PART – III : MAGNETIC EFFECTS OF CURRENT AND MAGNETISM

CHAPTER 4 MOVING CHARGES AND MAGNETISM

Syllabus

➢ *Concept of magnetic field, Oersted's experiment. Biot - Savart law and its application to current carrying circular loop. Ampere's law and its applications to infinitely long straight wire. Straight and toroidal solenoids (only qualitative treatment), force on a moving charge in uniform magnetic and electric fields. Force on a current-carrying conductor in a uniform magnetic field, force between two parallel current-carrying conductors-definition of ampere, torque experienced by a current loop in uniform magnetic field; moving coil galvanometer-its current sensitivity and conversion to ammeter and voltmeter.*

Revision Notes

Magnetic Field & Cyclotron

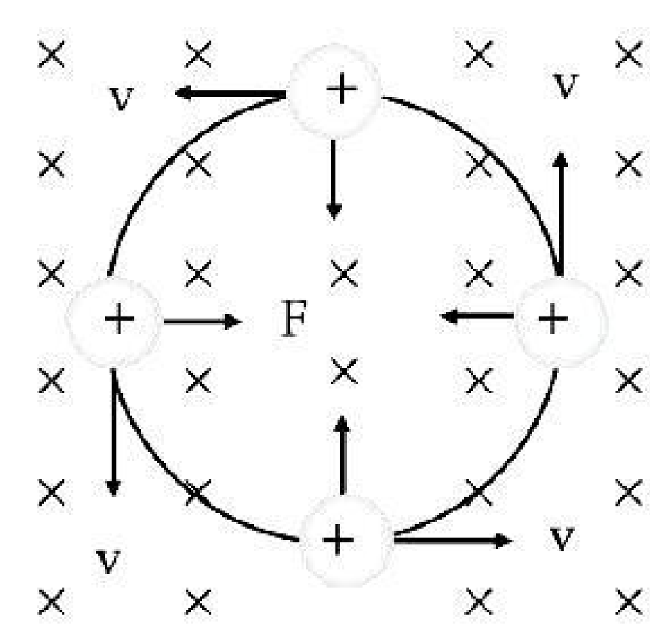
Concept of Magnetic field

➢ Magnetic field is a region around a magnet where force of magnetism acts which affects other magnets and magnetic materials.

➢ Magnetic field also known as B-field can be pictorially represented by magnetic field lines.

➢ Magnetic fields are produced by electric currents, which can be macroscopic currents in wires, or microscopic currents associated with electrons in atomic orbits.

➢ **Lorentz Force:** When a charge q moving with velocity v enters a region where both magnetic fields and electric fields exist, both fields exert a force on it.



Lorentz Force, $$\vec{F} = q[\vec{E} + \vec{v} \times \vec{B}]$$

where, $\vec{F}$ = magnetic force, $\vec{q}$ = charge, $\vec{v}$ = velocity, $\vec{B}$ = magnetic field, $\vec{E}$ = electric field, $q\,\vec{E}$ = electric force on the charge, $q(\vec{v} \times \vec{B})$ = magnetic force on the charge

➢ SI unit of magnetic field is Tesla, while smaller magnetic fields are measured in terms of Gauss.

$$1 \text{ Tesla} = 10^4 \text{ G}$$

➢ When a test charge q_0 enters a magnetic field $\vec{B}$ directed along negative z-axis with a velocity $\vec{v}$ making an angle θ with the z-axis, then,

$$\vec{F_m} = q_0(\vec{v} \times \vec{B}) = q_0 vB\sin\theta\,\hat{n}$$

Moving Charges & Magnetism

Magnetic Field ($\vec{B}$)

- It is a region around a magnet or current carrying conductor or a moving charge in which its magnetic effect can be felt
- SI unit is Tesla(T) = weber/m^2
- 1 Gauss = 10^{-4} Tesla where gauss is the CGS unit

Cyclotron

To accelerate a charged particle (except electron)

Max. energy gained $= \left(\frac{q^2B^2}{2m}\right)p^2$

Oersted's Law

In April 1820, Hans Christian Oersted discovered that flow of current in a wire can deflect a nearby magnetic compass needle.

Ampere's Law

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

where i = Total current crossing the area bounded by closed curve.

Solenoid

- Magnetic field at a point inside due to a long solenoid, $B = \mu_0 ni$
- At a point on one end $B = \frac{\mu_0 ni}{2}$

where n = number of turns per unit length along the length of solenoid.

Magnetic field due to Toroid

$B = \frac{\mu_0 Ni}{2\pi r}$, N = Total Number of turns, i = Current in toroid

Force on a current carrying conductor

$d\vec{F} = i(d\vec{l} \times \vec{B})$ $F = ilB$

Force between parallel current carrying wires

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

Torque experienced by a loop in uniform magnetic field

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

$\tau = NBiA$

Definition of Ampere

If two parallel wire kept 1 m apart, if and $F = 2\times10^{-7}$ N, then current = 1A in each wire.

Galvanometer

- **Sensitivity**: Voltage sensitivity $= NBA/CG$ current sensitivity $= NBA/C$
- **Ammeter**: $S = \frac{Ig}{I - Ig}G$
- **Voltmeter**: $R = \frac{V}{Ig} - G$

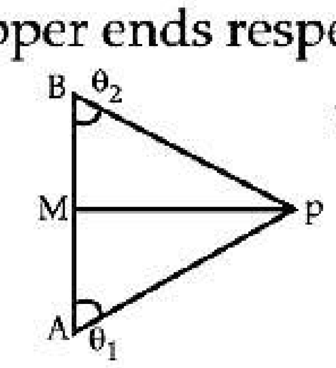
Field due to a current carrying circular ring

- **Field at the centre**: $B = \frac{\mu_0 i}{2a}$ ⊗ ⊙
- **Field at an axial point**: $B = \frac{\mu_0 i a^2}{2(a^2 + d^2)^{3/2}}$
- **Field at a point far away from the centre**: i.e. for $d >> a$, $B = \frac{\mu_0 i a^2}{2d^3}$

Magnetic field due to straight current carrying wire

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

where θ_1 and θ_2 are the angles corresponding to the lower and upper ends respectively



i.e $\theta_1 = 0$

$\theta_2 = \pi$

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

biot-Savart Law

⊙ ⊗

$d\vec{B} = \frac{\mu_0}{4\pi}\frac{id\vec{l} \times \vec{r}}{r^3}$ [θ = angle between $d\vec{l}$ and $\vec{r}$]

$dB = \frac{\mu_0}{4\pi}\frac{idl\sin\theta}{r^2}$ [Direction of field will be perpendicular to the plane containing current element and the point of observation]

where $\mu_0 = \frac{1}{\varepsilon_0 c^2}$

Magnetic Force on a moving charge

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

$= qvB\sin\theta$

- For $\theta = 0$, $\vec{F} = 0$ along the magnetic field
- For $\theta = 90°$, *i.e.* if charge's velocity is perpendicular to field direction, force is perpendicular to both field and velocity

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

$r = \frac{mv}{qB}$ = Radius of the circle in which charge rotates

Time period $(T) = \frac{2\pi m}{qB}$

ν(frequency) $= \frac{1}{T} = \frac{qB}{2\pi m}$

If $\theta \neq 0, 180°, 90°$

Then, $F = qvB\sin\theta$

And the charge particle will follow helical path whose

$r = \frac{mv_\perp}{qB}$ and pitch $= V_\parallel \times T = V_\parallel \times \frac{2\pi m}{qB}$

Trace the Mind Map: ‣ First Level ‣ Second Level ‣ Third Level

Characteristics of motion of particle in magnetic field

- Velocity and kinetic energy of particle do not change, as force is always perpendicular to velocity.
- Direction of velocity will continuously change, if $\theta - 0$.
  when $\theta = 0$, no force will act on the particle, hence there will be no change in velocity.
- When $\theta = 90°$, test charge describes a circle of radius $\frac{mv}{q_0 B}$,
  where, m is mass of the particle; larger the momentum, bigger the circle described.
- In case of θ being any other angle than 0° and 90°, test charge will show circular path of radius $\frac{mv\sin\theta}{q_0 B}$, which moves along the direction of magnetic field with speed of $v\cos\theta$.
- Momentum along the direction of magnetic field will remain same.
- Angular speed of test charge $\frac{q_0 B}{m}$ is independent of initial speed of particle.
- Centripetal force on test charge $q_0 v B\sin\theta$ is independent of the mass of particle.
- When the particle enters the magnetic field with the same momentum, then radius of path will be,

$$r = \frac{mv}{q_0 B}$$

where,

$$r \propto \frac{1}{q_0}$$

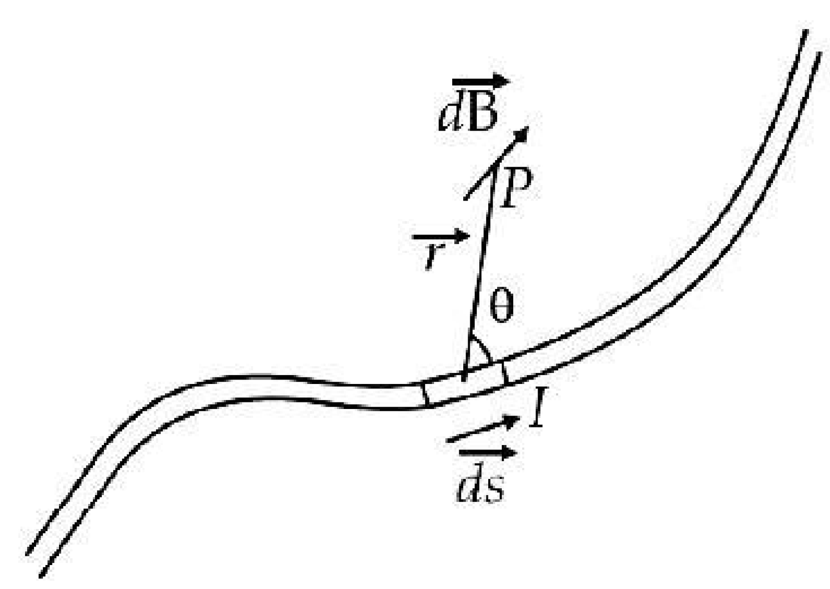
Oersted's experiment

Oersted observed that:

- When there is no current, compass needle below a wire shows no deflection.
- When the flow of current is in single direction, then the compass needle deflects in a particular direction.
- When the flow of current is reversed, deflection in compass needle occurs in the opposite direction.
- From an experiment, it is concluded that an electrical current produces a magnetic field which surrounds the wire.

