DAY TWENTY TWO

Magnetic Effects of Current

Learning & Revision for the Day

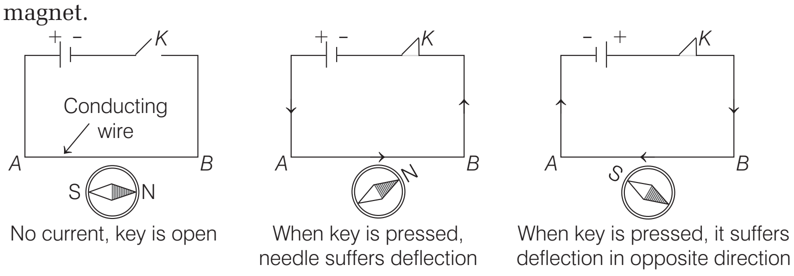
- Concept of Magnetic Field
- Biot-Savart's Law
- Ampere's Circuital Law
- Force on a Moving Charge in Uniform Magnetic Field and Electric Field
- Cyclotron
- Magnetic Force on a Current Carrying Conductor
- Current loop as a Magnetic Dipole
- Torque
- Moving Coil Galvanometer

Concept of Magnetic Field

A compass needle suffers a deflection when brought near a current carrying wire. This means that electric current, i.e. electric charge in motion, gives rise to magnetism.

Oersted's Experiment

A magnetic field is established around a current carrying conductor just as it occurs around a magnet.



Biot-Savart Law

The magnetic field $d\mathbf{B}$ at a point P, due to a current element $I\,d\mathbf{l}$ is given by

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

where, θ is the angle between $d\mathbf{l}$ and $\mathbf{r}$.

Direction of magnetic field produced due to a current carrying straight wire can be obtained by the right hand thumb rule.

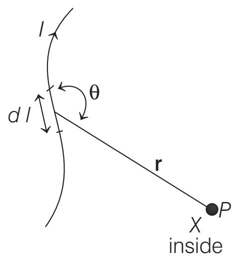


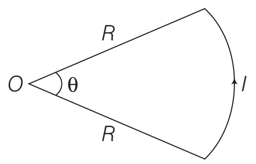
Illustration of the Biot-Savart Law

Magnetic Field due to Circular Current Loop

- If there is a circular coil of radius R and N number of turns, carrying a current I through the turns, then magnetic field at the centre of coil is given by

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

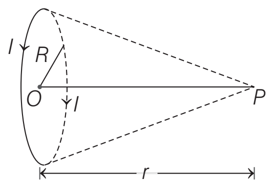
- If there is a circular arc of wire subtending an angle θ at the centre of arc, then the magnetic field at the centre point



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

- At a point O situated at a distance r from centre of a current carrying circular coil along its axial line.

  The magnetic field is



Circular current carrying loop

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

If $r >> R$, then at a point along the axial line, $B = \dfrac{\mu_0 NIR^2}{2r^3}$

Ampere's Circuital Law

The line integral of the magnetic field **B** around any closed path is equal to μ_0 times the net current I threading through the area enclosed by the closed path.

Mathematically, $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 \Sigma I$

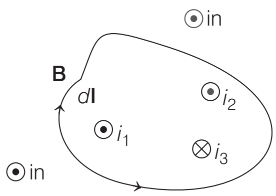


Illustration of the Ampere's circuital law

Now, consider the diagram above.

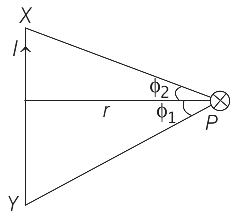
Here, $\Sigma I = i_1 + i_2 - i_3$

Hence, $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 \cdot (i_1 + i_2 - i_3)$

Applications of Ampere's law

1. Magnetic field due to Straight Current Carrying Wire

The magnetic field due to a current carrying wire of finite length at a point P situated at a normal distance r is



Straight current carrying wire

$$B = \frac{\mu_0 I}{4\pi r}(\sin \phi_1 + \sin \phi_2)$$

- If point P lies symmetrically on the perpendicular bisector of wire XY, then $\phi_1 = \phi_2 = \phi$ (say) and hence

$$B = \frac{\mu_0 I}{4\pi r} \cdot 2 \sin \phi = \frac{\mu_0 I \sin \phi}{2\pi r}$$

- For a wire of infinite length $\phi_1 = \phi_2 = 90°$ and hence

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

- When the wire XY is of infinite length, but the point P lies near the end X or Y, then $\phi_1 = 0°$ and $\phi_2 = 90°$ and hence,

$$B = \frac{\mu_0 I}{4\pi r}$$

- When point P lies on axial position of current carrying conductor, then magnetic field at P,

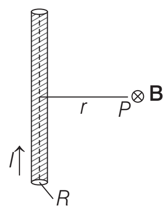
$$B = 0.$$

- When wire is of infinite length, then magnetic field near the end will be half, that of at the perpendicular bisector.

2. Magnetic Field due to a Thick (Cylindrical) Wire

Magnetic field at a point outside the wire

$B = \dfrac{\mu_0 I}{2\pi r}$, where r is the distance of given point from centre of wire and $r > R$.



Thick cylindrical wire

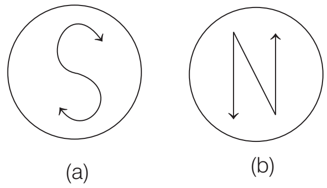
- Magnetic field at a point inside the wire at a distance r from centre of wire ($r < R$) is

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

- Magnetic field inside a hollow current carrying conductor is zero.

3. Magnetic Field due to a Solenoid

A current carrying solenoid behaves as a bar magnet. The face, where current is flowing clockwise behaves as South pole and the face, where current is seen flowing anti-clockwise, behaves as North pole.



For such a solenoid, the magnetic field inside it is uniform and directed axially.

- For a solenoid coil of infinite length at a point on its axial line, the magnetic field, $B = \mu_0 nI$

  where, n is number of turns per unit length.
- At the end of solenoid, $B = \dfrac{1}{2}\mu_0 nI$
- At the end field is half of at the centre, this is called **end effect**.

4. Toroidal Solenoids

For a toroid (i.e. a ring shaped closed solenoid) magnetic field at any point within the core of toroid $B = \mu_0 nI$,

where $n = \dfrac{N}{2\pi R}$, R = radius of toroid.

Force on a Moving Charge in Uniform Magnetic Field and Electric Field

- 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

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

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

- 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.

Motion of a Charged Particle in a Uniform Magnetic Field

- (i) If a charge particle enters a uniform magnetic field B with a velocity v in a direction perpendicular to that of B (i.e. $\theta = 90°$), then the charged particle experiences a force $F_m = qvB$. Under its influence, the particle describes a circular path, such that

  Radius of circular path, $r = \dfrac{mv}{qB}$

  In general,

$$r = \frac{mv}{qB} = \frac{p}{qB} = \frac{\sqrt{2mK}}{qB} = \frac{\sqrt{2mqV}}{qB} = \frac{1}{B}\sqrt{\frac{2mV}{q}}$$

  where, $p = mv$ = momentum of charged particle, K = kinetic energy of charged particle and V = accelerating potential difference.

  (ii) The **period of revolution** of charged particle $T = \dfrac{2\pi m}{qB}$,

  the **frequency of revolution** $\nu = \dfrac{qB}{2\pi m}$

  or **angular frequency** $\omega = \dfrac{qB}{m}$.

- (i) If a charged particle is moving at an angle θ, to the magnetic field (where θ, is other than 0°, 90° or 180°), it describes a helical path, where

  radius of helical path,

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

  (ii) **Revolution period**, $T = \dfrac{2\pi m}{qB}$

  or **Frequency**, $\nu = \dfrac{qB}{2\pi m}$

  (iii) Moreover, pitch (the linear distance travelled during one complete revolution) of helical path is given by

$$p = v\cos\theta \cdot T = \frac{2\pi mv\cos\theta}{qB}$$

- If the direction of a $\mathbf{v}$ is parallel or anti-parallel to $\mathbf{B}$, $\theta = 0$ or $\theta = 180°$ and therefore $F = 0$. Hence, the trajectory of the particle is a straight line.

