CHAPTER

4

Moving Charges and Magnetism

CASE STUDY / PASSAGE BASED QUESTIONS

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.

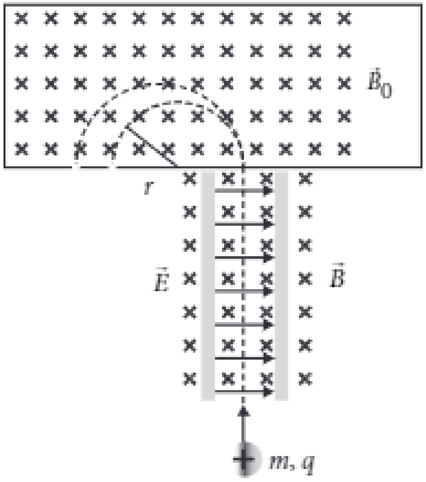
Questions 1-10 are Case Study based questions and are compulsory. Attempt any 4 sub parts from each question. Each question carries 1 mark.

1

Mass Spectrometer

Various methods can be used to measure the mass of an atom. One possibility is through the use of a mass spectrometer. The basic feature of a Banbridge mass spectrometer is illustrated in figure. A particle carrying a charge $+q$ is first sent through a velocity selector and comes out with velocity $v = E/B$.

The applied electric and magnetic fields satisfy the relation $E = vB$ so that the trajectory of the particle is a straight line. Upon entering a region where a second magnetic field $\vec{B}_0$ pointing into the page has been applied, the particle will move in a circular path with radius r and eventually strike the photographic plate.



(i) In mass spectrometer, the ions are sorted out in which of the following ways?

(a) By accelerating them through electric field.

(b) By accelerating them through magnetic field.

(c) By accelerating them through electric and magnetic field.

(d) By applying a high voltage.

(ii) Radius of particle in second magnetic field B_0 is

(a) $\dfrac{2mv}{qE_0}$ (b) $\dfrac{mv}{qE_0}$ (c) $\dfrac{mv}{qB_0}$ (d) $\dfrac{2mE_0v}{qB_0}$

(iii) Which of the following will trace a circular trajectory with largest radius?

(a) Proton (b) α-particle (c) Electron

(d) A particle with charge twice and mass thrice that of electron.

(iv) Mass of the particle in terms q, B_0, B, r and E is

(a) $\frac{qBr}{E}$ (b) $\frac{qB_0Br}{E}$ (c) $\frac{qBr}{EB_0}$ (d) $\frac{qBrE}{B_0}$

(v) The particle comes out of velocity selector along a straight line, because

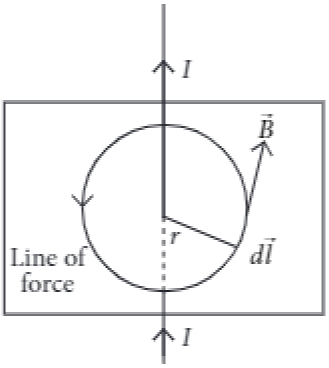
(a) electric force is less than magnetic force (b) electric force is greater than magnetic force

(c) electric and magnetic force balance each other (d) can't say.

2

Ampere's Circuital Law

Ampere's law gives a method to calculate the magnetic field due to given current distribution. According to it, the circulation $\oint \vec{B}\cdot d\vec{l}$ of the resultant magnetic field along a closed plane curve is equal to μ_0 times the total current crossing the area bounded by the closed curve provided the electric field inside the loop remains constant. Ampere's law is more useful under certain symmetrical conditions. Consider one such case of a long Straight wire with circular cross-section (radius R) carrying current I uniformly distributed across this cross-section.



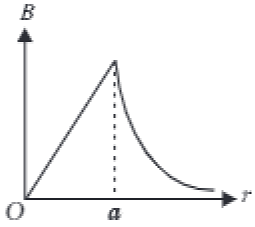
(i) The magnetic field at a radial distance r from the centre of the wire in the region $r > R$, is

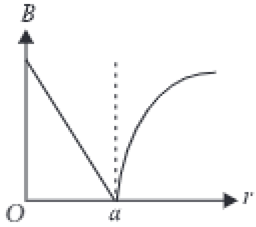
(a) $\frac{\mu_0 I}{2\pi r}$ (b) $\frac{\mu_0 I}{2\pi R}$ (c) $\frac{\mu_0 IR^2}{2\pi r}$ (d) $\frac{\mu_0 Ir^2}{2\pi R}$

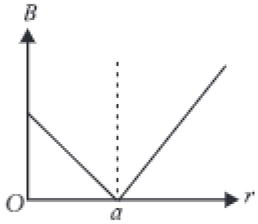
(ii) The magnetic field at a distance r in the region $r < R$ is

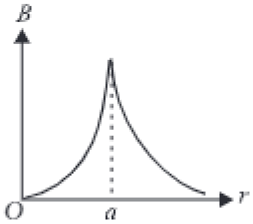
(a) $\frac{\mu_0 I}{2r}$ (b) $\frac{\mu_0 Ir^2}{2\pi R^2}$ (c) $\frac{\mu_0 I}{2\pi r}$ (d) $\frac{\mu_0 Ir}{2\pi R^2}$

(iii) A long straight wire of a circular cross section (radius a) carries a steady current I and the current I is uniformly distributed across this cross-section. Which of the following plots represents the variation of magnitude of magnetic field B with distance r from the centre of the wire?