Biot-Savart's law

- The magnetic field due to a current element at a nearby point is given by:



$$\vec{dB} = \left[\frac{\mu_0}{4\pi}\right] I \frac{\vec{ds} \times \vec{r}}{r^3}$$

where,

$\vec{dB}$ = Magnetic field produced by current element

$\vec{ds}$ = Vector length of small section of wire in direction of current

$\vec{r}$ = Positional vector from section of wire to where magnetic field is measured

I = Current in the wire

θ = Angle between $\vec{ds}$ and $\vec{r}$

μ_0 = Permeability of free space and $\mu_0 = 4\pi \times 10^{-7}$ Wb/Am

Scan to know more about this topic

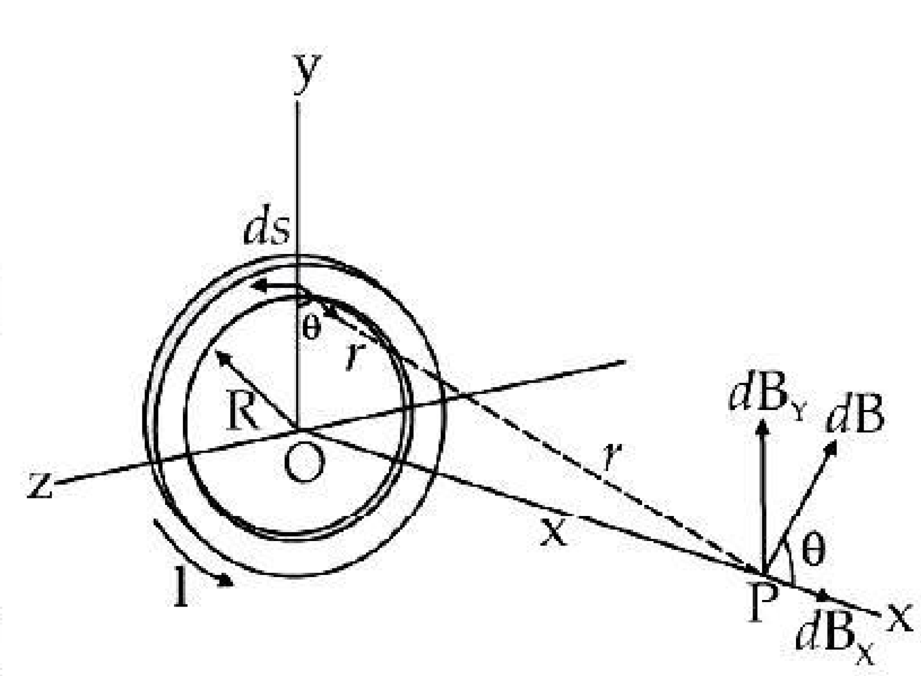
Biot-Savart's Law

The magnitude of magnetic field, $$|\vec{dB}| = \left(\frac{\mu_0}{4\pi}\right)\frac{Idl\sin\theta}{r^2}$$

Applications of Biot-Savart's Law

- Magnetic field at a point in circular loop will be:

$$\vec{B} = \frac{\mu_0 I R^2}{2\left(R^2 + x^2\right)^{3/2}}\vec{r} \qquad \text{[Here, } r^2 = R^2 + x^2\text{]}$$



- Magnetic field at the centre of the coil

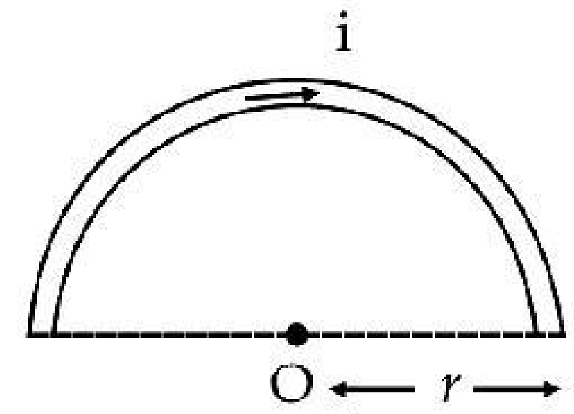
$$\vec{B} = \frac{\mu_0 N I}{2R}\vec{r}, \qquad [x = 0]$$

- Magnetic field at very large distance from the centre: $B = \frac{2\mu_0 NiA}{4\pi x^3}$ [Here, $R^2 << r^2$ or, $R^2 + x^2 \approx x^2$]

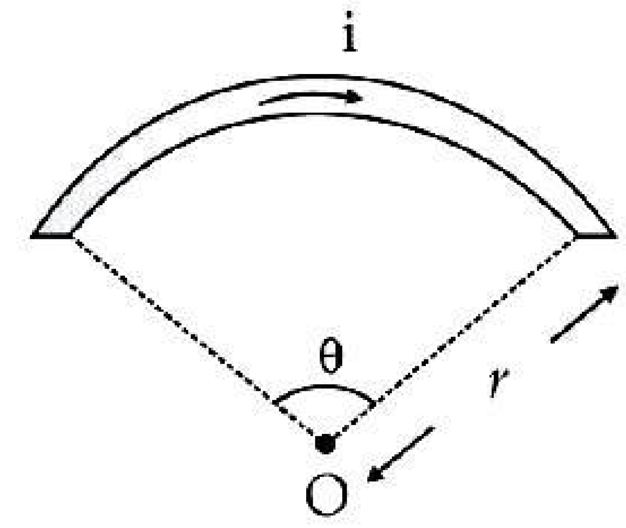
where, A = Area of circular loop
$= \pi R^2$

- Magnetic field due to current carrying circular arc with centre O will be:

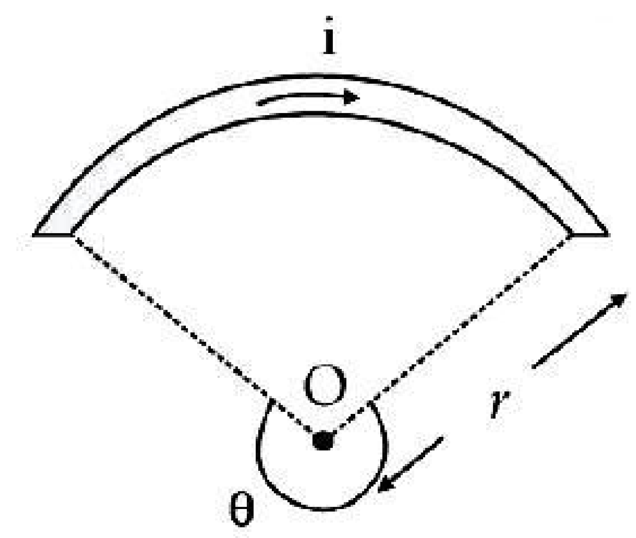
(i) $B = \frac{\mu_0}{4\pi} \cdot \frac{\pi i}{r} = \frac{\mu_0 i}{4r}$



(ii) $B = \frac{\mu_0}{4\pi} \cdot \frac{\theta i}{r}$

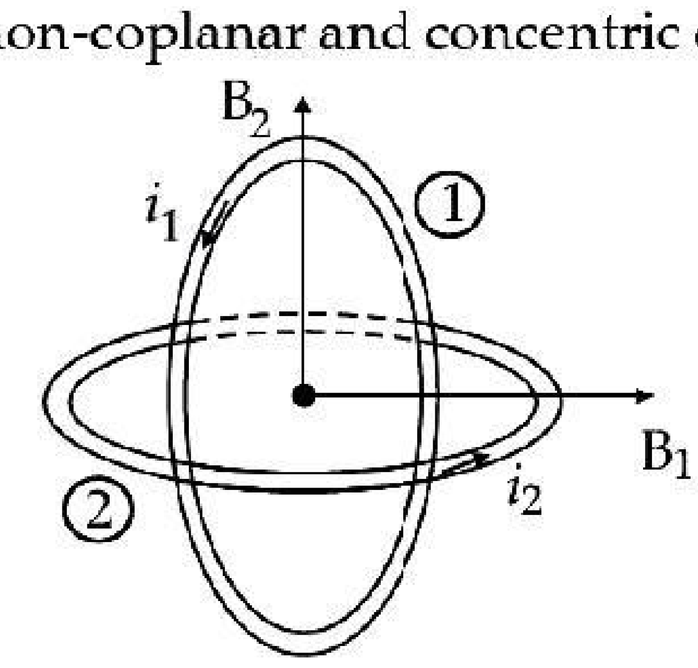


(iii) $B = \frac{\mu_0}{4\pi} \cdot \frac{(2\pi - \theta) i}{r}$



- Magnetic field at common centre of non-coplanar and concentric coils, where both coils are perpendicular to each other will be:

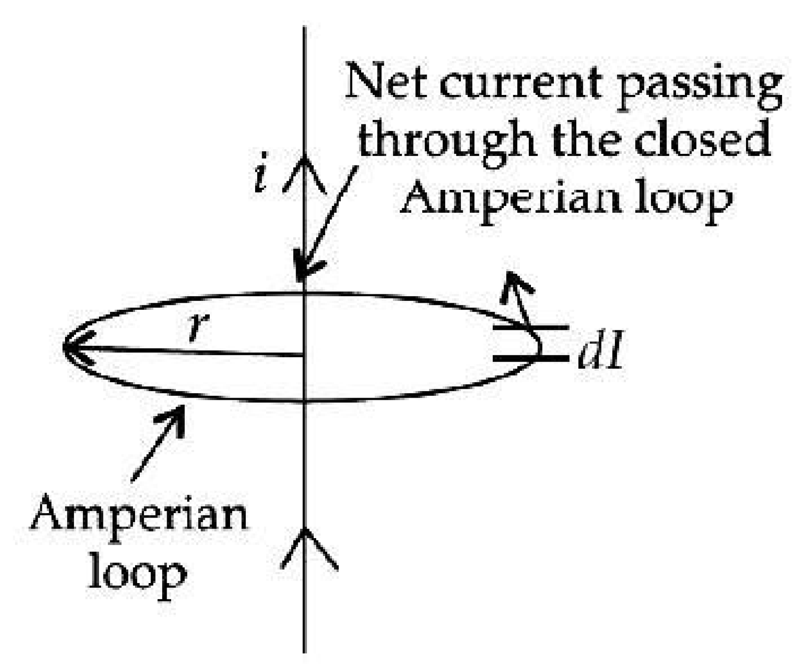
$B = \sqrt{B_1^2 + B_2^2} = \frac{\mu_0}{2r}\sqrt{i_1^2 + i_2^2}$



Ampere's Circuital Law and its Applications

- Ampere's circuital law states that the line integral of magnetic field around a closed path is μ_0 times of total current enclosed by the path, $\oint B.dI = \mu_0 I$

where,
B = Magnetic field
dl = Infinitesimal segment of the path
μ_0 = Magnetic permeability of free space
I = Enclosed electric current by the path



- Magnetic field at a point will not depend on the shape of Amperian loop and will remain same at every point on the loop.

Forces between two parallel currents

- Two parallel wires separated by distance r having currents I_1 and I_2 where magnetic field strength at second wire due to current flowing in first wire is given as:

$B = \frac{\mu_0 I_1}{2\pi r}$

- In this, the field is orientated at right-angles to second wire where force per unit length on the second wire will be:

$$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

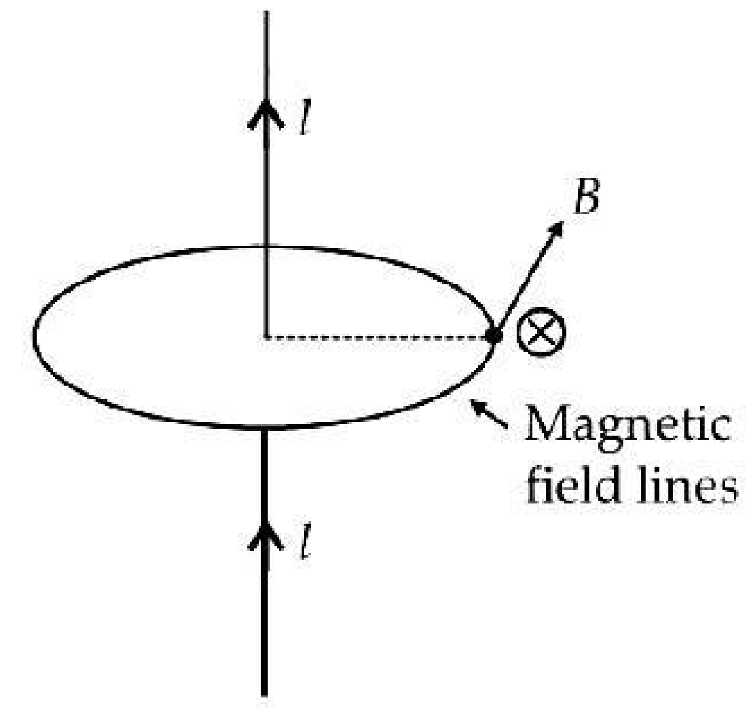
- Magnetic field-strength at first wire due to the current flowing in second wire will be:

$$B = \frac{\mu_0 I_2}{2\pi r}$$

➢ One ampere is the magnitude of current which, when flowing in each parallel wire one metre apart, results in a force between the wires as 2×10^{-7} N per metre of length.

Applications of Ampere's law to infinitely long straight wire, straight and toroidal solenoids:

(i) Magnetic Field due to long straight wire



➢ Ampere's law describes the magnitude of magnetic field of a straight wire as:

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

where,

- **Field B is tangential to a circle of radius r centered on the wire.**
- **Magnetic field B and path length L will remain parallel where magnetic field travels.**

(ii) Magnetic Field due to Solenoid

➢ **Solenoid:** An electromagnet that generates a controlled magnetic field.

➢ Solenoid is a tightly wound helical coil of wire whose diameter is small compared to its length.

➢ Magnetic field generated in the centre, or core of a current carrying solenoid is uniform and is directed along the axis of solenoid.

➢ Magnetic field due to a straight solenoid:

- **at any point in the solenoid,** $B = \mu_0 n I$
- **at the ends of solenoid,** $B_{end} = \frac{\mu_0 n I}{2}$

where, n = number of turns per unit length, I = current in the coil.

(iii) Magnetic Field due to Toroid

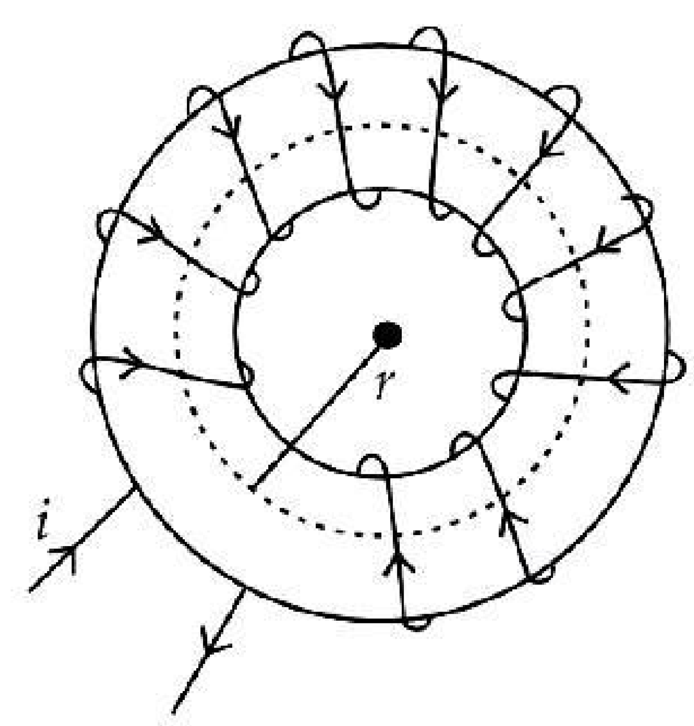
➢ **Toroid:** It is an electronic component made of hollow circular ring wound with number of turns of copper wire.

➢ The toroid is a hollow circular ring on which a large number of turns of a wire are closely wound.

➢ In a toroid with n turns per unit length with mean radius r, where current i is flowing through it, the magnetic field experienced by the toroid with total number of turns N will be:

$$\oint \vec{B}.\vec{dl} = \mu_0 i \Rightarrow B \times 2\pi r = \mu_0 N i$$

where, r = average radius



Here,

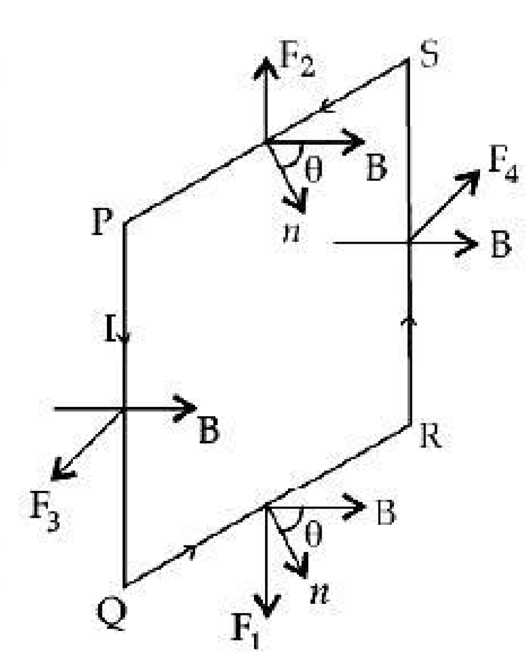
$$B = \frac{\mu_0 N i}{2\pi r} = \mu_0 n i$$

$$\left(\text{here}, n = \frac{N}{2\pi r}\right)$$

➢ At any point, empty space surrounded by toroid and outside the toroid, magnetic field B will be zero as net current is zero.