  If the velocity of the charged particle is not perpendicular to the field, we will break the velocity in parallel ($v_{||}$) and perpendicular ($v_{\perp}$) components.

$$r = \frac{mv_{\perp}}{qB}$$

$$\text{Pitch, } p = (v_{||})T$$

Cyclotron

It is a device used to accelerate positively charged particles, e.g. proton, deuteron, α-particle and other heavy ions to high energy of 100 MeV or more.

Cyclotron frequency, $\nu = \dfrac{Bq}{2\pi m}$.

Maximum energy gained by the charged particle

$$E_{\max} = \left[\frac{q^2B^2}{2m}\right]r^2$$

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

Maximum energy obtained by the particle is in the form of kinetic energy.

Magnetic Force on a Current Carrying Conductor

If a current carrying conductor is placed in a magnetic field $\mathbf{B}$, then a small current element $I\,d\mathbf{l}$ experiences a force given by

$$d\mathbf{F}_m = Id\mathbf{l} \times \mathbf{B}$$

and the total force experienced by whole current carrying conductor will be

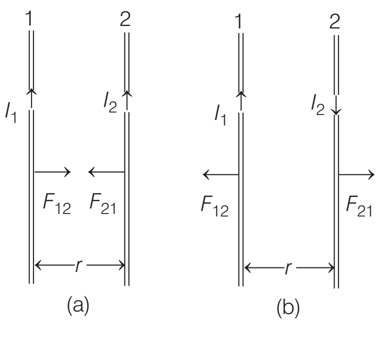
$$\mathbf{F}_m = \int d\mathbf{F}_m = \int I(d\mathbf{l} \times \mathbf{B})$$

The direction of force can also be determined by applying Fleming's left hand rule or right hand thumb rule.

Force between Two Parallel Current Carrying Conductors

- Two parallel current carrying conductors exert magnetic force on one another.
- Magnetic force experienced by length l of any one conductor due to the other current carrying conductor is

$$F = \frac{\mu_0}{4\pi} \cdot \frac{2I_1I_2}{r}\,l$$



Force per unit length, $\dfrac{F}{l} = F_0 = \dfrac{\mu_0}{4\pi} \cdot \dfrac{2I_1I_2}{r}$

NOTE
- If the conductors carries current in same direction, then force between them will be attractive.
- If the conductor carries current in opposite direction, then force will be repulsive.

Current Loop as a Magnetic Dipole

A current carrying loop (of any shape) behaves as a magnetic dipole whose magnetic moment is given by

$$\mathbf{M} = I\mathbf{A}$$

If we have a current carrying coil having N turns, then magnetic moment $\mathbf{M}$ of dipole will be

$$\mathbf{M} = NI\mathbf{A}$$

Magnetic moment of a current carrying coil is a vector and its direction is given by right hand thumb rule.

Torque

When a current carrying loop placed in a uniform magnetic field, it experience torque,

$$\tau = NIAB\sin\theta$$

where, NiA is defined as the magnitude of the dipole moment of the coil

$$(p_m)\cdot \tau = p_m B\sin\theta$$

$$\Rightarrow \quad \tau = \mathbf{p}_m \times \mathbf{B}$$

Moving Coil Galvanometer (MCG)

MCG is used to measure the current upto nanoampere. The deflecting torque of MCG,

$$\tau_{\text{def}} = NBIA$$

A restoring torque is set up in the suspension fibre. If α is the angle of trust, the restoring torque is

$$\tau_{\text{restoring}} = KI$$

where, K is galvanometer constant.

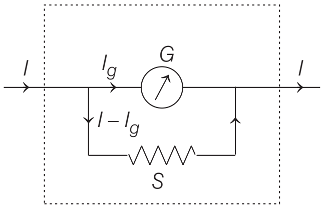
Some Important Concepts Related to Moving Coil Galvanometer

Some of the important concepts related to galvanometer, i.e. current sensitivity, voltage sensitivity and some of conversions used in galvanometer are given below.

- **Conversion of Galvanometer into Ammeter** An ammeter is made by connecting a low resistance S in parallel with a pivoted type moving coil galvanometer G. S is known as shunt. Then, from circuit,

$$I_g \times G = (I - I_g) \times S$$

$$\Rightarrow \quad S = \left(\frac{I_g}{I - I_g}\right) G$$



Ammeter

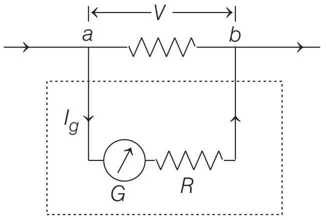
So, $S << G$, only a small fraction of current goes through the galvanometer.

- **Conversion of Galvanometer into Voltmeter**

A voltmeter is made by connecting a resistor of high resistance R in series with a pivoted type moving coil galvanometer G.

From the circuit, $I_g = \dfrac{V}{G + R}$

$$\Rightarrow \quad R = \frac{V}{I_g} - G$$



Voltmeter

- **Current Sensitivity** The current sensitivity of a galvanometer is defined as the deflection produced in the galvanometer per unit current flowing through it.

$$S_I = \frac{\alpha}{I} = \frac{NBA}{C}$$

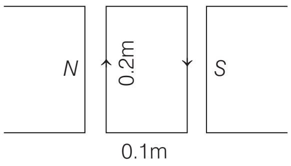
- **Voltage Sensitivity** Voltage sensitivity of a galvanometer is defined as the deflection produced in the galvanometer per unit voltage applied to it.

$$S_V = \frac{\alpha}{V} = \frac{\alpha}{IR} = \frac{S_I}{R} = \frac{NBA}{RC}$$

DAY PRACTICE SESSION 1

FOUNDATION QUESTIONS EXERCISE

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



(a) 1 N-m (b) 2 N-m
(c) 3 N-m (d) 4 N-m

2 A current loop in a magnetic field ➔ NEET 2013

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

3 A beam of α-particles having specific charge $2.5\times 10^7 \text{C kg}^{-1}$ move with a speed of $2\times 10^5 \text{ms}^{-1}$ in a magnetic field of 0.05 T. What is the radius of the circular path described by the α-particles?

(a) 4 cm (b) 8 cm
(c) 16 cm (d) 32 cm

4 Current of 5 A and 2 A are passed through two parallel wires *A* and *B* respectively, in opposite directions. If the wire *A* is infinitely long and the length of the wire *B* is 5 m, the force on the conductor *B*, which is situated at 20 cm distance from *A* will be

(a) 5×10^{-5} N (b) 2×10^{-5} N
(c) $5\pi\times 10^{-7}$ N (d) $2\pi\times 10^{-7}$ N

5 A cyclotron is used to obtain a 2 MeV beam of protons. The alternating potential difference applied between the dees has a peak value of 20 kV and its frequency is 5 MHz. The intensity of magnetic field to be applied for resonance will be

(a) 0.0327 T (b) 0.327 T
(c) 3.27 T (d) None of these

6 A current *I* ampere flows along an infinitely long straight thin walled tube. The magnetic induction at any point inside the tube at a distance *r* metre from axis, is

(a) 0 (b) ∞
(c) $\frac{\mu_0 I}{2r}$ (d) $\frac{\mu_0 I}{2\pi r}$

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

(a) $\mathbf{B}\perp\mathbf{v}$ (b) $\mathbf{B}\,||\,\mathbf{v}$
(c) it obey inverse cube law
(d) it is along the line joining the electron and point of observation

8 Magnetic field *B* on the axis of a circular coil far away at distance *x* from the centre of the coil are related as

(a) $B\propto x^{-3}$ (b) $B\propto x^{-2}$
(c) $B\propto x^{-1}$ (d) None of these

9 A current carrying coil is bent sharply, so as to convert it into a double loop both carrying current in the same direction. If *B* be the initial magnetic field at the centre, what will be the final concentric magnetic field ?