(a)


(b)


(c)


(d)


(iv) A long straight wire of radius R carries a steady current I. The current is uniformly distributed across its cross-section. The ratio of magnetic field at $R/2$ and $2R$ is

(a) $\frac{1}{2}$
(b) 2
(c) $\frac{1}{4}$
(d) 1

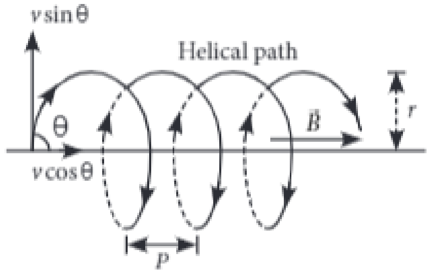
(v) A direct current I flows along the length of an infinitely long straight thin walled pipe, then the magnetic field is

(a) uniform throughout the pipe but not zero
(b) zero only along the axis of the pipe
(c) zero at any point inside the pipe
(d) maximum at the centre and minimum at the edges.

3

Helical Motion

The path of a charged particle in magnetic field depends upon angle between velocity and magnetic field.
If velocity $\vec{v}$ is at angle θ to $\vec{B}$, component of velocity parallel to magnetic field ($v \cos \theta$) remains constant and component of velocity perpendicular to magnetic field ($v \sin\theta$) is responsible for circular motion, thus the charge particle moves in a helical path.



The plane of the circle is perpendicular to the magnetic field and the axis of the helix is parallel to the magnetic field. The charged particle moves along helical path touching the line parallel to the magnetic field passing through the starting point after each rotation.

Radius of circular path is $r = \dfrac{mv\sin\theta}{qB}$

Hence the resultant path of the charged particle will be a helix, with its axis along the direction of $\vec{B}$ as shown in figure.

(i) When a positively charged particle enters into a uniform magnetic field with uniform velocity, its trajectory can be (i) a straight line (ii) a circle (iii) a helix.

(a) (i) only
(b) (i) or (ii)
(c) (i) or (iii)
(d) any one of (i), (ii) and (iii)

(ii) Two charged particles A and B having the same charge, mass and speed enter into a magnetic field in such a way that the initial path of A makes an angle of 30° and that of B makes an angle of 90° with the field. Then the trajectory of

(a) B will have smaller radius of curvature than that of A
(b) both will have the same curvature
(c) A will have smaller radius of curvature than that of B
(d) both will move along the direction of their original velocities.

(iii) An electron having momentum 2.4×10^{-23} kg m/s enters a region of uniform magnetic field of 0.15 T. The field vector makes an angle of 30° with the initial velocity vector of the electron. The radius of the helical path of the electron in the field shall be

(a) 2 mm (b) 1 mm (c) $\frac{\sqrt{3}}{2}$ mm (d) 0.5 mm

(iv) The magnetic field in a certain region of space is given by $\vec{B} = 8.35 \times 10^{-2}\hat{i}$ T. A proton is shot into the field with velocity $\vec{v} = (2 \times 10^5 \hat{i} + 4 \times 10^5 \hat{j})$ m/s. The proton follows a helical path in the field. The distance moved by proton in the x-direction during the period of one revolution in the yz-plane will be
(Mass of proton = 1.67×10^{-27} kg)

(a) 0.053 m (b) 0.136 m (c) 0.157 m (d) 0.236 m

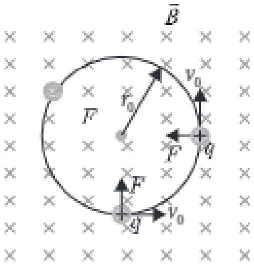
(v) The frequency of revolution of the particle is

(a) $\frac{m}{qB}$ (b) $\frac{qB}{2\pi m}$ (c) $\frac{2\pi R}{v\cos\theta}$ (d) $\frac{2\pi R}{v\sin\theta}$

4

Motion of Charge in Magnetic Field

An electron with speed $v_0 << c$ moves in a circle of radius r_0 in a uniform magnetic field. This electron is able to traverse a circular path as magnetic field is perpendicular to the velocity of the electron. A force acts on the particle perpendicular to both $\vec{v}_0$ and $\vec{B}$. This force continuously deflects the particle sideways without changing its speed and the particle will move along a circle perpendicular to the field. The time required for one revolution of the electron is T_0.