Torque and Galvanometer

Torque experienced by a current loop in uniform magnetic field



➢ In a rectangular loop of length l, breadth b with current I flowing through it in a uniform magnetic field of induction B where angle θ is between the normal and in direction of magnetic field, then the torque experienced will be:

$$\tau = nBIA\sin\theta$$

where, n = number of turns in the coil

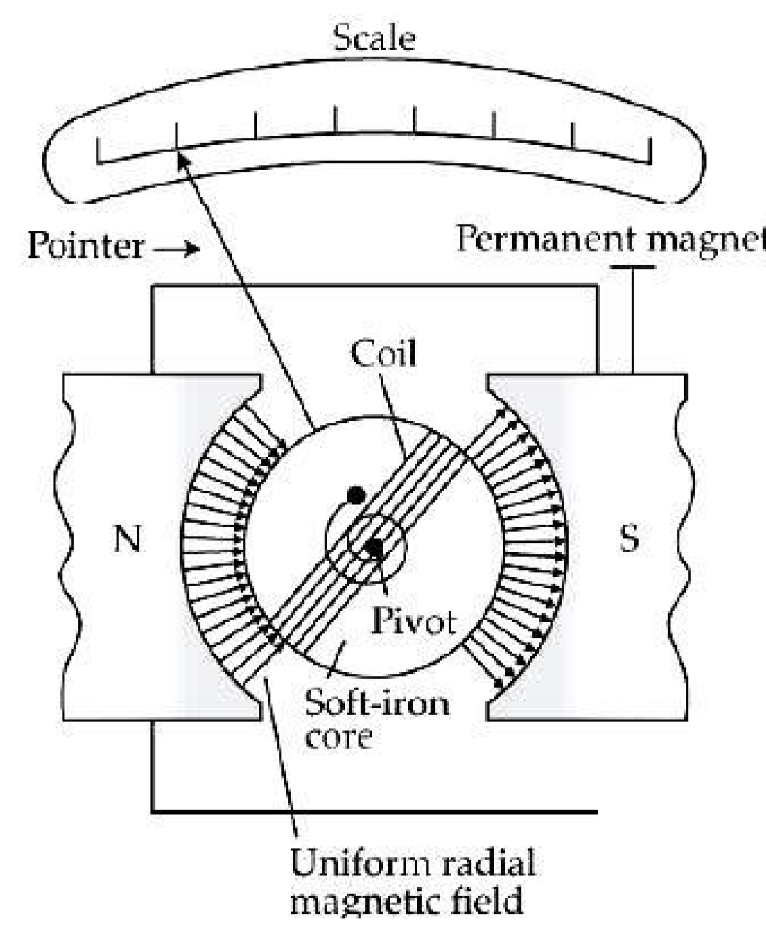
$\therefore$ $nIA = m$

Further, $\tau = mB\sin\theta$

➢ Torque will be maximum when the coil is parallel to magnetic field and will be zero when coil is perpendicular to magnetic field.

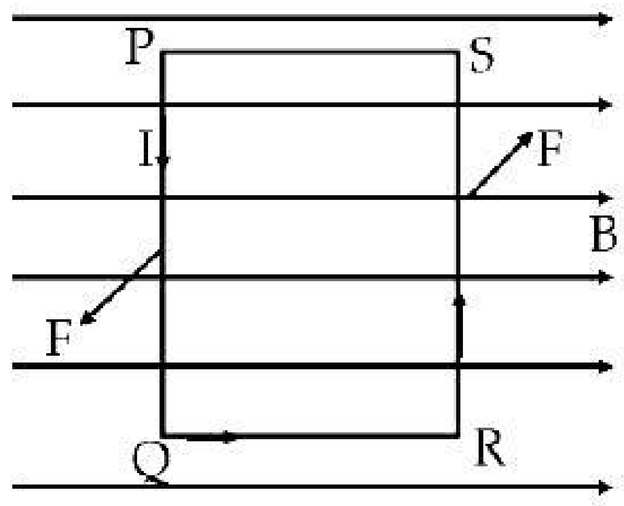
➢ In vector notation, torque $\vec{\tau}$ experienced will be $\vec{\tau} = \vec{m} \times \vec{B}$

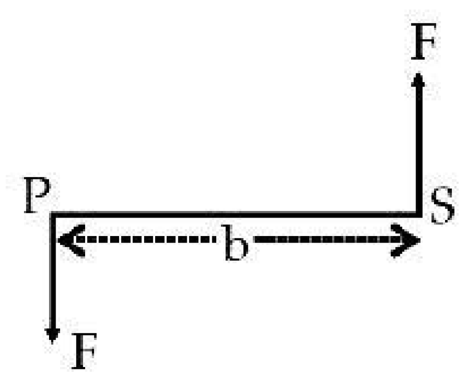
Moving coil galvanometer



- It is an instrument used for detection and measurement of small electric currents.
- In this, when a current carrying coil is suspended in uniform magnetic field, it experiences a torque which rotates the coil.
- The force experienced by each side of the galvanometer will be $F = BIl$ which are opposite in direction.
- Opposite and equal forces form the couple which generates deflecting torque on the coil having number of turns n is given as:

$$\begin{aligned}\tau &= F \times b \\ &= nBIl \times b \\ &= nBIA\end{aligned}$$





- In moving coil galvanometer, current in the coil will be directly proportional to the angle of the deflection of the coil, $I \propto \theta$
  i.e., where, θ is the angle of deflection.

Current sensitivity of galvanometer

- Current sensitivity of galvanometer is the deflection produced when unit current passes through the galvanometer. A galvanometer is said to be sensitive if it produces large deflection for a small current.

$$I = \frac{C}{nBA}\theta$$

Current Sensitivity, $$\frac{\theta}{I} = \frac{nBA}{C}$$

- Voltage sensitivity of galvanometer is the deflection per unit voltage given as

Voltage Sensitivity, $$\frac{\theta}{V} = \frac{\theta}{IG} = \frac{nBA}{CG}$$

where, G = galvanometer resistance, C = torsional constant.

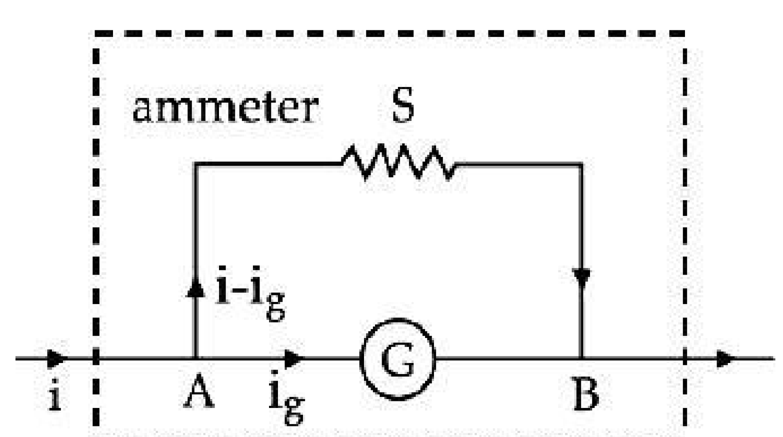
- Increase in sensitivity of moving coil galvanometer depends on:
  (i) number of turns n **(ii)** magnetic field B **(iii)** area of coil A and **(iv)** torsional constant.

Conversion of galvanometer into ammeter

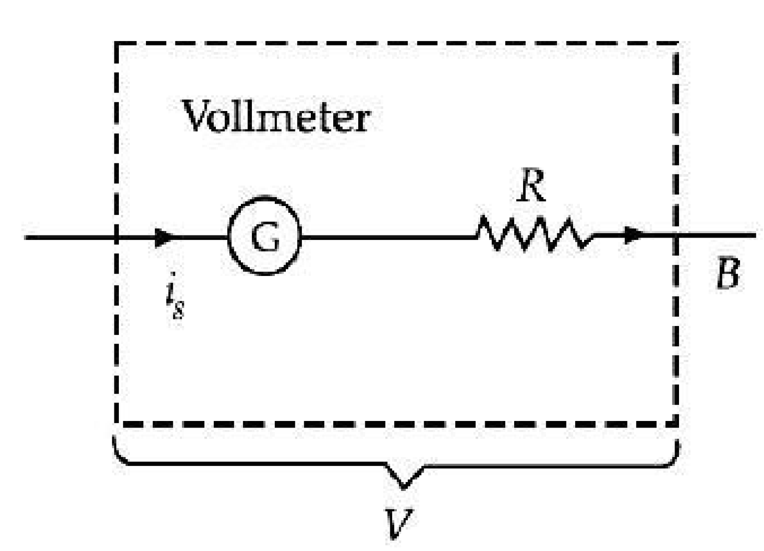
- Galvanometer can be converted into ammeter by connecting a low resistance known as shunt in parallel with the galvanometer coil.
- If I_g being the maximum current with full scale deflection passes through galvanometer, then current through shunt resistance will be $i_s = (i - i_g)$
  where, G = Galvanometer resistance, S = Shunt resistance and i = Current in circuit
- Now, effective resistance of ammeter will be:

$$\frac{1}{R_a} = \frac{1}{G} + \frac{1}{S}$$

$$R_a = \frac{GS}{G+S}$$



Conversion of galvanometer into voltmeter



- Voltmeter measures the potential difference between the two ends of a current carrying conductor.
- Galvanometer can be converted to voltmeter by connecting high resistance in series with galvanometer coil.
- As resistance R is connected in series with galvanometer, current through the galvanometer will be,

$$i_g = \frac{V}{R+G} \text{ or, } R = \frac{V}{i_g} - G$$

- Effective resistance of voltmeter is $R_v = G + R$,

  where, R_v is very large making the voltmeter to connect in parallel since it can draw less current from the circuit.