(a) 2*B* (b) 4*B* (c) 8*B* (d) Zero

10 Two similar coils of radius *R* are lying concentrically with their planes at right angles to each other. The currents flowing in them are I and $2I$, respectively. The resultant magnetic field induction at the centre will be ➔ CBSE AIPMT 2012

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

11 A current of 4×10^{-3} A is flowing in a long straight conductor. The value of line integral of magnetic field around the closed path enclosing the straight conductor will be

(a) $1.6\pi\times 10^{-9}$ Wbm^{-2} (b) 1.6×10^{-9} Wbm^{-2}
(c) 1.6×10^{-8} Wbm^{-2} (d) $1.6\pi\times 10^{-7}$ Wbm^{-2}

12 The magnetic force acting on a charged particle of charge $-2\,\mu$C in a magnetic field of 2 T acting in *y*-direction, when the particle velocity is $(2\hat{\mathbf{i}}+3\hat{\mathbf{j}})\times 10^6 \text{ ms}^{-1}$ is ➔ CBSE AIPMT 2009

(a) 8 N in *z*-direction (b) 4 N in *z*-direction
(c) 8 N in *y*-direction (d) 8 N in *z*-direction

13 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

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

(a) speed will decrease ➜ CBSE AIPMT 2011
(b) speed will increase
(c) will turn towards left of direction of motion
(d) will turn towards right of direction of motion

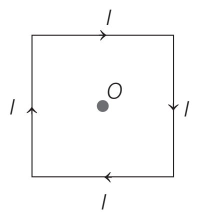
15 The radius of the earth is 6.4×10^6m. The specific charge of proton is 9.6×10^7 Ckg^{-1}. What should be the value of minimum magnetic field at the equator of earth, such that a proton moving with velocity 1.92×10^7 ms^{-1} may revolve round the earth ?

(a) 1.57×10^{-8} T
(b) 3.12×10^{-8} T
(c) 5.36×10^{-6} T
(d) 7.83×10^{-6} T

16 When a charged particle moving with velocity **v** is subjected to a magnetic field of induction **B**, the force on it is non-zero. This implies that

(a) angle between **v** and **B** is necessarily 90°
(b) angle between **v** and **B** can have any value other than 90°
(c) angle between **v** and **B** can have any value other than zero and 180°
(d) angle between **v** and **B** is either zero or 180°

17 A square wire of each side l carries a current I. What is the magnetic field at the mid-point of the square ?



(a) $4\sqrt{2}\frac{\mu_0}{4\pi}\frac{I}{l}$ (b) $8\sqrt{2}\frac{\mu_0}{4\pi}\frac{I}{l}$ (c) $16\sqrt{2}\frac{\mu_0}{4\pi}\frac{I}{l}$ (d) $32\sqrt{2}\frac{\mu_0}{4\pi}\frac{I}{l}$

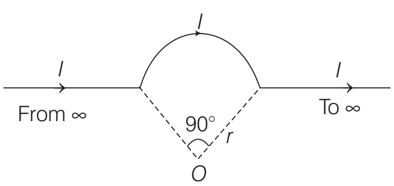
18 An electron moving in a circular orbit of radius r, makes n rotations per second. The magnetic field produced at the centre has magnitude ➜ CBSE AIPMT 2015

(a) $\frac{\mu_0 ne}{2\pi r}$ (b) zero (c) $\frac{\mu_0 n^2 e}{r}$ (d) $\frac{\mu_0 ne}{2r}$

19 A regular hexagon carries current I. The hexagon can be inscribed inside a circle of radius R. What is the magnetic field at the centre of the circle ?

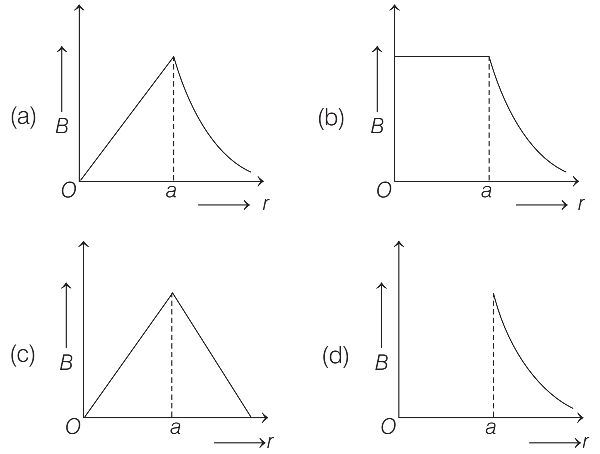
(a) $\frac{\mu_0}{4\pi}\frac{2I}{R}$ (b) $\frac{\mu_0}{4\pi}\frac{12I}{R}$ (c) $\frac{\mu_0}{4\pi}\frac{I}{R}\sqrt{3}$ (d) $\frac{\mu_0}{4\pi}\frac{12I}{R}\sqrt{3}$

20 What is the magnetic field at the centre of arc in the figure below?

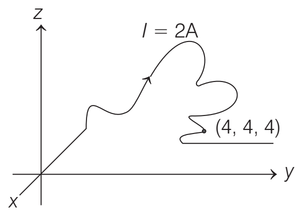


(a) $\frac{\mu_0}{4\pi}\frac{2I}{r}[\sqrt{2} + \pi]$
(b) $\frac{\mu_0}{4\pi}\frac{2I}{r}\left[\sqrt{2} + \frac{\pi}{4}\right]$
(c) $\frac{\mu_0}{4\pi}\frac{I}{r}[\sqrt{2} + \pi]$
(d) $\frac{\mu_0}{4\pi}\frac{I}{r}\left[\sqrt{2} + \frac{\pi}{4}\right]$

21 The magnetic field due to a straight conductor of uniform cross-section of radius a and carrying a steady current is represented by

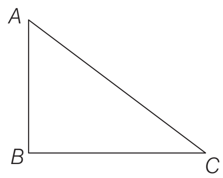


22 A wire of arbitrary shape carries a current $I = 2$A, consider the portion of wire between (0, 0, 0) and (4, 4, 4). A magnetic field given by $\mathbf{B} = (1.2 \times 10^{-4}\ \hat{\mathbf{i}} + 2 \times 10^{-4}\ \hat{\mathbf{j}})$ exists in the space. The force acting on the given portion, is



(a) in calculatable as length of wire is not known
(b) $\mathbf{F} = [(\hat{\mathbf{i}} + \hat{\mathbf{j}} + \hat{\mathbf{k}}) \times (1.2\ \hat{\mathbf{i}} + 1.2\ \hat{\mathbf{j}})]$ N
(c) $\mathbf{F} = 8 \times 10^{-4}[(\hat{\mathbf{i}} + \hat{\mathbf{j}} + \hat{\mathbf{k}}) \times (1.2\ \hat{\mathbf{i}} + 2\ \hat{\mathbf{j}})]$ N
(d) zero

23 A current carrying closed loop in the form of a right angled isosceles $\Delta\ ABC$ is placed in a uniform magnetic field acting along AB. If the magnetic force on the arm BC is **F**, the force on the arm AC is ➜ CBSE AIPMT 2011

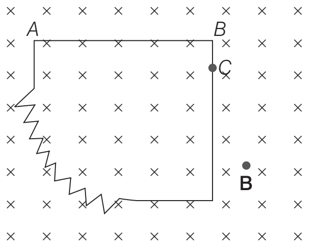


(a) $-$**F** (b) **F** (c) $\sqrt{2}$**F** (d) $-\sqrt{2}$**F**

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

(a) They have equal z-components of momenta
(b) They must have equal charges
(c) They necessarily represent a particle-anti-particle pair
(d) The charge to mass ratio satisfy : $\left(\frac{e}{m}\right)_1 + \left(\frac{e}{m}\right)_2 = 0$

25 An irregular loop carrying current 5 A is placed in a uniform magnetic field $B = 0.5$ T, as such straight segment AB of length 10 cm is out of magnetic field. The magnitude and the direction of the magnetic force acting on the loop are



(a) ON and unlike parallel to BC
(b) 0.25 N and unlike parallel to BC
(c) 0.25 N and like parallel to BC
(d) None of the above

26 An electron moves in a circular orbit with a uniform speed v. It produces a magnetic field B at the centre of the circle. The radius of the circle is proportional to

(a) $\frac{B}{v}$ (b) $\frac{v}{B}$ (c) $\sqrt{\frac{v}{B}}$ (d) $\sqrt{\frac{B}{v}}$

27 An electron is revolving around a proton in a circular path of diameter 0.1 nm. It produces a magnetic field 4 W m^{-2} on the proton. What is the angular speed of the electron?