(i) If the speed of the electron is now doubled to $2v_0$. The radius of the circle will change to

(a) $4r_0$ (b) $2r_0$ (c) r_0 (d) $r_0/2$

(ii) If $v_0 = 2v_0$, then the time required for one revolution of the electron will change to

(a) $4T_0$ (b) $2T_0$ (c) T_0 (d) $T_0/2$

(iii) A charged particles is projected in a magnetic field $\vec{B} = (2\hat{i} + 4\hat{j}) \times 10^2$ T. The acceleration of the particle is found to be $\vec{a} = (x\hat{i} + 2\hat{j})$ m s^{-2}. Find the value of x.

(a) 4 m s^{-2} (b) –4 m s^{-2} (c) –2 m s^{-2} (d) 2 m s^{-2}

(iv) If the given electron has a velocity not perpendicular to B, then trajectory of the electron is

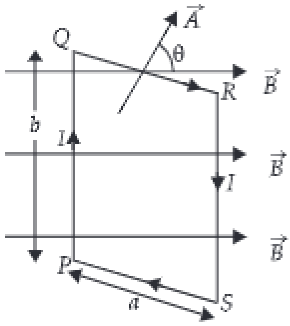
(a) straight line (b) circular (c) helical (d) zig-zag

(v) If this electron of charge (e) is moving parallel to uniform magnetic field with constant velocity v, the force acting on the electron is

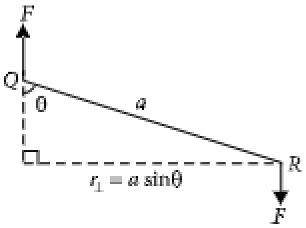
(a) Bev (b) $\frac{Be}{v}$ (c) $\frac{B}{ev}$ (d) zero

Torque on a Rectangular Loop Placed in Uniform Magnetic Field

When a rectangular loop *PQRS* of sides '*a*' and '*b*' carrying current *I* is placed in uniform magnetic field $\vec{B}$, such that area vector $\vec{A}$ makes an angle θ with direction of magnetic field, then forces on the arms *QR* and *SP* of loop are equal, opposite and collinear, thereby perfectly cancel each other, whereas forces on the arms *PQ* and *RS* of loop are equal and opposite but not collinear, so they give rise to torque on the loop.



Force on side *PQ* or *RS* of loop is $F = IbB \sin 90° = Ib\,B$ and perpendicular distance between two non-collinear forces is $r_{\perp} = a \sin \theta$



So, torque on the loop, $\tau = IAB \sin \theta$

In vector form torque, $\vec{\tau} = \vec{M} \times \vec{B}$

where $\vec{M} = NI\vec{A}$ is called magnetic dipole moment of current loop and is directed in direction of area vector $\vec{A}$ *i.e.*, normal to the plane of loop.

(i) A circular loop of area 1 cm^2, carrying a current of 10 A is placed in a magnetic field of 0.1 T perpendicular to the plane of the loop. The torque on the loop due to the magnetic field is

(a) zero (b) 10^{-4} N m (c) 10^{-2} N m (d) 1 N m

(ii) Relation between magnetic moment and angular velocity is

(a) $M \propto \omega$ (b) $M \propto \omega^2$ (c) $M \propto \sqrt{\omega}$ (d) none of these

(iii) A current loop in a magnetic field

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

(iv) The magnetic moment of a current *I* carrying circular coil of radius *r* and number of turns *N* varies as

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

(v) A rectangular coil carrying current is placed in a non-uniform magnetic field. On that coil the total

(a) force is non-zero (b) force is zero (c) torque is zero (d) none of these

6

Biot Savart Law

A magnetic field can be produced by moving, charges or electric currents. The basic equation governing the magnetic field due to a current distribution is the Biot-Savart law.

Finding the magnetic field resulting from a current distribution involves the vector product, and is inherently a calculas problem when the distance from the current to the field point is continuously changing.

According to this law, the magnetic field at a point due to a current element of length $d\vec{l}$ carrying current I, at a distance r from the element is $dB = \frac{\mu_0}{4\pi}\frac{I(d\vec{l}\times\vec{r})}{r^3}$.

Biot-Savart law has certain similarities as well as difference with Coloumb's law for electrostatic field *e.g.*, there is an angle dependence in Biot-Savart law which is not present in electrostatic case.

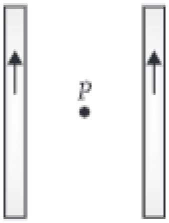
(i) The direction of magnetic field $d\vec{B}$ due to a current element $Id\vec{l}$ at a point of distance $\vec{r}$ from it, when a current I passes through a long conductor is in the direction

(a) of position vector $\vec{r}$ of the point
(b) of current element $d\vec{l}$
(c) perpendicular to both $d\vec{l}$ and $\vec{r}$
(d) perpendicular to $d\vec{l}$ only

(ii) The magnetic field due to a current in a straight wire segment of length L at a point on its perpendicular bisector at a distance r ($r >> L$)

(a) decreases as $\frac{1}{r}$.
(b) decreases as $\frac{1}{r^2}$.
(c) decreases as $\frac{1}{r^3}$.
(d) approaches a finite limit as $r \rightarrow \infty$

(iii) Two long straight wires are set parallel to each other. Each carries a current i in the same direction and the separation between them is $2r$. The intensity of the magnetic field midway between them is



(a) $\mu_0 i/r$
(b) $4\mu_0 i/r$
(c) zero
(d) $\mu_0 i/4r$

(iv) A long straight wire carries a current along the z-axis for any two points in the $x - y$ plane. Which of the following is always false?