Mnemonics

Path of a charged particle in a uniform magnetic field depending on the angle between the magnetic field and the velocity of the particle:

Mnemonics : Circle ninety (90°) angle, go straight if it zero (0°), go for helical, all other angle magnet field is zero.

Circle circle ninety (90°) angle ⇨	Path is a circle if angle between magnetic field and velocity of charged particle is 90°.
Go **straight** if it zero **(0°)** ⇨	Path is a straight line if angle between magnetic field and velocity of charged particles is 90°
Go for **helical, all other angle** ⇨	Path is helix if any other angle between magnetic field and velocity of charged particle.
Magnet field is hero.	

Key Formulae

- Lorentz force, $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$
- In uniform magnetic field B, frequency of circular motion of charged particle,

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

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

- Biot-Savart's law, $d\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{i(\vec{dl} \times \vec{r})}{r^3}$
- Magnetic field at a point due to circular loop, $\vec{B} = \frac{\mu_0}{2} \cdot I \frac{R^2}{(R^2 + x^2)^{3/2}}$
- Ampere's circuital law: $\oint \vec{B} . \vec{dl} = \mu_0 I$
- Magnetic field at the surface of a solid cylinder: $B = \frac{\mu_0 I}{2\pi R}$
- Magnetic field inside the solenoid: $B = \mu_0 n I$
- Magnetic field in a toroid with mean radius r: $r = \frac{\mu_0 N i}{2\pi r}$
- Force between two parallel wires, $F = \frac{\mu_0}{4\pi} \times \frac{2 i_1 i_2}{a} \times l$
- Force between two moving charge particle, $F_m = \frac{\mu_0}{4\pi} \times \frac{q_1 q_2 v_1 v_2}{r^2}$
- $\tau_{max} = NBiA$
- Current Sensitivity $= \frac{0}{I} = \frac{nAB}{C}$
- Voltage Sensitivity $= \frac{\theta}{V} = \frac{nAB}{CG}$

STAND ALONE MCQs (1 Mark each)

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

(A) They have equal z-components of momenta.

(B) They must have equal charges.

(C) They necessarily represent a particle-antiparticle pair.

(D) The charge to mass ratio satisfy: $\left(\frac{e}{m}\right)_1 + \left(\frac{e}{m}\right)_2 = 0$

Ans. Option (D) is correct.

> ***Explanation:*** When charge/mass ratio of these two particles is same and charges on them are of opposite nature, then the charged particles will traverse identical helical paths in a completely opposite sense. Therefore, option (D) is correct.

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

(A) $B \perp v$.

(B) $B \,||\, v$.

(C) it obeys inverse cube law.

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

Ans. Option (A) is correct.

> ***Explanation:*** In Biot-Savart's law, magnetic field $B \parallel idl \times r$ and idl due to flow of electron is in opposite direction of v and by direction of cross product of two vectors, B.
>
> $$dB = \frac{I.dl \sin 0}{r^2}$$
>
> or $$dB = \frac{I \times dl}{r}$$
>
> According to Biot-Savart law, if magnetic field is not perpendicular to the motion of charge, then it will not move in helical path, which is not possible for motion of a charge in magnetic field. So, the magnetic field is perpendicular to the direction of flow of charge verifies answer 'A'.

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

(A) The magnitude of magnetic moment now diminishes.

(B) The magnetic moment does not change.

(C) The magnitude of B at $(0.0.z)$, $z >> R$ increases.

(D) The magnitude of B at $(0.0.z)$, $z >> R$ is unchanged.

Ans. Option (A) is correct.

> ***Explanation :*** For a circular loop of radius R, carrying current I in x-y plane, the magnetic moment $M = I \times \pi R_2$.
>
> It acts perpendicular to the loop along z-direction.
>
> When half of the current loop is bent in y-z plane, then magnetic moment due to half current loop is x-y plane, $M_1 = I(\pi R_2/2)$ acting along z-direction.
>
> Magnetic moment due to half current loop in y-z plane, $M_2 = I(\pi R_2/2)$ along x-direction.
>
> Net magnetic moment due to entire bent current loop,
>
> $$M_{net} = \sqrt{M_1^2 + M_2^2} = \sqrt{2}\,\frac{I\pi R^2}{2} = \frac{M}{\sqrt{2}}$$
>
> Therefore, $M_{net} < M$ or M diminishes.

Q. 4. *A* circular current loop of magnetic moment M is in an arbitrary orientation in an external magnetic field B. The work done to rotate the loop by 30° about an axis perpendicular to its plane is

(A) MB **(B)** $\frac{\sqrt{3}MB}{2}$.

(C) $\frac{MB}{2}$. **(D)** zero.

Ans. Option (D) is correct.

> ***Explanation :*** The work done to rotate the loop in magnetic field, $W = MB(\cos\theta_1 - \cos\theta_2)$.
>
> When current carrying coil is rotated then there will be no change in angle between magnetic moment and magnetic field.
>
> Here, $\theta_1 = \theta_2 = \alpha$
>
> $\Rightarrow W = MB(\cos\alpha - \cos\alpha) = 0$.

Q. 5. When a charge of 1C moving with velocity 1 m/s normal to a magnetic field experiences a force 1 N, then the magnitude of the magnetic field is

(A) 1 Gauss **(B)** 1 Tesla

(C) 1 Orested **(D)** None of the above

Ans. Option (A) is correct.

> ***Explanation :*** $F = qvB\sin\theta$
>
> When $q = 1$ C, $v = 1$ m/s, F = 1 N, $\theta = 90°$,
>
> then B = 1T

Q. 6. An electron is projected with uniform velocity along the axis of a current carrying long solenoid. Which of the following is true?

(A) The electron will be accelerated along the axis.

(B) The electron path will be circular about the axis.

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

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

Ans. Option (D) is correct.

> *Explanation:* The magnetic field inside the long current carrying solenoid is uniform. Therefore, magnitude of force on the electron of charge ($-e$) is given by $F = -evB \sin\theta = 0$ ($\theta = 0°$) as magnetic field and velocity are parallel. The electron will continue to move with uniform velocity along the axis of the solenoid.

Q. 7. When a charged particle moves through a magnetic field perpendicular to its direction. Then

(A) Linear momentum changes

(B) kinetic energy remains constant

(C) Both (A) and (B)

(D) Both linear momentum and kinetic energy varies

Ans. Option (B) is correct.

> *Explanation:* When a charged particle perpendicularly enters a magnetic field to the direction, the path of the motion is circular. In circular motion, the direction of velocity changes at every point (the magnitude remains constant). Therefore, the linear momentum changes at every point. But kinetic energy remains constant since the magnitude of velocity does not change.

Q. 8. A length L of wire carries a steady current I. It is bent first to form a circular plane coil of one turn. A current I flowing through it produces a magnetic field B at the centre of the coil. The same length is now bent more sharply to form a double loop of smaller radius. The magnetic field at the centre caused by the same current is

(A) B (B) 2B

(C) 4B (D) B/2

Ans. Option (C) is correct.

> *Explanation:* $B_2 = n^2 B_1$
> Here $n = 2$, $B_1 = B$.
> $\therefore$ $B_2 = 4B$

Q. 9. A straight conductor carries a current from south to north. Point P and Q lie to the east and west of it at the same distance. The magnetic field at P is

(A) equal to magnetic field at Q.

(B) smaller than the magnetic field at Q.

(C) greater than the magnetic field at Q.

(D) cannot be predicted unless the value if I is known.

Ans. Option (A) is correct.

> *Explanation:* $B \propto I$, $B \propto 1/r$
> So, if I and r remains constant, then magnetic field at P = Magnetic field at Q.

Q. 10. Magnetic field due to a straight solenoid at any point inside it is $B = \mu_0 ni$. Magnetic field at the end of the solenoid is

(A) B (B) B/2

(C) 2B (D) B/4

Ans. Option (B) is correct.

> *Explanation:* Magnetic field at the end of a current carrying solenoid is half of the magnetic field inside it.

Q. 11. At any point, empty space surrounded by a toroid, the magnetic field is B_1. At any point, outside the toroid, the magnetic field is B_2.

