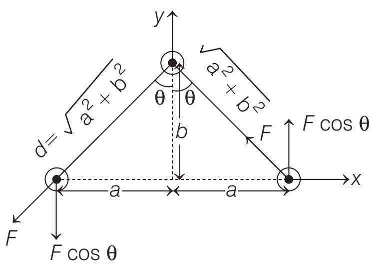
Only sides BC and AD will experience force due to current carrying wire.

Force on side AD = Force on side $BC = F$ (say)

Net force on loop, $F = Bil_{\text{loop}}\sin 90°$

$$= \left(\frac{\mu_0 i}{2\pi d}\right) i(2a)$$

$$F = \frac{\mu_0 i^2 a}{\pi\sqrt{a^2+b^2}} \qquad (\because d = \sqrt{a^2+b^2})$$



Force on AD and BC acts in two different directions as shown in above figure, so torque is produced in square loop.

$\therefore$ Torque on loop $= F\cos\theta \times 2a$

$$= \frac{\mu_0 i^2 a}{\pi\sqrt{a^2+b^2}} \times \frac{b}{\sqrt{a^2+b^2}} \times 2a$$

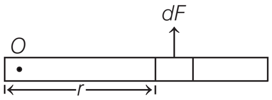
$$= \frac{2\mu_0 i^2 a^2 b}{\pi(a^2+b^2)}$$

If $b >> a$, then $a^2 + b^2 \simeq b^2$.

$$\therefore \qquad \tau = \frac{2\mu_0 i^2 a^2}{\pi b}$$

40. The force acting on the elementary portion of the current carrying conductor is given as,

$dF = i\,(dr)\,B\sin 90° \Rightarrow dF = iB\,dr$



The torque applied by dr about O, $d\tau = rdF$.

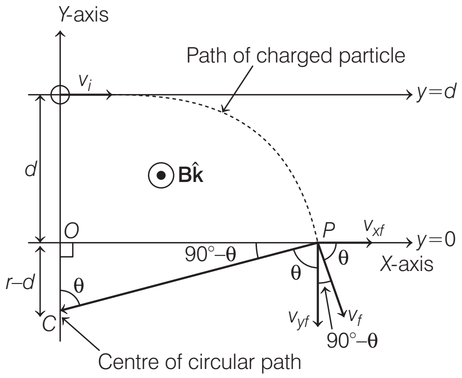
$\Rightarrow$ The total torque about $O = \tau = \int dF = \int r\,(iBdr)$

$$\Rightarrow \qquad \tau = iB\int_0^l r\,dr = \frac{iBl^2}{2}$$

The angular acceleration, $\alpha = \frac{\tau}{I}$ (where, MI = moment of inertia)

$$\Rightarrow \qquad \alpha = \left(\frac{ibl^2}{2}\right) / \left(\frac{ml^2}{3}\right) \Rightarrow \alpha = \frac{3iB}{2m}$$

41. Situation given in question is shown below



Path taken by particle of charge q and mass m is a circle of radius r, where

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

Here, final velocity

$$\mathbf{v}_f = \mathbf{v}_{xf}\hat{\mathbf{i}} + \mathbf{v}_{yf}(-\hat{\mathbf{j}}) = v\cos 60°\,\hat{\mathbf{i}} - v\sin 60°\,\hat{\mathbf{j}}$$

$$= v\left(\frac{1}{2}\hat{\mathbf{i}} - \frac{\sqrt{3}}{2}\hat{\mathbf{j}}\right)$$

So, change of velocity of charged particle is

$$\Delta\mathbf{v} = \mathbf{v}_f - \mathbf{v}_i = v\left(\frac{1}{2}\hat{\mathbf{i}} - \frac{\sqrt{3}}{2}\hat{\mathbf{j}}\right) - v\hat{\mathbf{i}}$$

$$= -v\left(\frac{1}{2}\hat{\mathbf{i}} + \frac{\sqrt{3}}{2}\hat{\mathbf{j}}\right)$$

If t = time taken by charged particle to cross region of magnetic field, then

$$t = \frac{\text{distance } OP}{\text{speed in direction } OP}$$

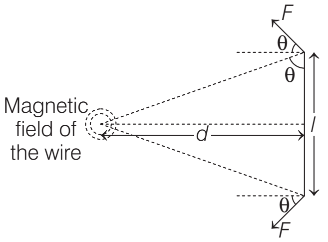
$$= \frac{r \times \frac{\sqrt{3}}{2}}{v} = \frac{\frac{mv}{Bq} \times \frac{\sqrt{3}}{2}}{v} = \frac{\sqrt{3}m}{2Bq}$$

So, acceleration of charged particle at the point its emergence,

$$\mathbf{a} = \frac{\Delta \mathbf{v}}{\Delta t} = \frac{-v\left(\frac{1}{2}\hat{\mathbf{i}} + \frac{\sqrt{3}}{2}\hat{\mathbf{j}}\right)}{\frac{\sqrt{3}}{2}\frac{m}{Bq}} = \frac{-Bqv}{m}\left(\frac{\hat{\mathbf{i}}}{\sqrt{3}} + \hat{\mathbf{j}}\right) \text{ms}^{-2}$$

None of the option given matches with answer.