(a) The magnetic fields are equal
(b) The directions of the magnetic fields are the same
(c) The magnitudes of the magnetic fields are equal
(d) The field at one point is opposite to that at the other point

(v) Biot-Savart law can be expressed alternatively as

(a) Coulomb's Law
(b) Ampere's circuital law
(c) Ohm's Law
(d) Gauss's Law

Moving Coil Galvanometer

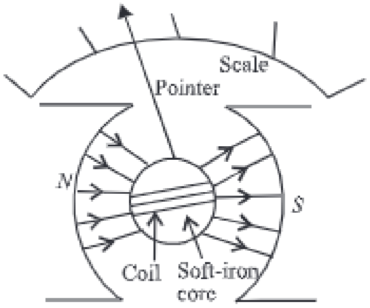
Moving coil galvanometer operates on Permanent Magnet Moving Coil (PMMC) mechanism and was designed by the scientist D'arsonval.

Moving coil galvanometers are of two types

(i) Suspended coil

(ii) Pivoted coil type or tangent galvanometer.

Its working is based on the fact that when a current carrying coil is placed in a magnetic field, it experiences a torque. This torque tends to rotate the coil about its axis of suspension in such a way that the magnetic flux passing through the coil is maximum.



(i) A moving coil galvanometer is an instrument which

- (a) is used to measure emf
- (b) is used to measure potential difference
- (c) is used to measure resistance
- (d) is a deflection instrument which gives a deflection when a current flows through its coil

(ii) To make the field radial in a moving coil galvanometer.

- (a) number of turns of coil is kept small
- (b) magnet is taken in the form of horse-shoe
- (c) poles are of very strong magnets
- (d) poles are cylindrically cut

(iii) The deflection in a moving coil galvanometer is

- (a) directly proportional to torsional constant of spring
- (b) directly proportional to the number of turns in the coil
- (c) inversely proportional to the area of the coil
- (d) inversely proportional to the current in the coil

(iv) In a moving coil galvanometer, having a coil of N-turns of area A and carrying current I is placed in a radial field of strength B.

The torque acting on the coil is

- (a) NA^2B^2I
- (b) $NABI^2$
- (c) N^2ABI
- (d) $NABI$

(v) To increase the current sensitivity of a moving coil galvanometer, we should decrease

- (a) strength of magnet
- (b) torsional constant of spring
- (c) number of turns in coil
- (d) area of coil

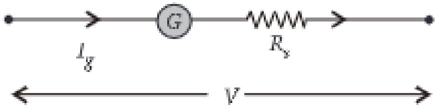
8

Conversion of Galvanometer to Voltmeter

A galvanometer can be converted into voltmeter of given range by connecting a suitable resistance R_s in series with the galvanometer, whose value is given by

$$R_s = \frac{V}{I_g} - G$$

where V is the voltage to be measured, I_g is the current for full scale deflection of galvanometer and G is the resistance of galvanometer.



Series resistor(R_s) increases range of voltmeter and the effective resistance of galvanometer. It also protects the galvanometer from damage due to large current.
Voltmeter is a high resistance instrument and it is always connected in parallel with the circuit element across which potential difference is to be measured. An ideal voltmeter has infinite resistance.
In order to increase the range of voltmeter n times the value of resistance to be connected in series with galvanometer is $R_s = (n - 1)G$.

(i) 10 mA current can pass through a galvanometer of resistance 25 Ω. What resistance in series should be connected through it, so that it is converted into a voltmeter of 100 V?

(a) 0.975 Ω (b) 99.75 Ω (c) 975 Ω (d) 9975 Ω.

(ii) There are 3 voltmeter A, B, C having the same range but their resistance are 15,000 Ω, 10,000 Ω and 5,000 Ω respectively. The best voltmeter amongst them is the one whose resistance is

(a) 5000 Ω (b) 10, 000 Ω (c) 15, 000 Ω (d) all are equally good

(iii) A milliammeter of range 0 to 25 mA and resistance of 10 Ω is to be converted into a voltmeter with a range of 0 to 25 V. The resistance that should be connected in series will be

(a) 930 Ω (b) 960 Ω (c) 990 Ω (d) 1010 Ω

(iv) To convert a moving coil galvanometer (MCG) into a voltmeter

(a) a high resistance R is connected in parallel with MCG
(b) a low resistance R is connected in parallel with MCG
(c) a low resistance R is connected in series with MCG
(d) a high resistance R is connected in series with MCG

(v) The resistance of an ideal voltmeter is

(a) zero (b) low (c) high (d) infinity

9

Motion of Charged Particle Inside Magnetic Field

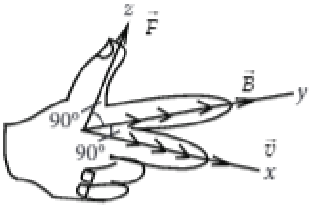
A charged particle moving in a magnetic field experiences a force that is proportional to the strength of the magnetic field, the component of the velocity that is perpendicular to the magnetic field and the charge of the particle.