(a) 1.4×10^{16} rad s^{-1} (b) 2.2×10^{6} rad s^{-1}
(c) 6.4×10^{16} rad s^{-1} (d) 8.8×10^{16} rad s^{-1}

28 A beam of electrons passes undeflected through mutually perpendicular electric and magnetic fields. If the electric field is switched OFF and the same magnetic field is maintained, the electrons move

(a) in an elliptical orbit (b) in a circular orbit
(c) along a parabolic path (d) along a straight line

29 A square conducting loop of side length L carries a current I. The magnetic field at the centre of the loop is

(a) independent of L (b) proportional to L^2
(c) inversely proportional to L (d) linearly proportional to L

30 Two identical long conducting wires AOB and COD are placed at right angle to each other, with one above other such that O is their common point for the two. The wires carry I_1 and I_2 currents, respectively. Point P is lying at distance d from O along a direction perpendicular to the plane containing the wires. The magnetic field at the point P will be → CBSE AIPMT 2014

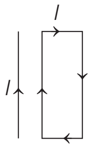
(a) $\frac{\mu_0}{2\pi d}\left(\frac{I_1}{I_2}\right)$ (b) $\frac{\mu_0}{2\pi d}(I_1 + I_2)$

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

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

(a) nB (b) n^2B
(c) $2nB$ (d) $2n^2B$

32 A rectangular loop carrying a current I is situated near a long straight wire, such that the wire is parallel to one of the sides of the loop and is in the plane of the loop. If a steady current I is established in the wire as shown in the figure, the loop will → WB JEE 2013



(a) rotate about an axis parallel to the wire
(b) move away from the wire
(c) move towards the wire
(d) remain stationary

33 An α-particle describes a circular path of radius r in a magnetic field B. What will be the radius of the circular path described by the proton of same energy in the same magnetic field ?

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

34 Under the influence of a uniform magnetic field, a charged particle is moving in a circle of radius R with constant speed v. The time period of the motion

(a) depends on v are not on R
(b) depends on both R and v
(c) is independent on both R and v
(d) depends on R and not on v

35 A 250 turn rectangular coil of length 2.1 cm and width 1.25 cm carries a current of 85 μA and subjected to a magnetic field of strength 0.85 T. Work done for rotating the coil by 180° against the torque is → NEET 2017

(a) 9.1 μJ (b) 4.55 μJ (c) 2.3 μJ (d) 1.5 μJ

36 If a shunt of $\frac{1}{10}$ th of the coil resistance is applied to a moving coil galvanometer, its sensitivity becomes

(a) 10 fold (b) $\frac{1}{10}$ fold

(c) 11 fold (d) $\frac{1}{11}$ fold

37 A thin ring of radius R metre has charge q coulomb uniformly spread on it. The ring rotates about its axis with a constant frequency of f revolution/s. The value of magnetic induction in Wb m^{-2} at the centre of the ring is → CBSE AIPMT 2010

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

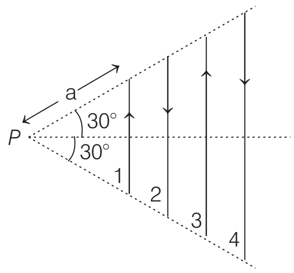
DAY PRACTICE SESSION 2

PROGRESSIVE QUESTIONS EXERCISE

1 Torques τ_1 and τ_2 are required for magnetic needle to remain perpendicular to the magnetic field B_1 and B_2 at two different places. The ratio $\frac{B_1}{B_2}$ is

(a) $\frac{\tau_2}{\tau_1}$ (b) $\frac{\tau_1}{\tau_2}$ (c) $\frac{\tau_1 + \tau_2}{\tau_1 - \tau_2}$ (d) $\frac{\tau_1 - \tau_2}{\tau_1 + \tau_2}$

2 Infinite number of straight wires, each carrying current I are equally placed as shown in the figure. Adjacent wires have current in opposite direction. Net magnetic field at point P, is



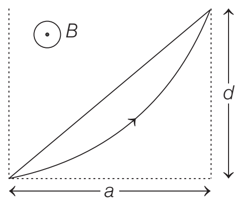
(a) $\frac{\mu_0 I}{8\pi} \frac{\ln 2}{\sqrt{3}a} \hat{\mathbf{k}}$

(b) $\frac{\mu_0 I}{4\pi} \frac{\ln 4}{\sqrt{3}a} \hat{\mathbf{k}}$

(c) $\frac{\mu_0 I}{4\pi} \frac{\ln 4}{\sqrt{3}a} (-\hat{\mathbf{k}})$

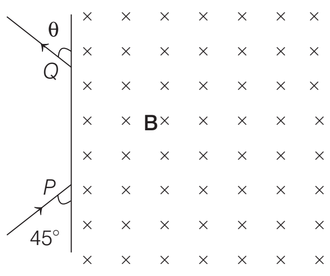
(d) zero

3 A charged particle q enters a region of uniform magnetic field B (out of page) and is deflected a distance d after travelling a horizontal distance a. The magnitude of the momentum of the particle is



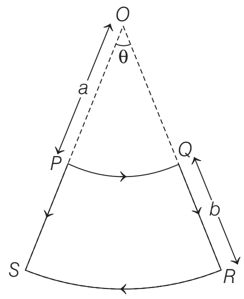
(a) $\frac{qB}{2}\left[\frac{a^2}{d} + d\right]$ (b) $\frac{qB}{2}$ (c) zero (d) $2qB$

4 A particle of mass 1.6×10^{-27} kg and charge 1.6×10^{-19}C enters a uniform magnetic field of 1 T as shown in the figure. The speed of the particle is 10^7 ms^{-1}. The distance PQ will be



(a) 0.141 m (b) 0.28 m (c) 0.4 m (d) 0.5 m

5 The magnetic moment of the current carrying loop as shown in figure, is equal to



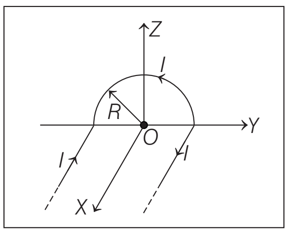
(a) $\frac{I(b^2 + 2ab)\theta}{2}$ (b) $Iab\,\theta$

(c) $\frac{I(a^2 + ba)\theta}{2}$ (d) None of these

6 A coil in the shape of an equilateral triangle of side l is suspended between the pole pieces of a permanent magnet, such that **B** is in plane of the coil. If due to a current I in the triangle, a torque τ acts on it. The side l of the triangle is

(a) $2\left(\frac{\tau}{\sqrt{3}BI}\right)^{1/2}$ (b) $\frac{2}{\sqrt{3}}\left(\frac{\tau}{BI}\right)$ (c) $2\left(\frac{\tau}{BI}\right)^{1/2}$ (d) $\frac{1}{\sqrt{3}}\frac{\tau}{BI}$

7 A wire carrying current I has the shape as shown in adjoining figure. Linear parts of the wire are very long and parallel to X-axis, while semi-circular portion of radius R is lying in YZ-plane. Magnetic field at point O is ➔ CBSE AIPMT 2015



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

(c) $\mathbf{B} = -\frac{\mu_0}{4\pi} \frac{I}{R} (\pi\hat{\mathbf{i}} + 2\hat{\mathbf{k}})$ (d) $\mathbf{B} = \frac{\mu_0}{4\pi} \frac{I}{R} (\pi\hat{\mathbf{i}} - 2\hat{\mathbf{k}})$

8 When a proton is released from rest in a room, it starts with an initial acceleration a_0 towards West. When it is projected towards North with a speed v_0, it moves with an initial acceleration $3a_0$ towards West. The electric and magnetic fields in the room are ➔ NEET 2013

(a) $\frac{ma_0}{e}$ West, $\frac{2ma_0}{ev_0}$ up (b) $\frac{ma_0}{e}$ West, $\frac{2ma_0}{ev_0}$ down

(c) $\frac{ma_0}{e}$ East, $\frac{3ma_0}{ev_0}$ up (d) $\frac{ma_0}{e}$ East, $\frac{3ma_0}{ev_0}$ down

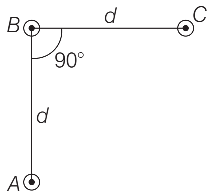
9 Two circular coils 1 and 2 are made from the same wire, but the radius of the 1st coil is twice that of the 2nd coil. What is the ratio of potential difference applied across them, so that the magnetic field at their centres is the same?