42. Suppose the effective length of this dipole be l. Thus, the top view of the condition can be shown in the figure given below.



Now, the net force on the loop (*i.e.* at the two poles) due to the wire is given as,

$$F_{\text{net}} = 2F\cos\theta = 2mB\cos\theta$$

where, m is the pole strength.

From the figure, we have

$$\cos\theta = \frac{\frac{l}{2}}{x} = \frac{\frac{l}{2}}{\sqrt{d^2 + \frac{l^2}{4}}} \Rightarrow F_{\text{net}} = \frac{2mB\,l}{2\sqrt{d^2 + \frac{l^2}{4}}} \quad \text{...(i)}$$

Since, the magnetic moment of a loop of radius a is

$$m = iA = i\pi a^2 \quad \text{...(ii)}$$

and magnetic field due to a straight infinitely long current carrying conductor at a distance x is

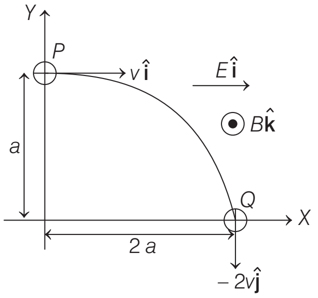
$$B = \frac{\mu_0 i'}{2\pi b} \quad \text{...(iii)}$$

$\therefore$ Using Eqs. (ii) and (iii), rewriting Eq. (i), we get

$$F_{\text{net}} = \frac{i\pi a^2 \mu_0 i'}{2\pi\left(\sqrt{d^2 + \frac{l^2}{4}}\right)^2}$$

$$\Rightarrow \quad F_{\text{net}} \propto \frac{a^2}{\left(d^2 + \frac{l^2}{4}\right)} \text{ or } F_{\text{net}} \propto \left(\frac{a}{d}\right)^2$$

43. Charged particle follows trajectory as shown in the figure.



As magnetic field is perpendicular to the velocity of charged particle, work done by magnetic field is zero.

So, work done by electric field = change in kinetic energy of charged particle

$$\Rightarrow \quad qE2a = \frac{1}{2}m(2v)^2 - \frac{1}{2}m(v)^2$$

$$\Rightarrow \quad E = \frac{3}{4}\frac{mv^2}{qa} \quad \text{(statement I is correct)}$$

Rate of work done = Power = $\mathbf{F}\cdot\mathbf{v} = qE\hat{\mathbf{i}}\cdot v\hat{\mathbf{i}}$

$$= qEv = q\cdot\frac{3}{4}\frac{mv^2}{qa}\cdot v$$

$$= \frac{3}{4}\frac{mv^3}{a} \quad \text{(statement II is correct)}$$

At point Q, both electric field and magnetic field are perpendicular to velocity of charged particle, so work done by both $\mathbf{E}$ and $\mathbf{B}$ at Q is zero.

(statement III is correct)

Angular momentum about origin at $P = mva\hat{\mathbf{i}}$.

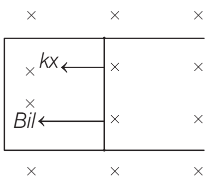
Angular momentum about origin at $Q = -4mva\hat{\mathbf{j}}$.

Difference between magnitudes of angular momentum at P and Q,

$$\Delta L = L_Q - L_P$$
$$= 4mva - mva$$
$$= 3mva \quad \text{(statement IV is incorrect)}$$

Thus, option (b) is correct.

44. There are two forces on slider.



Spring force = kx

where, k = spring constant.

As the slider is kept in a uniform magnetic field $B = 0.1$ T, hence it will experience a force, *i.e.*

Magnetic force = Bil

where, l = length of the strip.

Now, using

$$F_{\text{net}} = ma$$

We have,

$$(-kx) + (-Bil) = ma$$

$$\Rightarrow \quad -kx - Bil - ma = 0$$

$$\Rightarrow \quad -kx - \frac{B^2 l^2}{R}\cdot v - ma = 0 \quad \left(\because i = \frac{Blv}{R}\right)$$

and acceleration, $a = \frac{d^2x}{dt^2}$

Hence, the modified equation becomes

$$\Rightarrow \quad \frac{md^2x}{dt^2} + \frac{B^2l^2}{R}\left(\frac{dx}{dt}\right) + kx = 0$$

This is the equation of damped simple harmonic motion.