This force is given by $\vec{F} = q(\vec{v} \times \vec{B})$ where q is the electric charge of the particle, v is the instantaneous velocity of the particle, and B is the magnetic field (in tesla).

The direction of force is determined by the rules of cross product of two vectors.

Force is perpendicular to both velocity and magnetic field. Its direction is same as $\vec{v} \times \vec{B}$ if q is positive and opposite of $\vec{v} \times \vec{B}$ if q is negative.

The force is always perpendicular to both the velocity of the particle and the magnetic field that created it. Because the magnetic force is always perpendicular to the motion, the magnetic field can do no work on an isolated charge. It can only do work indirectly, via the electric field generated by a changing magnetic field.



(i) When a magnetic field is applied on a stationary electron, it

- (a) remains stationary
- (b) spins about its own axis
- (c) moves in the direction of the field
- (d) moves perpendicular to the direction of the field.

(ii) A proton is projected with a uniform velocity v along the axis of a current carrying solenoid, then

- (a) the proton will be accelerated along the axis
- (b) the proton path will be circular about the axis
- (c) the proton moves along helical path
- (d) the proton will continue to move with velocity v along the axis.

(iii) A charged particle experiences magnetic force in the presence of magnetic field. Which of the following statement is correct ?

- (a) The particle is stationary and magnetic field is perpendicular.
- (b) The particle is moving and magnetic field is perpendicular to the velocity.
- (c) The particle is stationary and magnetic field is parallel.
- (d) The particle is moving and magnetic field is parallel to velocity.

(iv) A charge q moves with a velocity 2 m s^{-1} along x-axis in a uniform magnetic field $\vec{B} = (\hat{i} + 2\hat{j} + 3\hat{k})$ T, then charge will experience a force

- (a) in z-y plane
- (b) along $-y$ axis
- (c) along $+z$ axis
- (d) along $-z$ axis

(v) Moving charge will produce

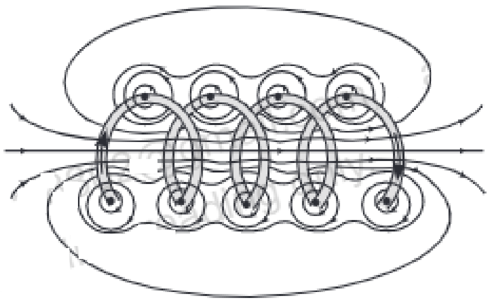
- (a) electric field only
- (b) magnetic field only
- (c) both electric and magnetic field
- (d) none of these.

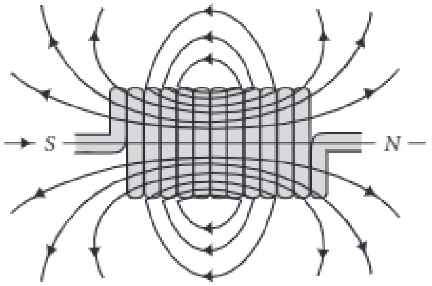
10

Magnetic Field Due to Solenoid

A solenoid is a long coil of wire tightly wound in the helical form. Solenoid consists of closely stacked rings electrically insulated from each other wrapped around a non-conducting cylinder.

Figure below shows the magnetic field lines of a solenoid carrying a steady current I. We see that if the turns are closely spaced, the resulting magnetic field inside the solenoid becomes fairly uniform, provided that the length of the solenoid is much greater than its diameter. For an "ideal" solenoid, which is infinitely long with turns tightly packed, the magnetic field inside the solenoid is uniform and parallel to the axis, and vanishes outside the solenoid.





(i) A long solenoid has 800 turns per metre length of solenoid. A current of 1.6 A flows through it. The magnetic induction at the end of the solenoid on its axis is

(a) 16×10^{-4} T (b) 8×10^{-4} T (c) 32×10^{-4} T (d) 4×10^{-4} T

(ii) Choose the correct statement in the following.