(a) 3 (b) 4 (c) 6 (d) 2

10 Current sensitivity of a moving coil galvanometer is 5 div/mA and its voltage sensitivity (angular deflection per unit voltage applied) is 20 div/V. The resistance of the galvanometer is → NEET 2018

(a) 250 Ω (b) 25 Ω
(c) 40 Ω (d) 500 Ω

11 An arrangement of three parallel straight wires placed perpendicular to plane of paper carrying same current I along the same direction is shown in figure. Magnitude of force per unit length on the middle wire B is given by → NEET 2017



(a) $\frac{\mu_0 I^2}{2\pi d}$ (b) $\frac{2\mu_0 I^2}{\pi d}$

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

12 A long straight wire of radius a carries a steady current I. The current is uniformly distributed over its cross-section. The ratio of the magnetic fields **B** and **B′** at radial distances $\frac{a}{2}$ and $2a$ respectively, from the axis of the wire is → NEET 2016

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

(c) 4 (d) $\frac{1}{4}$

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

(a) 1 GHz (b) 100 MHz (c) 62.8 MHz (d) 6.28 MHz

14 An alternating electric field of frequency ν, is applied across the dees (radius $= R$) of a cyclotron, i.e. being used to accelerate protons (mass $= m$). The operating magnetic field (B) used in the cyclotron and the kinetic energy (K) of the proton beam, produced by it, are given by → CBSE AIPMT 2012

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

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

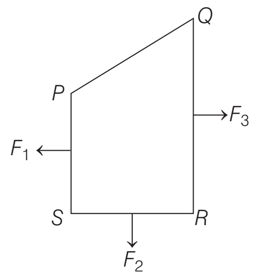
(c) $B = \frac{2\pi m\nu}{e}$ and $K = 2m\pi^2\nu^2R^2$

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

15 A beam of cathode rays is subjected to crossed electric (E) and magnetic fields (B). The fields are adjusted such that the beam is not deflected. The specific charge of the cathode rays is given by → CBSE AIPMT 2010

(a) $\frac{B^2}{2VE^2}$ (b) $\frac{2VB^2}{E^2}$ (c) $\frac{2VE^2}{B^2}$ (d) $\frac{E^2}{2VB^2}$

16 A closed loop $PQRS$ carrying a current is placed in a uniform magnetic field. If the magnetic forces on segments PS, SR and RQ are F_1, F_2 and F_3 respectively and are in the plane of the paper and along the directions shown in figure, the force on the segment QP is



(a) $F_3 - F_1 - F_2$ (b) $\sqrt{(F_3 - F_1)^2 + F_2^2}$
(c) $\sqrt{(F_3 - F_1)^2 - F_2^2}$ (d) $F_3 - F_1 + F_2$

ANSWERS

SESSION 1

1 (b)	**2** (d)	**3** (c)	**4** (a)	**5** (b)	**6** (a)	**7** (a)	**8** (a)	**9** (b)	**10** (a)
11 (a)	**12** (a)	**13** (d)	**14** (a)	**15** (b)	**16** (c)	**17** (b)	**18** (d)	**19** (d)	**20** (b)
21 (a)	**22** (c)	**23** (a)	**24** (d)	**25** (b)	**26** (c)	**27** (b)	**28** (b)	**29** (c)	**30** (d)
31 (b)	**32** (c)	**33** (a)	**34** (c)	**35** (a)	**36** (d)	**37** (d)			

SESSION 2

1 (b)	**2** (a)	**3** (a)	**4** (a)	**5** (a)	**6** (a)	**7** (c)	**8** (b)	**9** (b)	**10** (a)
11 (d)	**12** (b)	**13** (a)	**14** (c)	**15** (d)	**16** (b)				

Hints and Explanations

1 $\therefore$ Torque, $\tau = NBIA$

$= 100 \times 1 \times 1 \times 0.2 \times 0.1 = 2$ N-m

2 For parallel magnetic field is stable and for anti-parallel is unstable.

3 $\therefore$ Radius of circular path,

$$R = \frac{mv}{Bq_0} = \frac{v}{B}\frac{1}{q_0/M}$$

$$= 2 \times 10^5 / 0.05 \times 2.5 \times 10^7$$

$$= 0.16 \text{ m} = 16 \text{ cm}$$

4 Force, $F = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r}l$

Here, $I_1 = 5$ A, $I_2 = 2$A, $l = 5$m,

$r = 20$ cm $= 0.2$ m

Hence,

$$F = 10^{-7} \times \frac{2 \times 5 \times 2 \times 5}{0.2} = 5 \times 10^{-5} \text{ N}$$

5 Frequency, $n = \frac{Bq}{2\pi m}$

$$\text{or } B = \frac{2\pi n}{\left(\frac{q}{m}\right)} = \frac{2 \times 3.14 \times 5 \times 10^6}{96 \times 10^6}$$

$$= 0.327 \text{ Wbm}^{-2} = 0.327 \text{ T}$$

6 Inside the tube, the magnetic field is zero.

7 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

$$\mathbf{B} = \frac{\mu_0}{4\pi}\frac{q(\mathbf{v} \times \mathbf{r})}{r^3} \text{ or } B = \frac{\mu_0}{4\pi}\frac{v\sin\theta}{r^2}.$$

The direct $\mathbf{B}$ 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.

8 Magnetic field on the axis of circular coil is $= \frac{\mu_0}{4\pi}\frac{2\pi IR^2}{(R^2 + x^2)^{3/2}}$

where, R is the radius of the coil and x is the distance of the observation point. At the far away point $x >> R$, so R^2 may be neglected as compared to x^2. Hence, magnetic field is related to x as, $B \propto x^{-3}$.

9 Radius of the double loop $r = \frac{R}{2}$, where R is the radius of single loop B (centre)

$$= \frac{\mu_0}{4\pi}\frac{2\pi I}{R}.$$

So, magnetic field due to each coil is double of that due to single coil. And total magnetic field is $2B + 2B = 4B$.

10 The magnetic field (B) at the centre of circular current carrying coil of radius R and current I is $B = \frac{\mu_0 I}{2R}$

Similarly, if current is $2I$, then

$$\text{Magnetic field} = \frac{\mu_0 2I}{2R} = 2B$$

So, resultant magnetic field

$$= \sqrt{B^2 + (2B)^2} = \sqrt{5B^2} = \sqrt{5}B = \sqrt{5}\frac{\mu_0 I}{2R}$$

11 $\therefore$ Ampere's law, $\oint B \cdot dl = \mu_0 I$

$$\text{or } \oint B \cdot dl = 4\pi \times 10^{-7} \times 4 \times 10^{-3}$$

$$= 1.6\ \pi \times 10^{-9} \text{ Wbm}^{-2}$$

12 Magnetic Lorentz force, $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$

$$= -2 \times 10^{-6}\{(2\hat{\mathbf{i}} + 3\hat{\mathbf{j}}) \times 10^6 \times 2\hat{\mathbf{j}}\}$$

$$= -2 \times 10^{-6}[2 \times 2 \times 10^6 \hat{\mathbf{k}}]$$

$= 8$ N along negative z-direction

13 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

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

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 uniform velocity along the axis of the solenoid.