So, amplitude of oscillation varies with time as

$$A = A_0 e^{-\frac{B^2 l^2}{2Rm} \cdot t}$$

Now, when amplitude is $\frac{A_0}{e}$, then

$$\frac{A_0}{e} = \frac{A_0}{e^{\frac{B^2 l^2}{2Rm} \cdot t}} \quad \text{(as given)}$$

$$\Rightarrow \quad \left(\frac{B^2 l^2}{2Rm}\right) t = 1 \text{ or } t = \frac{2Rm}{B^2 l^2}$$

According to the question, magnetic field $B = 0.1$ T, mass of strip $m = 50 \times 10^{-3}$ kg, resistance $R = 10\ \Omega$, $l = 10$ cm $= 10 \times 10^{-2}$ m

$$\therefore \quad t = \frac{2Rm}{B^2 l^2} = \frac{2 \times 10 \times 50 \times 10^{-3}}{(0.1)^2 \times (10 \times 10^{-2})^2}$$

$$= \frac{1}{10^{-4}} = 10000 \text{ s}$$

Given, spring constant, $k = 0.5\ \text{Nm}^{-1}$

Also, time period of oscillation is

$$T = 2\pi\sqrt{\frac{m}{k}}$$

$$= 2\pi\sqrt{\frac{50 \times 10^{-3}}{0.5}} = \frac{2\pi}{\sqrt{10}} \approx 2 \text{ s}$$

So, number of oscillations,

$$N = \frac{t}{T} = \frac{10000}{2} = 5000$$

45. Since, the currents are flowing in the opposite directions, the magnetic field at a point equidistant from the two wires will be zero. Hence, the force acting on the charge at this instant will be zero.

46. Torque, $\tau = BINA \sin\theta$

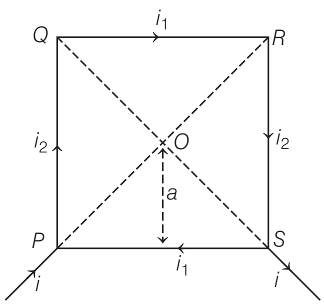
Here, $\theta = 90°$

$\Rightarrow \sin\theta = 1$, $\tau = 1.5$ N-m

$A = 3 \times 10^{-4} \text{m}^2$, $N = 500$ and $i = 0.5$ A

So, $\quad B = \frac{\tau}{iNA} = \frac{1.5}{0.5 \times 500 \times 3 \times 10^{-4}} = 20$ T

47. The resistance of arm $PQRS$ is 3 times the resistance of arm PS. If resistance of arm $PS = r$, then resistance of arm $PQRS = 3r$.



Potential difference across P and $S = i_1 r = i_2 \times 3r$

Magnetic field induction at O due to current through arm PS is $B_1 = \frac{\mu_0}{4\pi}\frac{i_1}{a}[\sin 45° + \sin 45°]$ acting perpendicular to the loop upwards.

Magnetic field due to PQ and RS are equal and opposite.

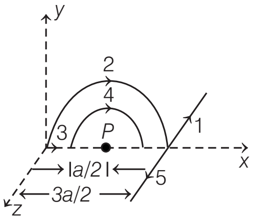
Therefore magnetic field due to QR,

$$B_2 = \frac{\mu_0}{4\pi} \cdot \frac{I_1}{a}[\sin 45° + \sin 45°]$$

perpendicular to the loop in downward direction.

$\therefore$ Resultant magnetic field at centre, $\mathbf{B} = \mathbf{B}_1 + \mathbf{B}_2 = 0$

48. $\mathbf{B}_P = (\mathbf{B}_1)_P + (\mathbf{B}_2)_P + (\mathbf{B}_3)_P + (\mathbf{B}_4)_P + (\mathbf{B}_5)_P$



where, $(\mathbf{B}_1)_P = \frac{\mu_0 i}{4\pi\left(\frac{3a}{2}\right)}(\hat{\mathbf{j}})$ (semi-finite wire)

$$(\mathbf{B}_2)_P = \frac{\mu_0 i}{4(3a/2)}(-\hat{\mathbf{k}}), (\mathbf{B}_3)_P = 0$$

$$(\mathbf{B}_4)_P = \frac{\mu_0 i}{4(3a/2)}(-\hat{\mathbf{k}})$$

$$\Rightarrow \quad (\mathbf{B}_5)_P = \frac{\mu_0 i}{4\pi\left(\frac{a}{2}\right)}(-\hat{\mathbf{j}})$$

$$\Rightarrow \quad B_{\text{net}} = \sqrt{(B_4 - B_2)^2 + (B_5 - B_1)^2}$$

$$= \sqrt{\left(\frac{2\mu_0 i}{6a}\right)^2 + \left(\frac{\mu_0 i}{2\pi a} + \frac{\mu_0 i}{6\pi a}\right)^2} = \frac{\mu_0 i}{3\pi a}\sqrt{\pi^2 + 4}$$

$$\Rightarrow \quad P = 3$$

49. The net electric field,

$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2$$

$$\Rightarrow \quad E = \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{\varepsilon_0}$$

The net force acting on the electron is zero because it moves with cosntant velocity

$$\mathbf{F}_{\text{net}} = \mathbf{F}_e + \mathbf{F}_m = 0$$

$$\Rightarrow \quad |\mathbf{F}_e| = |\mathbf{F}_m|$$

$$\text{or} \quad eE = evB$$

$$\text{or} \quad v = \frac{E}{B} = \frac{\sigma}{\varepsilon_0 B}$$

$\therefore$ The time of motion inside the capacitor, $t = \frac{l}{v} = \frac{\varepsilon_0 lB}{\sigma}$.

$$\Rightarrow \quad x = 1$$