(a) The magnetic field inside the solenoid is less than that of outside
(b) The magnetic field inside an ideal solenoid is not at all uniform
(c) The magnetic field at the centre, inside an ideal solenoid is atmost twice that at the ends
(d) The magnetic field at the centre, inside an ideal solenoid is almost half of that at the ends

(iii) The magnetic field (B) inside a long solenoid having n turns per unit length and carrying current I when iron core is kept in it is (μ_0 = permeability of vacuum, χ = magnetic susceptibility)

(a) $\mu_0 nI(1 - \chi)$ (b) $\mu_0 nI \chi$ (c) $\mu_0 nI^2 (1 + \chi)$ (d) $\mu_0 nI (1 + \chi)$

(iv) A solenoid of length l and having n turns carries a current I is in anticlockwise direction. The magnetic field is

(a) $\mu_0 nI$ (b) $\mu_0 \frac{nI}{l^2}$
(c) along the axis of solenoid (d) perpendicular to the axis of coil

(v) The magnitude of the magnetic field inside a long solenoid is increased by

(a) decreasing its radius (b) decreasing the current through it
(c) increasing its area of cross-section (d) introducing a medium of higher permeability

ASSERTION & REASON

For question numbers 11-30, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

(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 also false

11. Assertion (A) : Voltmeter is connected in parallel with the circuit.
Reason (R) : Resistance of a voltmeter is very large.

12. **Assertion (A) :** Magnetic field lines can be entirely confined within the core of a toroid, but not within a straight solenoid.
Reason (R) : The magnetic field inside the solenoid is uniform.

13. **Assertion (A) :** An ammeter is connected in series in the circuit.
Reason (R) : An ammeter is a high resistance galvanometer.

14. **Assertion (A) :** There is a spark in the switch when the switch is closed.
Reason (R) : Current flowing in the conductor produces magnetic field

15. **Assertion (A) :** The magnetic field intensity at the centre of a circular coil carrying current changes, if the current through the coil is doubled.
Reason (R) : The magnetic field intensity is dependent on current in conductor.

16. **Assertion (A) :** When a charged particle moves perpendicular to magnetic field then its kinetic energy and momentum gets affected.
Reason (R) : Force changes velocity of charged particle.

17. **Assertion (A) :** In electric circuits, wires carrying currents in opposite directions are often twisted together.
Reason (R) : If the wire are not twisted together, the combination of the wires forms a current loop. The magnetic field generated by the loop might affect adjacent circuits or components.

18. **Assertion (A) :** When two long parallel wires, hanging freely are connected in parallel to a battery, they come closer to each other.
Reason (R) : Wires carrying current in opposite direction repel each other.

19. **Assertion (A) :** When the observation point lies along the length of the current element, magnetic field is zero.
Reason (R) : Magnetic field close to current element is zero.

20. **Assertion (A) :** A solenoid tends to expand, when a current passes through it.
Reason (R) : Two straight parallel metallic wires carrying current in same direction repel each other.

21. **Assertion (A) :** In a conductor, free electrons keep on moving but no magnetic force acts on a conductor in a magnetic field.
Reason (R) : Force on free electron due to magnetic field always acts perpendicular to its direction of motion.

22. **Assertion (A) :** When force is zero, the charged particle follows linear path.
Reason (R) : A charged particle enters in a uniform magnetic field, whose velocity makes an angle θ with magnetic field will cover a linear path.

23. **Assertion (A) :** When current is represented by a straight line, the magnetic field will be circular.
Reason (R) : According to Fleming's left hand rule, direction of force is parallel to the magnetic field.

24. **Assertion (A) :** An electron and proton enters a magnetic field with equal velocities, then, the force experienced by proton will be more than electron.
Reason (R) : The mass of proton is 1999 times more than the mass of electron.

25. **Assertion (A) :** Magnetic field is useful in producing parallel beam of charged particle.
Reason (R) : Magnetic field inhibits the motion of charged particle moving across it.

26. **Assertion (A) :** When a magnetic dipole is placed in a non uniform magnetic field, only a torque acts on the dipole.
Reason (R) : Force would act on dipole if magnetic field is uniform.

27. **Assertion (A) :** Magnetic moment is measured in joule/tesla or amp m^2.
Reason (R) : Joule/tesla is equivalent to amp m^2.

28. **Assertion (A) :** The kinetic energy of a charged particle moving in a uniform magnetic field does not change.
Reason (R) : In a uniform magnetic field no force acts on the charge particle.

29. **Assertion (A) :** A charged particle moving in a uniform magnetic field penetrates a layer of lead and there by loses half of its kinetic energy. The radius of curvature of its path is now reduced to half of its initial value.
Reason (R) : Kinetic energy is inversely proportional to radius of curvature.

30. **Assertion (A) :** A charge, whether stationary or in motion produces a magnetic field around it.
Reason (R) : Moving charges produce only electric field in the surrounding space.

HINTS & EXPLANATIONS

1. **(i) (c) :** In mass spectrometer, the ions are sorted out by accelerating them through electric and magnetic field.

(ii) (c) : As $\frac{mv^2}{r} = qvB_0 \therefore r = \frac{mv}{qB_0}$

(iii) (b): As radius, $r \propto \frac{m}{q}$.

$\therefore$ r will be maximum for α - particle.

(iv) (b) : Here, $r = \frac{mv}{qB_0}$ or $m = \frac{rqB_0}{v}$

As $v = \frac{E}{B}$, $\therefore$ $m = \frac{qB_0Br}{E}$

(v) (c) : From the relation $v = E/B$, it is clear electric and magnetic force balance each other.