14 Magnetic field (B) will not apply any force. Only electric field $\mathbf{E}$ will apply a force opposite to velocity of the electron, hence speed decreases.

15 $\therefore$ Force, $F = qvB = \frac{mv^2}{R}$

$$\text{or } B = \frac{v}{\left(\frac{q}{m}\right)R} = \frac{1.92 \times 10^7}{9.6 \times 10^7 \times 6.4 \times 10^6}$$

$$= 3.12 \times 10^{-8} \text{ T}$$

16 When a charged particle q is moving in a uniform magnetic field $\mathbf{B}$ with velocity $\mathbf{v}$ such that angle between $\mathbf{v}$ and $\mathbf{B}$ be θ, the charge q experiences a force which is given by

$$F = qvB\sin\theta$$

If $\theta = 0°$ or $180°$, then $\sin\theta = 0$

$\therefore$ $F = qvB\sin\theta = 0$

Since, force on charged particle is non-zero, so angle between $\mathbf{v}$ and $\mathbf{B}$ can have any value other than zero and 180°.

17 $\therefore$ Magnetic field,

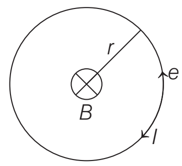
$$B = 4\left[\frac{\mu_0}{4\pi}\frac{I}{a}(\sin\phi_1 + \sin\phi_2)\right]$$

$$= 4 \times \frac{\mu_0}{4\pi}\frac{I}{(l/2)}\left[\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}\right]$$

[Here, $\phi_1 = \phi_2 = 45°$]

$$= 8\sqrt{2}\left[\frac{\mu_0}{4\pi}\frac{I}{l}\right]$$

18 Current, $I = \frac{e}{T}$



$$I = \frac{e}{(2\pi/\omega)} = \frac{\omega e}{2\pi}$$

$$= \frac{(2\pi n)e}{2\pi} = ne$$

Magnetic field,

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

19 Each arm acts as a chord. Its distance from the centre is $d = R\cos\frac{\pi}{3} = \frac{R}{2}$.

Magnetic field due to each chord

$$= \frac{\mu_0}{4\pi}\frac{I}{d}\left[\sin\frac{\pi}{3} + \sin\frac{\pi}{3}\right]$$

$$= \frac{\mu_0}{4\pi}\frac{2I}{R} \times \sqrt{3}$$

$$\text{Total magnetic field} = 6\left[\frac{\mu_0}{4\pi}\frac{2I}{R}\sqrt{3}\right]$$

$$= \frac{\mu_0}{4\pi}\frac{12I}{R}\sqrt{3}$$

20 Distance of straight part from $O = l = \frac{r}{\sqrt{2}}$.

Hence,

$$B = B_1 + B_2$$

$$= \frac{\mu_0}{4\pi}\frac{2I}{r/\sqrt{2}} + \frac{\mu_0}{4\pi}\frac{2\pi I}{r}\left(\frac{1}{4}\right)$$

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

21 The magnetic field at a point outside the straight conductor is given by

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

It means $B \propto \frac{1}{r}$ [if, $r > a$] [hyperbola]

The magnetic field at a point inside the conductor is

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

or $B \propto r$ [if, $r < a$] [straight line]

22 The magnetic force in a uniform field is

$$\mathbf{F} = I(\mathbf{l} \times \mathbf{B})$$
$$I = 4\hat{\mathbf{i}} + 4\hat{\mathbf{j}} + 4\hat{\mathbf{k}}$$
$$B = (1.2\hat{\mathbf{i}} + 2\hat{\mathbf{j}}) \times 10^{-4} \text{ T}$$
$$\mathbf{F} = 8 \times 10^{-4} [(\hat{\mathbf{i}} + \hat{\mathbf{j}} + \hat{\mathbf{k}}) \times (1.2\hat{\mathbf{i}} + 2\hat{\mathbf{j}})] \text{ N}$$

23 Force on AB is given by

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

According to the question,

$$\mathbf{F}_{AB} = 0$$
$$\mathbf{F}_{AB} + \mathbf{F}_{BC} + \mathbf{F}_{CA} = 0$$
$$\mathbf{F}_{BC} + \mathbf{F}_{CA} = 0$$
$$\mathbf{F}_{CA} = -\mathbf{F}_{BC} = -\mathbf{F}$$

24 In a uniform magnetic field, the two charged particles will traverse identical helical paths in a completely opposite sense, if the charge/mass ratio of these two particles is same and charges on them are of opposite character. In this situation, $(e/m)_1 + (e/m)_2 = 0$, holds good.

25 If the loop is placed in a uniform magnetic field, then net magnetic force on the loop is zero.

$\therefore$ Magnetic force = Magnetic force due to loop –

Magnetic force on the line segment

$$= 0 - IlB = -5 \times 0.5 \times 10 \times 10^{-2}$$
$$= -0.25 \text{ N}$$

Since, magnetic force on the line segment is parallel to BC. So, magnetic force on the curve section is unlike parallel to BC.

26 The time period of electron moving in a circular orbit,

$$T = \frac{\text{Circumference of circular path}}{\text{Speed}} = \frac{2\pi r}{v}$$

and equivalent current due to electron flow,

$$I = \frac{e}{T} = \frac{e}{(2\pi r/v)} = \frac{ev}{2\pi r}$$

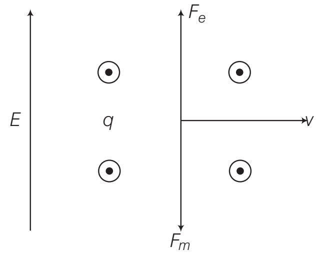
Magnetic field at centre of circle,

$$B = \frac{\mu_0 I}{2r} = \frac{\mu_0 ev}{4\pi r^2}$$
$$\Rightarrow \quad r \propto \sqrt{\frac{v}{B}}$$

27 Magnetic field,

$$B = \frac{\mu_0}{4\pi}\frac{2\pi}{R} I = \frac{\mu_0}{4\pi} \times 2\pi \frac{e}{t} \times \frac{1}{R}$$
$$= \frac{\mu_0}{4\pi} \times 2\pi \times \frac{e}{2\pi R/v} \times \frac{1}{R}$$
$$= \frac{\mu_0}{4\pi} \times 2\pi \times \frac{ev}{2\pi R^2} = \frac{\mu_0}{4\pi}\frac{e\omega}{R^2}$$
$$\therefore \omega = 2.2 \times 10^6 \text{ rads}^{-1}$$

28 If both electric and magnetic fields are present and perpendicular to each other; and the particle is moving perpendicular to both of them with $F_e = F_m$. In this situation, $\mathbf{E} \neq 0$ and $\mathbf{B} \neq 0$.



But, if electric field becomes zero, then only force due to magnetic field exists. Under this force, the charge moves along a circle.

29 Magnetic field at the centre due to either arm,

$$B_1 = \frac{\mu_0}{4\pi} \times \frac{I}{\left(\frac{L}{2}\right)}[\sin 45° + \sin 45°]$$
$$= \frac{\mu_0}{4\pi} \times \frac{2\sqrt{2}I}{L}$$

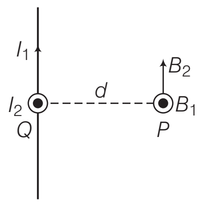
Field at centre due to the four arms of the square,

$$B = 4B_1 = \frac{\mu_0}{\pi} \times \frac{2\sqrt{2}I}{L}$$

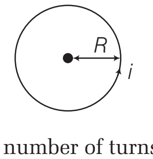
i.e. $\quad B \propto \frac{1}{L}.$

30 Magnetic field,

$$B = \sqrt{B_1^2 + B_2^2}$$
$$= \frac{\mu_0}{2\pi d}(I_1^2 + I_2^2)^{1/2}$$



31 $$B_{\text{centre}} = \frac{n \cdot \mu_0 i}{2R} \quad \text{(for a circular coil)}$$



where, n = number of turns in circular coil

$$B = \frac{\mu_0 i}{2R} = \frac{\mu_0 \pi i}{l}$$
$$= \frac{\mu_0 n i}{2\left(\frac{l}{2n\pi}\right)} = \frac{n^2 \mu_0 \pi i}{l} = n^2 B$$

32 Wires placed close to each other carry current in the same direction and hence attract. Wires placed far apart carry current in opposite direction and hence repel each other. But here attraction is strong and repulsion is weak. So, loop moves towards the wire.