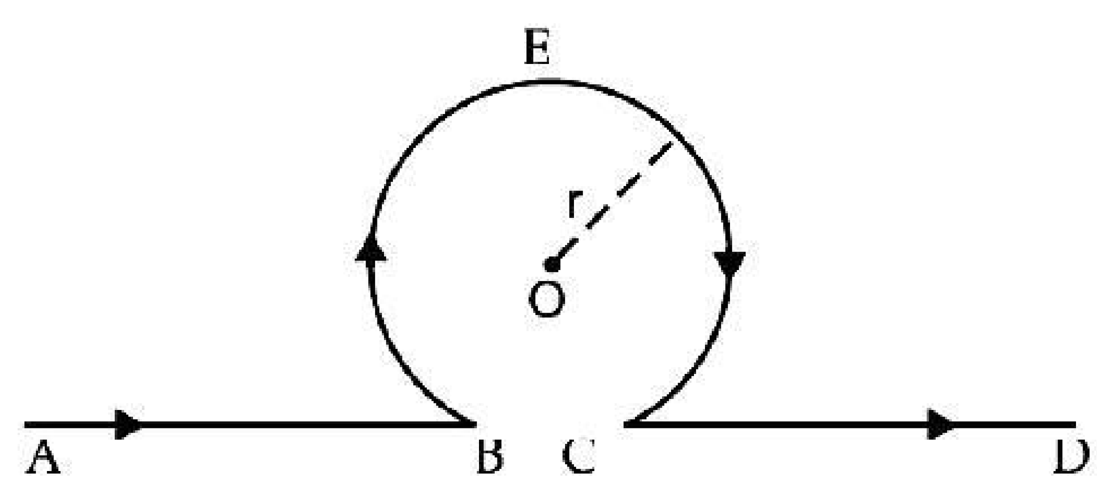
(A) $B_1 > B_2$ (B) $B_2 > B_1$

(C) $B_1 = B_2$ (D) $B_1 = B_2 = 0$

Ans. Option (D) is correct.

> *Explanation:* As net current is zero, magnetic field at the empty space surrounded by toroid and outside the toroid is zero.

Q. 12. An infinitely long straight conductor is bent into the shape as shown in the figure. Current in it is i and the radius of the circular loop is r. The magnetic field at its centre is



(A) Zero (B) Infinite

(C) $\frac{\mu_0 i}{2\pi r}(\pi - 1)$ (D) $\frac{\mu_0 i}{2\pi r}(\pi + 1)$

Ans. Option (C) is correct.

> *Explanation:* Magnetic field at O due to ABCD straight conductor $= \frac{\mu_0 i}{2\pi r}$
> Magnetic field at O due to the BEC circular conductor $= \frac{\mu_0 i}{2r}$
> The fields are in opposite direction. Hence the resultant field at O is $\frac{\mu_0 i}{2r} - \frac{\mu_0 i}{2\pi r} = \frac{\mu_0 i}{2\pi r}(\pi - 1)$

Q. 13. A solenoid of 1.5 metre length and 4.0 cm diameter has 10 turn per cm. A current of 5 A ampere is flowing through it. The magnetic field at axis inside the solenoid is

(A) $2\pi \times 10^{-3}$ T (B) $2\pi \times 10^{-3}$ G
(C) $2\pi \times 10^{-7}$ T (D) $2\pi \times 10^{-7}$ G

Ans. Option (A) is correct.

Explanation: $B = \mu_0 ni = 4\pi \times 10^{-7} \times 5 \times 10 \times 10^2 = 2\pi \times 10^{-3}$ T

Q. 14. The strength of the magnetic field at distance r from a long straight current carrying wire is B. The field at a distance $r/2$ will be

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

Ans. Option (B) is correct.

Explanation: $B \propto 1/r$

$B_1/B_2 = r_2/r_1 = \frac{r/2}{r}$

$\therefore B_2 = 2B_1 = 2B$

Q. 15. In a moving coil galvanometer, current in the coil is

(A) directly proportional to angle of deflection.
(B) inversely proportional to the angle of deflection.
(C) directly proportional to the square root of the angle of deflection.
(D) inversely proportional to the square root of the angle of deflection.

Ans. Option (A) is correct.

Explanation: In a moving coil galvanometer, current in the coil is directly proportional to angle of deflection.

Q. 16. Current sensitivity of a galvanometer is given by

(A) Cθ/nBA (B) nBA/C
(C) nBA/CG (D) CG/nBA

Ans. Option (B) is correct.

Explanation: Current sensitivity of a galvanometer is the deflection produced when unit current passes through it.

Current sensitivity = θ/I = nBA/C

Q. 17. The deflecting torque acting on the coil of a galvanometer is

(A) inversely proportional to number of turns.
(B) inversely proportional to current flowing.
(C) inversely proportional to area of the coil.
(D) directly proportional to the magnetic field strength.

Ans. Option (D) is correct.

Explanation: τ = nBIA.

So, torque is directly proportional to the magnetic field strength, area of the coil, number of turns and current flowing.

Q. 18. To convert a galvanometer to ammeter a shunt S is to be connected with the galvanometer. The effective resistance of the ammeter then is

(A) GS/(G+S) (B) (G+S)/GS
(C) G+S (D) None of the above

Ans. Option (A) is correct.

Explanation: Shunt (S) is connected in parallel to the galvanometer (resistance G). So, the effective resistance is GS/(G+S).

Q. 19. A galvanometer of 100 Ω resistance gives full scale deflection for 10 mA current. To use it as an ammeter of 10 A range, the resistance of the shunt required is

(A) 10 Ω (B) 0.10 Ω
(C) 0.01 Ω (D) 0.001 Ω

Ans. Option (B) is correct.

Explanation:

$$S = \frac{i_g G}{i - i_g} = \frac{100 \times 0.01}{10 - 0.01} = 0.1\ \Omega$$

Q. 20. An ammeter gives full scale deflection when current of 1.0 A is passed in it. It is converted into a 100 A range ammeter, What will be the ratio of the shunt resistance and its resistance ?

(A) 1 : 9 (B) 9 : 1
(C) 1 : 11 (D) 11 : 1

Ans. Option (A) is correct.

Explanation: $S = \frac{i_g G}{i - i_g}$

$$S/G = \frac{i_g G}{i - i_g} = \frac{1}{10 - 1} = 1:9$$

Q. 21. A galvanometer can be converted into a voltmeter by connecting a

(A) high resistance in series.
(B) high resistance in parallel.
(C) low resistance in parallel.
(D) low resistance in series.

Ans. Option (A) is correct.

Explanation: To convert a galvanometer into a voltmeter, a high value resistance is to be connected in series with it.

ASSERTION AND REASON BASED MCQs (1 Mark each)

Directions: In the following questions, A statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as.

(A) Both A and R are true and R is the correct explanation of A

(B) Both A and R are true but R is NOT the correct explanation of A

(C) A is true but R is false

(D) A is false and R is true

Q. 1. Assertion (A): Magnetic field interacts with a moving charge only.

Reason (R): Moving charge produces a magnetic field.

Ans. Option (A) is correct.

> *Explanation:* Current carrying wire creates magnetic field. This magnetic field has no effect on a stationary charge. But when the charge also moves, it creates a current. This current produces a magnetic field. Two fields interact and the charge is deflected. So, the assertion is true. Moving charge creates a current which produces a magnetic field. So, the reason is also true. Reason is the correct explanation of A.

Q. 2. Assertion (A): If an electron is not deflected when moving through a certain region of space, then the only possibility is that no magnetic field is present in that region.

Reason (R): Force on electron is directly proportional to the strength of the magnetic field.

Ans. Option (A) is correct.

> *Explanation:* In absence of magnetic field, moving electron will not be deflected. This possibility is true. So, assertion is true. $\vec{F} = q(\vec{V} \times \vec{B})$. So, force on electron is directly proportional to the strength of the magnetic field. So, reason is true. Reason properly explains the assertion.

Q. 3. Assertion (A): The energy of a charged particle moving in a uniform magnetic field remains constant.

Reasoning (R): Work done by the magnetic field on the charge is zero.

Ans. Option (A) is correct.

> *Explanation:* The force on a charged particle moving in a uniform magnetic field always acts in direction perpendicular to the direction of motion of the charge.
>
> So work done by the magnetic field,
>
> $W = FS \cos \theta = FS \cos 90° = 0$
>
> So, the energy of the charged particle does not change.
>
> Both, assertion and reason are true and reason also explains the assertion.

Q. 4. Assertion (A): An electron and a proton moving with same velocity enters a magnetic field. The force experienced by the proton is more than the force experienced by the electron.

Reason (R): The mass of proton is more than the mass of the electron.

Ans. Option (D) is correct.

> *Explanation:* $\vec{F} = q(\vec{v} \times \vec{B})$
>
> So, the force is mass independent. So, the assertion is false.
>
> Proton is obviously heavier than electron. So, reason is true. But reason does not explain the assertion.

Q. 5. Assertion (A): The magnetic field at the ends of a very long current carrying solenoid is half of that at the centre.

Reason (R): Magnetic field within a sufficiently long solenoid is uniform.

Ans. Option (B) is correct.

> *Explanation:* Magnetic field inside a solenoid is $B = \mu_0 ni$.
>
> Magnetic field at the end of a solenoid is ½ $\mu_0 ni$.
>
> So, the assertion is true.
>
> Magnetic field within a sufficiently long solenoid is uniform. So reason is also true. But it does not explain the assertion.

Q. 6. Assertion (A): The magnetic field produced by a current carrying solenoid is independent of its length and area of cross-section.

Reason (R): Magnetic field within a very long solenoid is uniform.

Ans. Option (B) is correct.

Explanation: Magnetic field inside solenoid $B = \mu_0 ni$. It is independent of length and area of cross-section. Hence the assertion is true. Reason is also true. But it does not explain the assertion.

Q. 7. Assertion (A): A direct current flowing through a metallic rod produces magnetic field both inside and outside of the rod.