2. **(i) (a) :** Magnetic field due to a long current carrying wire at r

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

(ii) (d): Let I' be the current in region $r < R$

Then, $I' = \frac{I}{\pi R^2}\pi(r^2)$ or $I' = \frac{Ir^2}{R^2}$

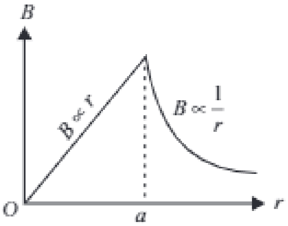
So, magnetic field, $B = \frac{\mu_0 I'}{2\pi r} = \frac{\mu_0 I r^2}{2\pi R^2 r} = \frac{\mu_0 I r}{2\pi R^2}$

(iii) (a) : Magnetic field due to a long straight wire of radius a carrying current I at a point distant r from the centre of the wire is given as follows

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

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

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



The variation of magnetic field B with distance r from the centre of wire is shown in the figure.

(iv) (d): Let the magnetic fields due to a long straight wire of radius R carrying a steady current I at a distance r from the centre of the wire are

$$B_1 = \frac{\mu_0 I r}{2\pi R^2} \quad \text{(For } r < R\text{)}$$

and $B_2 = \frac{\mu_0 I}{2\pi R}$ (For $r > R$)

So, the magnetic field at $r = \frac{R}{2}$ is $B_1 = \frac{\mu_0 I}{2\pi R^2}\left(\frac{R}{2}\right) = \frac{\mu_0 I}{4\pi R}$

and at $r = 2R$ is $B_2 = \frac{\mu_0 I}{2\pi(2R)} = \frac{\mu_0 I}{4\pi R}$

$\therefore$ Their corresponding ratio is

$$\frac{B_1}{B_2} = \frac{(\mu_0 I/4\pi R)}{(\mu_0 I/4\pi R)} = 1$$

(v) (c)

3. **(i) (d)**

(ii) (a): Using, $qvB\sin\theta = \frac{mv^2}{r}$

$r \propto \frac{1}{\sin\theta}$ for the same values of m, v, q and B

$$\therefore \frac{r_A}{r_B} = \frac{\sin 90^\circ}{\sin 30^\circ} = 2 \text{ or } r_A = 2r_B \text{ or } r_B < r_A$$

(iii) (d): The radius of the helical path of the electron in the uniform magnetic field is

$$r = \frac{mv_\perp}{eB} = \frac{mv\sin\theta}{eB} = \frac{(2.4\times10^{-23}\text{ kg m/s})\times\sin 30^\circ}{(1.6\times10^{-19}\text{ C})\times 0.15\text{ T}}$$

$$= 5\times10^{-4}\text{ m} = 0.5\times10^{-3}\text{ m} = 0.5\text{ mm}$$

(iv) (c): Here, $\vec{B} = 8.35\times10^{-2}\hat{i}$ T

$\vec{v} = 2\times10^5\hat{i} + 4\times10^5\hat{j}$ m/s, $m = 1.67\times10^{-27}$ kg

Pitch of the helix (*i.e.*, the linear distance moved along the magnetic field in one rotation) is given by

Pitch of the helix $= \dfrac{2\pi m v_\parallel}{qB}$

$$= \frac{2\times3.14\times1.67\times10^{-27}\times2\times10^5}{1.6\times10^{-19}\times8.35\times10^{-2}} = 0.157\text{ m}$$

(v) (b): Period of revolution

$$T = \frac{2\pi R}{v\sin\theta} \Rightarrow T = \frac{2\pi\left(\dfrac{mv\sin\theta}{qB}\right)}{v\sin\theta} \Rightarrow T = \frac{2\pi m}{qB}$$

∴ Frequency, $\upsilon = \dfrac{1}{T} = \dfrac{qB}{2\pi m}$

4. (i) (b): As, $r_0 = \dfrac{mv}{qB} \Rightarrow r' = \dfrac{m(2v_0)}{qB} = 2r_0$

(ii) (c): As, $T = \dfrac{2\pi m}{qB}$

Thus, it remains same as it is independent of velocity.

(iii) (b): As $F \perp B$

Hence, $a \perp B$

∴ $\vec{a}\cdot\vec{B} = 0$

$\Rightarrow (x\hat{i}+2\hat{j})\cdot(2\hat{i}+4\hat{j}) = 0$

$2x + 8 = 0 \Rightarrow x = -4\text{ m s}^{-2}$

(iv) (c): If the charged particle has a velocity not perpendicular to $\vec{B}$, then component of velocity along $\vec{B}$ remains unchanged as the motion along the $\vec{B}$ will not be affected by $\vec{B}$.

Then, the motion of the particle in a plane perpendicular to $\vec{B}$ is as before circular one. Thereby, producing helical motion.