33 Centripetal force = Magnetic force

i.e.

$$\frac{mv^2}{r} = q_0 vB, \text{ hence } r = \frac{mv}{q_0 B} = \frac{2mE}{q_0 B}$$

where, E is the energy of the particle. Mass of α-particle is 4 times that of proton and charge is 2 times that of proton.

34 When magnetic field is perpendicular to motion of charged particle, then centripetal force = magnetic force

i.e. $$\frac{mv^2}{R} = Bqv \text{ or } R = \frac{mv}{Bq}$$

Further, time period of the motion,

$$T = \frac{2\pi R}{v} = \frac{2\pi\left(\frac{mv}{Bq}\right)}{v}$$

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

So, the time period of the motion is independent on both R and v.

35 Work done for rotating the coil,

$$W = MB(\cos\theta_1 - \cos\theta_2)$$

where, M = magnetic moment

and B = magnetic field.

Given, $\theta_1 = 0°, \theta_2 = 180°$

$$\therefore \quad W = MB(\cos 0° - \cos 180°)$$
$$= 2MB = 2 \times NIA \times B$$
$$= 2 \times 250 \times 85 \times 10^{-6} \times (2.1 \times 1.25 \times 10^{-4}) \times 0.85$$
$$= 9.48 \times 10^{-6} \text{ J}$$
$$\approx 9.5 \times 10^{-6} \text{ J} = 9.5 \mu\text{J}$$

The closest option is (a).

36 Sensitivity of a galvanometer is directly proportional to the current through it.

When a shunt resistance, $S = \left(\frac{G}{10}\right)$ is applied to galvanometer of resistance G, then current through galvanometer I_g can be written as

$$I_g G = (I - I_g)S = \frac{(I - I_g)G}{10}$$

or $$I_g = \frac{(I - I_g)}{10}$$

or $$10 I_g = I - I_g$$

$$11 I_g = I, \; I_g = \frac{I}{11}$$

37 The magnetic field at the centre of the circle is

$$B = \frac{\mu_0}{4\pi} \times \frac{2\pi I}{R} \quad \ldots(i)$$

Since, $q = It$

On multiplying and dividing by t, we get

$$B = \frac{\mu_0}{4\pi} \times \frac{2\pi I t}{Rt} \Rightarrow B = \frac{\mu_0}{4\pi} \times \frac{2\pi \times q}{Rt}$$

Also, f = frequency $= \frac{1}{t}$

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

SESSION 2

1 Torque, $\tau = MB \sin\theta$

$\therefore \quad \tau_1 = MB_1 \sin 90° = MB_1$

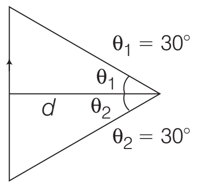
and $\quad \tau_2 = MB_2 \sin 90° = MB_2$

or $\quad \frac{MB_1}{MB_2} = \frac{\tau_1}{\tau_2}$

$\therefore \quad \frac{B_1}{B_2} = \frac{\tau_1}{\tau_2}$

2 Magnetic field due to straight wire is

$$B = \frac{\mu_0 I}{4\pi d} [\sin\theta_1 + \sin\theta_2]$$



$\therefore \quad \mathbf{B} = \mathbf{B}_1 + \mathbf{B}_2 + \ldots$

$\mathbf{B} = \mathbf{B}_1\hat{\mathbf{k}} + \mathbf{B}_2(-\hat{\mathbf{k}}) + \mathbf{B}_3\hat{\mathbf{k}} + \ldots$

$\mathbf{B} = \mathbf{B}_1 - \mathbf{B}_2 + \mathbf{B}_3 - \mathbf{B}_4 + \ldots$

$$\mathbf{B} = \frac{\mu_0 I}{16\pi d}\left[1 - \frac{1}{2} + \frac{1}{3} - \frac{1}{4} + \ldots\right]$$

$$\cos 30° = \frac{d}{a} \Rightarrow d = a\cos 30° = \frac{\sqrt{3}}{2} a$$

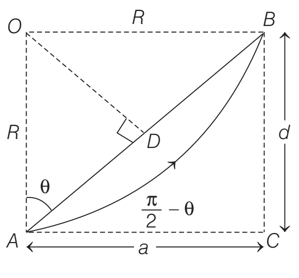
$$B = \frac{\mu_0 I \times 2}{16\pi\sqrt{3}\, a} \ln 2\hat{\mathbf{k}} \Rightarrow B = \frac{\mu_0 I \ln 2}{8\pi\sqrt{3} a}\hat{\mathbf{k}}$$

3 Hypotenuse, $AB = \sqrt{a^2 + d^2} = h$

In ΔOAD, $\cos\theta = \frac{h}{2R}$

In ΔACB, $\sin\left(\frac{\pi}{2} - \theta\right) = \frac{d}{h} \Rightarrow \frac{h}{2R} = \frac{d}{h}$

$\Rightarrow \quad h^2 = 2Rd \Rightarrow a^2 + d^2 = 2Rd$



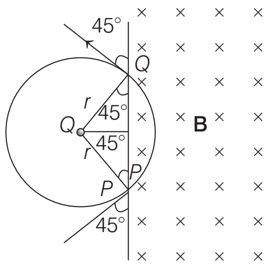
$$\Rightarrow \quad R = \frac{a^2}{2d} + \frac{d}{2}$$

$\therefore$ Momentum,

$$p = mv = qBR = \frac{qB}{2}\left(\frac{a^2}{d} + d\right)$$

4 Magnetic force = Centripetal force,

i.e. $\quad qvB = \frac{mv^2}{r}$ or $r = \frac{mv}{qB}$



$$PQ = 2r\cos 45° = \sqrt{2} \times r = \sqrt{2}\,\frac{mv}{qB}$$

$$= \frac{1.41 \times 1.6 \times 10^{-27} \times 10^{7}}{1.6 \times 10^{-19} \times 1} = 0.141 \text{ m}$$

5 Magnetic moment, $M = IA = I(A_2 - A_1)$

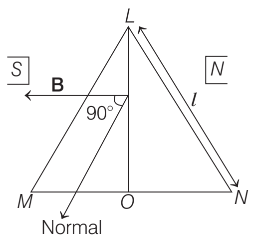
$$\Rightarrow \quad M = I\left\{\frac{(a+b)^2}{2}\theta - \frac{a^2}{2}\theta\right\}$$

$$= I\left\{\frac{(b^2 + 2ab)}{2}\theta\right\}$$

6 Torque acting on equilateral triangle in a magnetic field **B** is $\tau = IAB\sin\theta$

Area of ΔLMN, $A = \frac{\sqrt{3}}{4} l^2$ and $\theta = 90°$

Substituting the given values in the expression for torque, we have



$$\tau = I \times \frac{\sqrt{3}}{4} l^2 B \sin 90°$$

$$= \frac{\sqrt{3}}{4} Il^2 B \quad [\because \sin 90° = 1]$$

Hence, $\quad l = 2\left(\frac{\tau}{\sqrt{3}\, BI}\right)^{1/2}$

7 $\therefore B_{\text{I}} = \frac{\mu_0}{4\pi}\frac{I}{R}(-\hat{\mathbf{k}})$,

$B_{\text{III}} = \frac{\mu_0}{4\pi}\frac{I}{R}(-\hat{\mathbf{k}})$,

$B_{\text{II}} = \frac{\mu_0 I}{4R}(-\hat{\mathbf{i}})$

Net magnetic field,

$$B = B_{\text{I}} + B_{\text{II}} + B_{\text{III}}$$

$$B = \frac{\mu_0 I}{4R\pi}(-2\hat{\mathbf{k}} - \pi\hat{\mathbf{i}})$$

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

8 Initial acceleration, $a_0 = \frac{eE}{m} \quad \ldots(i)$

$\therefore$ Electric field, $E = \frac{a_0 m}{e}$ West

$\therefore \quad \frac{ev_0 B + eE}{m} = 3a_0$

or $ev_0 B + eE = 3a_0 m$

$\therefore \quad ev_0 B = 3ma_0 - eE$

$\Rightarrow \quad ev_0 B = 3ma_0 - ma_0 \quad$ [from Eq. (i)]

$\Rightarrow \quad ev_0 B = 2ma_0$

$\therefore$ Magnetic field, $B = \frac{2ma_0}{ev_0}$ down

9 Magnetic field at the centre of circular coil is

$$B = \frac{\mu_0}{4\pi} \times \frac{2\pi I}{r}$$

where, I is current flowing in the coil and r is radius of coil.