Reason (R): There is no flow of charge carrier inside the rod.

Ans. Option (C) is correct.

Explanation: Charge carries flows through whole cross-section. So, the filed exists both inside and outside. So, the assertion is true and the reason is false.

Q. 8. Assertion (A): In moving coil galvanometer, the coil is wound on a metallic frame.

Reason (R): The metallic frame helps in making steady deflection without oscillation.

Ans. Option (A) is correct.

Explanation: Coil of a moving coil galvanometer is wound on a metal frame. So, the assertion is true. It is done to avoid any oscillation and fluctuating reading. The metal frame provides damping to reduce the oscillation so that the reading becomes steady. So the reason is also true and properly explains the assertion.

Q. 9. Assertion (A): Torque on a coil is maximum when it is suspended radially in a magnetic field.

Reason (R): Torque tends to rotate a coil .

Ans. Option (B) is correct.

Explanation: The torque on the coil in a magnetic field is given by

$\tau = nIBA \sin\theta$

For radial field, $\theta = 90°$ and $\sin\theta = 1$

Torque = $nIBA$ and it is maximum.

So assertion is true.

Torque is the rotational equivalence of force. So, torque will tend to rotate a coil.

Reason is also true. But reason cannot explain the assertion that why the torque is maximum in the specified position.

Q. 10. Assertion (A): Galvanometer to ammeter conversion takes place by connecting a low value resistance in parallel with it.

Reason (R): The low value resistance increases the effective resistance and protects the galvanometer.

Ans. Option (C) is correct.

Explanation: Galvanometer to ammeter conversion takes place by connecting a low value resistance known as "shunt" in parallel with it. The assertion is true.

When two resistors are connected in parallel then the effective resistance becomes lower than the lowest value of the two resistors. Hence the reason is false.

Q. 11. Assertion (A): Earth's magnetic field does not affect the functioning of a moving coil galvanometer.

Reason (R): Earth's magnetic field is too weak.

Ans. Option (A) is correct.

Explanation: The coil of moving coil galvanometer is suspended in a very strong radial magnetic field. Earth's magnetic field is too weak compared to that and hence its effect is negligible. So, assertion and reason both are true and the reason explains the assertion properly.

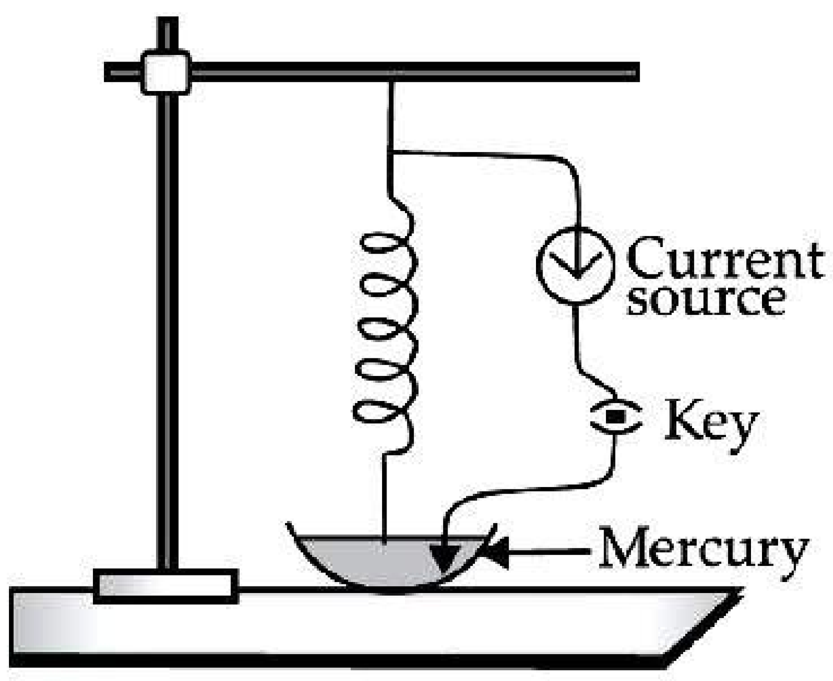
CASE-BASED MCQs

Attempt any 4 sub-parts out of 5. Each sub-part carries 1 mark.

I. Read the following text and answer the following questions on the basis of the same:

Roget's spiral:

Magnetic effects are generally smaller than electric effects. As a consequence, the force between currents is rather small, because of the smallness of the factor μ. Hence, it is difficult to demonstrate attraction or repulsion between currents. Thus, for 5 A current in each wire at a separation of 1 cm, the force per metre would be 5 × 10–4 N, which is about 50 mg weight. It would be like pulling a wire by a string going over a pulley to which a 50 mg weight is attached. The displacement of the wire would be quite unnoticeable. With the use of a soft spring, we can increase the effective length of the parallel current and by using mercury, we can make the displacement of even a few mm observable very dramatically. You will also need a constant-current supply giving a constant current of about 5 A. Take a soft spring whose natural period of oscillations is about 0.5 – 1s. Hang it vertically and attach a pointed tip to its lower end, as shown in the figure here. Take some mercury in a dish and adjust the spring such that the tip is just above the mercury surface. Take the DC current source, connect one of its terminals to the upper end of the spring and dip the other terminal in mercury. If the tip of the spring touches mercury, the circuit is completed through mercury. Let the DC source be put off to begin with. Let the tip be adjusted so that it just touches the mercury surface. Switch on the constant current supply and watch the fascinating outcome. The spring shrinks with a jerk, the tip comes out of mercury (just by a mm or so), the circuit is broken, the current stops, the spring relaxes and tries to come back to its original position, the tip again touches mercury establishing a current in the circuit and the cycle continues with tick, tick, tick,...



Q. 1. Magnetic effects:

(A) are equal to electric effects.

(B) are greater than electric effects.

(C) are smaller than electric effects.

(D) cannot be compared with electric effects.

Ans. Option (C) is correct.

> ***Explanation:*** Magnetic effects are generally smaller than electric effects.

Q. 2. The force 10^{-3} N,is equivalent to:

(A) 100 mg **(B)** 100 g

(C) 10 g **(D)** 10 mg

Ans. Option (A) is correct.

> ***Explanation:*** 10^{-3} N = mass in kg × g in m/s^2
> Or, 10^{-3} = mass × 10
> $\therefore$ Mass = 10^{-4} kg = 100 mg

Q. 3. Why the spring shrinks in Roget's spiral ?

(A) The spring functions as a solenoid

(B) Due to force acting between two current carrying wires

(C) Due to magnetic effect of current

(D) Since the spring is soft

Ans. Option (B) is correct.

> ***Explanation:*** The spring shrinks due to force acting between two current carrying wires.

Q. 4. What are the main 3 components in a Roget's spiral?

(A) Mercury, AC voltage source

(b) Mercury, DC voltage source

(C) Mercury, DC voltage source, key

(D) Mercury, AC voltage source, key

Ans. Option (C) is correct.

> ***Explanation:*** Mercury, DC voltage source, key is essential components for the Roget's spiral to work.

Q. 5. What else can be used instead of mercury in Roget's spiral ?

(A) Any liquid

(B) Water

(C) Kerosene oil

(D) Only mercury, nothing else

Ans. Option (D) is correct.

> ***Explanation:*** Only mercury can be used in Roget's spiral since mercury is a liquid metal through which an electrical circuit, may be completed.

II. Read the following text and answer the following questions on the basis of the same:

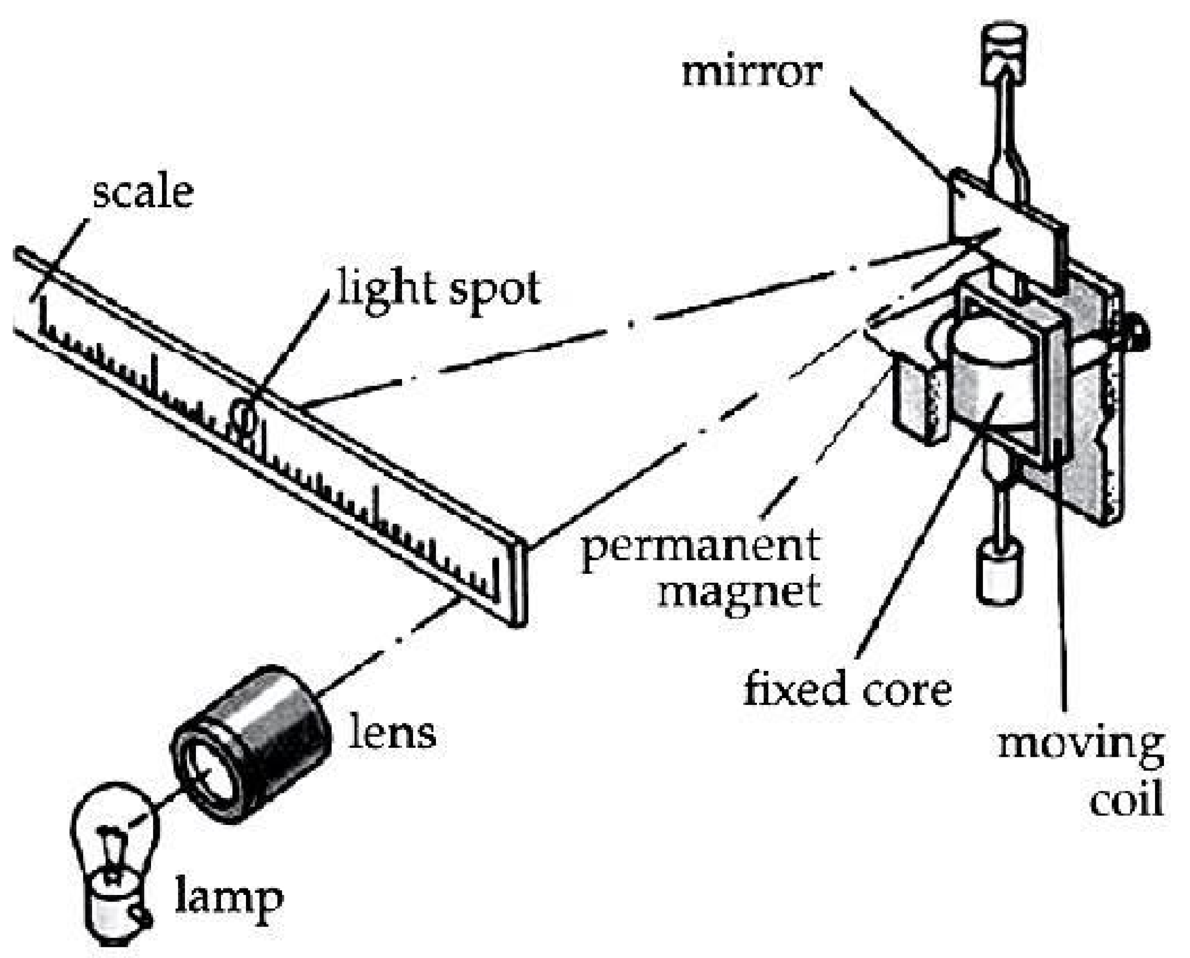
Galvanometer can sense/measure current. Improved mirror galvanometer was developed by William Thomson, later to become Lord Kelvin, in 1858. Thomson intended the instrument to read weak signal currents on very long submarine telegraph cables.

The fundamental problems of transmitting/receiving a signal through a lengthy submarine cable was that the electrical current tended to be very low (as little as 1/100,000th of a standard light bulb). So, it was very difficult to detect it. To solve the problem it was thought that larger amount of electric current would be sent through the line. But Thomson had a different approach. He thought the best response was to devise a device that could read faint signals. The galvanometer, first invented in 1802, was a means of detecting electric current. It consisted of a needle that was deflected by the magnetic field created by the electric current. But the galvanometers of the day couldn't detect the weak signals that came through a long underwater cable. But the improved version of galvanometer was highly sensitive to detect the lowest current.

The mirror galvanometer consists of a long fine coil of silk-covered copper wire. In the heart of that coil, within a little air-chamber, a small round mirror is hung by a single fibre of floss silk, with four tiny magnets cemented to its back.

A beam of light is thrown from a lamp upon the mirror, and reflected by it upon a white screen or scale a few feet distant, where it forms a bright spot of light; when there is no current on the instrument, the spot of light remains stationary at the zero position on the screen; but the instant a current traverses the long wire of the coil, the suspended magnets twist themselves horizontally out of their former position, the mirror is inclined with them, and the beam of light is deflected along the screen to one side or the other, according to the nature of the current. If a positive electric current gives a deflection to the right of zero, a negative current will give a deflection to the left of zero, and vice versa.

The air in the little chamber surrounding the mirror is compressed, so as to act like a cushion, and deaden the movements of the mirror; the mirror is thus prevented from idly swinging about at each deflections.



Q. 1. Improved mirror galvanometer was developed by

(A) Lord Kelvin

(B) Johann Schweigger

(C) Luigi Galvani

(D) André-Marie Ampère

Ans. Option (A) is correct.

> ***Explanation:*** Improved mirror galvanometer was developed by William Thomson, later to become Lord Kelvin, in 1858.

Q. 2. Mirror galvanometer was primarily used to

(A) measure the current passing through electric bulb.

(B) measure the weak current received through lengthy submarine cable.

(C) measure current passing through human body.

(D) all of these.

Ans. Option (B) is correct.

> ***Explanation:*** The fundamental problem was that the transmitting/receiving a signal through a lengthy submarine cable was very low. Instead of increasing the magnitude of the current transmission, Lord Kelvin modified the existing galvanometer so that it became capable to measure the weakest current.

Q. 3. The basic principle of galvanometer is

(A) heating effect of current.

(B) torque developed by the electric current passing through a coil.

(C) magnetic effect of current.

(D) none of the above.

Ans. Option (C) is correct.

> ***Explanation:*** The galvanometer, was a means of detecting electric current. It consisted of a needle that was deflected by the magnetic field created by the electric current.

Q. 4. The mirror galvanometer consists of

(A) a small round mirror attached to a fine coil of silk-covered copper wire.

(B) a long fine coil of silk-covered copper wire and a small round mirror hung by a single fibre of floss silk, with four tiny magnets cemented to its back.

(C) a small round mirror attached to four tiny magnets.

(D) None of the above

Ans. Option (B) is correct.

> ***Explanation:*** The mirror galvanometer consists of a long fine coil of silk-covered copper wire. In the heart of that coil, within a little air-chamber, a small round mirror is hung by a single fibre of floss silk, with four tiny magnets cemented to its back.

Q. 5. How the idly swinging of the mirror of mirror galvanometer is prevented?

(A) The little chamber surrounding the mirror was filled with a viscous liquid

(B) The mirror was placed in little chamber which was completely vacuum

(C) The mirror was attached to a spring

(D) The little chamber surrounding the mirror was filled with compressed air

Ans. Option (D) is correct.

> ***Explanation:*** The air in the little chamber surrounding the mirror is compressed, so as to act like a cushion, and deaden the movements of the mirror; the mirror is thus prevented from idly swinging about at each deflections.

III. Read the following text and answer the following questions on the basis of the same:

TOROID

A toroid is a coil of insulated or enameled wire wound on a donut-shaped form made of powdered iron. A toroid is used as an inductor in electronic circuits, especially at low frequencies where comparatively large inductances are necessary.

A toroid has more inductance , for a given number of turns, than a solenoid with a core of the same material and similar size. This makes it possible to construct high-inductance coils of reasonable physical size and mass. Toroidal coils of a given inductance can carry more current than solenoidal coils of similar size, because larger-diameter wires can be used, and the total amount of wire is less, reducing the resistance .

In a toroid, all the magnetic flux is contained in the core material. This is because the core has no ends from which flux might leak off. The confinement of the flux prevents external magnetic fields from affecting the behavior of the toroid, and also prevents the magnetic field in the toroid from affecting other components in a circuit.

Standard toroidal transformers typically offer a 95% efficiency, while standard laminated transformers typically offer less than a 90% rating.

One of the most important differences between a toroidal transformer and a traditional laminated transformer is the absence of gaps. The leakage flux through the gaps contributes to the stray losses in the form of eddy currents (which is also expelled in the form of heat).

A toroidal core doesn't have an air gap. The core is tightly wound . The result is a stable, predictable toroidal core, free from discontinuities and holes.

Audible vibration or hum in transformers is caused by vibration of the windings and core layers from the forces between the coil turns and core laminations. The toroidal transformer's construction helps quiet this noise.

In audio, or signal transmitting applications, unwarranted noise will affect sound quality, so a transformer with low audible vibration is ideal. For this reason, many sound system engineers prefer to use a toroidal transformer instead of a traditional laminated transformer.

Q. 1. Toroid is a

(A) fixed value resistor.

(B) capacitor.

(C) inductor.

(D) variable resistor.

Ans. Option (C) is correct.

> *Explanation:* A toroid is a coil of insulated or enameled wire wound on a donut-shaped form made of powdered iron. A toroid is used as an inductor in electronic circuits.

Q. 2. A toroid has _____ inductance, for a given number of turns, than a solenoid with a core of same material and similar size.

(A) same **(B)** more

(C) less **(D)** variable

Ans. Option (B) is correct.

> *Explanation:* A toroid has more inductance , for a given number of turns, than a solenoid with a core of the same material and similar size. This makes it possible to construct high-inductance coils of reasonable physical size and mass.

Q. 3. Why inductance of solenoid is more than the inductance of a solenoid having same number of turns, core of same material and similar size?

(A) Core is endless hence there no leakage of flux.

(B) Resistance of wire is less hence magnitude of current flow is more

(C) Number of turns per unit length is more.

(D) Both (A) and (B)

Ans. Option (A) is correct.

> *Explanation:* In a toroid, all the magnetic flux is contained in the core material. This is because the core has no ends from which flux might leak off.

Q. 4. Why sound system engineers prefer to use toroidal transformer?

(A) It is cheaper.

(B) It is lighter.

(C) It is compact.

(D) It does not create vibration or hum.

Ans. Option (D) is correct.

> *Explanation:* Audible vibration or hum in transformers is caused by vibration of the windings and core layers from the forces between the coil turns and core laminations. The toroidal transformer's construction helps quiet this noise. For this reason, many sound system engineers prefer to use a toroidal transformer instead of a traditional laminated transformer.

Q. 5. Efficiency of toroidal transformer is around ______ % which is ______ than laminated core transformer.

(A) 95, lower (B) 95, higher

(C) 50, lower (D) 80, higher

Ans. Option (B) is correct.

Explanation: Standard toroidal transformers typically offer a 95% efficiency, while standard laminated transformers typically offer less than a 90% rating.