At the centre of coil1,

$$B_1 = \frac{\mu_0}{4\pi} \times \frac{2\pi I_1}{r_1} \quad \ldots(i)$$

At the centre of coil 2,

$$B_2 = \frac{\mu_0}{4\pi} \times \frac{2\pi I_2}{r_2} \quad \ldots(ii)$$

But $B_1 = B_2$

$\therefore \quad \frac{\mu_0}{4\pi}\frac{2\pi I_1}{r_1} = \frac{\mu_0}{4\pi}\frac{2\pi I_2}{r_2}$ or $\frac{I_1}{r_1} = \frac{I_2}{r_2}$

As, $\quad r_1 = 2r_2$

$\therefore \quad \frac{I_1}{2r_2} = \frac{I_2}{r_2}$ or $I_1 = 2I_2 \quad \ldots(iii)$

Now, ratio of potential differences,

$$\frac{V_2}{V_1} = \frac{I_2 \times r_2}{I_1 \times r_1} = \frac{I_2 \times r_2}{2I_2 \times 2r_2} = \frac{1}{4}$$

$\therefore \quad \frac{V_1}{V_2} = \frac{4}{1}$

10 Current sensitivity of a moving coil galvanometer is the deflection (θ) per unit current (I) flowing through it, i.e.

$$I_S = \frac{\theta}{I} = \frac{NAB}{k} \quad \ldots(i)$$

where,

N = number of turns in the coil,

A = area of each turn of coil,

B = magnetic field

and k = restoring torque per unit twist of the fibre strip.

Similarly, voltage sensitivity is the deflection per unit voltage, i.e.

$$V_S = \frac{\theta}{V} = \left(\frac{NAB}{k}\right)\frac{I}{V} = \frac{NAB}{kR_G} \quad \ldots(ii)$$

where, R_G is the resistance of the galvanometer.

From Eqs. (i) and (ii), we get

$$R_G = \frac{I_S}{V_S} \quad \ldots\text{(iii)}$$

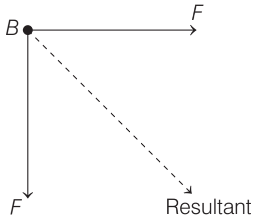
Here, $I_S = 5\,\text{div/mA} = 5 \times 10^{-3}$ div/A

and $V_S = 20$ div/V

Substituting the given values in Eq. (iii), we get $R_G = \frac{5 \times 10^3}{20} = 250$

$\therefore$ The resistance of the galvanometer is 250 Ω.

11 As force on wire B due to A and C are attractive, so we have following condition



$$F = \frac{\mu_0 I^2}{2\pi d}$$

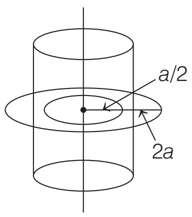
Resultant force on

$$B = \sqrt{F_1^2 + F_2^2}$$

$$= \sqrt{2}\, F = \sqrt{2} \times \frac{\mu_0 I^2}{2\pi d}$$

$$= \frac{\mu_0 I^2}{\sqrt{2}\pi d}$$

12 Consider two amperian loops of radius $\frac{a}{2}$ and $2a$ as shown in the figure.



Applying Ampere's circuital law for these loops, we get

$$\oint \mathbf{B} \cdot dL = \mu_0 I_{\text{enclosed}}$$

For the smaller loop,

$$B \times 2\pi \frac{a}{2} = \mu_0 \times \frac{I}{\pi a^2} \times \pi \left(\frac{a}{2}\right)^2$$

$$= \mu_0 I \times \frac{1}{4} = \frac{\mu_0 I}{4}$$

$\Rightarrow$ $B_I = \frac{\mu_0 I}{4\pi a}$, at distance $\frac{a}{2}$ from the axis of the wire.

Similarly, for bigger amperian loop, $B' \times 2\pi\,(2a) = \mu_0 I$ [total current enclosed by Amperian loop is 2]

$$\Rightarrow \quad B' = \frac{\mu_0 I}{4\pi a},$$

At distance $2a$ from the axis of the wire.

So, ratio of, $\frac{B}{B'} = \frac{\mu_0 I}{4\pi a} \times \frac{4\pi a}{\mu_0 I} = 1$

13 As we know that, radius of a charged particle in a magnetic field B is given by

$$r = \frac{mv}{qB} \quad \ldots\text{(i)}$$

where, r = charge on the particle

and v = speed of the particle.

$\therefore$ The time taken to complete the circle,

$$T = \frac{2\pi r}{v}$$

$$\Rightarrow \quad \frac{T}{2\pi} = \frac{m}{qB} \quad \text{[from Eq. (i)]}$$

$$\therefore \quad \omega = \frac{2\pi}{T} = \frac{qB}{m}$$

$$\because \quad q = e \text{ and } \frac{e}{m} = 1.76 \times 10^{11}\ \text{C/kg}$$

$$B = 3.57 \times 10^{-2}\ \text{T}$$

$$\Rightarrow \quad \frac{2\pi}{T} = \frac{eB}{m}\ f = \frac{1}{2\pi}\frac{e}{m}B \quad \left(\because \frac{1}{T} = f\right)$$

$$= \frac{1}{2\pi} \times 1.76 \times 10^{11} \times 3.57 \times 10^{-2}$$

$$= 1.0 \times 10^9\ \text{Hz} = 1\ \text{GHz}$$

14 Frequency, $\nu = \frac{eB}{2\pi m}$

KE $= \frac{1}{2} m\nu^2$ and radius $R = \frac{m\nu}{eB}$

Here, velocity, $v = \frac{\pi R}{T/2} = \frac{2\pi R}{T} = 2\pi R\nu$

$\therefore$ Radius, $R = \frac{m(2\pi R\nu)}{eB}$

Magnetic field, $B = \frac{2\pi m\nu}{e}$

Kinetic energy, $K = \frac{1}{2} m (2\pi R\nu)^2$

$$= 2 m\pi^2 \nu^2 R^2$$

15 As the electron beam is not deflected, then

$$F_m = F_e \quad \text{or} \quad Bev = Ee$$

$$\text{or} \quad v = \frac{E}{B} \quad \ldots\text{(i)}$$

As the electron moves from cathode to anode, its potential energy at the cathode appears as its kinetic energy at the anode. If V is the potential difference between the anode and cathode, then potential energy of the electron at cathode $= eV$. Also, kinetic energy of the electron at anode $= \frac{1}{2} mv^2$.

According to law of conservation of energy,

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

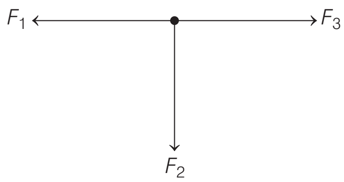
$$\text{or} \quad v = \sqrt{\frac{2eV}{m}} \quad \ldots\text{(ii)}$$

From Eqs. (i) and (ii), we have

$$\sqrt{\frac{2eV}{m}} = \frac{E}{B}$$

$$\text{or} \quad \frac{e}{m} = \frac{E^2}{2VB^2}$$

16 As the net force on closed loop is equal to zero. So, force on QP will be equal and opposite to sum of forces on other three sides.



So, from vector laws,

$$F_{QP} = \sqrt{(F_3 - F_1)^2 + F_2^2}$$