(v) (d): The force on electron $F = qvB\sin\theta$

As the electron is moving parallel to B

So, $\theta = 0^\circ \Rightarrow qvB\sin 0^\circ = 0$

5. (i) (a): Torque on a current carrying loop in magnetic field, $\tau = IBA\sin\theta$

Here, $I = 10$ A, $B = 0.1$ T, $A = 1\text{ cm}^2 = 10^{-4}\text{ m}^2$, $\theta = 0^\circ$

∴ $\tau = 10\times0.1\times10^{-4}\sin 0^\circ = 0$

(ii) (a): Magnetic moment, $M = IA = I(\pi r^2) = \dfrac{q}{T}\times\pi r^2$

As $\omega = \dfrac{2\pi}{T}$ ∴ $M = \dfrac{q\omega r^2}{2}$ or $M \propto \omega$

(iii) (b): When a current loop is placed in a magnetic field it experiences a torque. It is given by

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

where $\vec{M}$ is the magnetic moment of the loop and $\vec{B}$ is the magnetic field.

or $\tau = MB\sin\theta$ where θ is angle between M and B

When $\vec{M}$ and $\vec{B}$ are parallel (*i.e.* $\theta = 0^\circ$) the equilibrium is stable and when they are antiparallel (*i.e.* $\theta = \pi$) the equilibrium is unstable.

(iv) (d): Magnetic moment, $M = NIA = NI\pi r^2$ *i.e.*, $M \propto r^2$

(v) (a)

6. (i) (c): According to Biot-Savart's law, the magnetic induction due to a current element is given by

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

This is perpendicular to both $d\vec{l}$ and $\vec{r}$.

(ii) (b): From Biot-savart's law,

$$dB = \frac{\mu_0}{4\pi}\frac{Idl}{r^2}\ \text{ i.e. } dB \propto \frac{1}{r^2}$$

(iii) (c): $B = \dfrac{\mu_0}{2\pi}\cdot\dfrac{i}{r} - \dfrac{\mu_0}{2\pi}\cdot\dfrac{i}{r} = 0$

(iv) (a)

(v) (b): Biot-Savart law can be expressed alternatively as Ampere circuital law.

7. (i) (d): A moving coil galvanometer is a sensitive instrument which is used to measure a deflection when a current flows through its coil.

(ii) (d): Uniform field is made radial by cutting pole pieces cylindrically.

(iii) (b): The deflection in a moving coil galvanometer, $\phi = \dfrac{NAB}{k}\cdot I$ or $\phi \propto N$, where N is number of turns in a coil, B is magnetic field and A is area of cross-section.

(iv) (d): The deflecting torque acting on the coil.

$$\tau_{\text{deflection}} = NIAB$$

(v) **(b):** Current sensitivity of galvanometer

$$\frac{\phi}{I} = S_i = \frac{NBA}{k}$$

Hence, to increase (current sensitivity) S_i, (torsional constant of spring) k must be decrease.

8. (i) **(d):** A galvanometer can be converted into a voltmeter of given range by connecting a suitable high resistance R in series of galvanometer, which is given by

$$R = \frac{V}{I_g} - G = \frac{100}{10 \times 10^{-3}} - 25 = 10000 - 25 = 9975\ \Omega.$$

(ii) **(c):** An ideal voltmeter should have a very high resistance.

(iii) **(c):** Resistance of voltmeter $= \frac{25}{25 \times 10^{-3}} = 1000\ \Omega$

$\therefore \quad X = 1000 - 10 = 990\ \Omega$

(iv) **(d):** To convert a moving coil galvanometer into a voltmeter, it is connected with a high resistance in series. The voltmeter is connected in parallel to measure the potential difference. As the resistance is high, the voltmeter itself does not consume current.

(v) **(d):** The resistance of an ideal voltmeter is infinity.

9. (i) **(a):** For stationary electron, $\vec{v} = 0$

$\therefore$ Force on the electron is, $\vec{F}_m = -e(\vec{v} \times \vec{B}) = 0$

(ii) **(d):** Force on the proton, $\vec{F}_B = e(\vec{v} \times \vec{B})$

Since, $\vec{v}$ is parallel to $\vec{B}$

$\therefore \quad \vec{F}_B = 0$

Hence proton will continue to move with velocity v along the axis of solenoid.

(iii) **(b):** Magnetic force on the charged particle q is

$\vec{F}_m = q(\vec{v} \times \vec{B})$ or $F_m = qvB\sin\theta$

where θ is the angle between $\vec{v}$ and $\vec{B}$.

Out of the given cases, only in case (b) it will experience the force while in other cases it will experience no force.

(iv) **(a):** $\vec{F} = q(\vec{v} \times \vec{B})$

$$= q[(2\hat{i} \times (\hat{i} + 2\hat{j} + 3\hat{k})] = (4q)\hat{k} - (6q)\hat{j}$$

(v) **(c):** When an electric charge is moving both electric and magnetic fields are produced, whereas a static charge produces only electric field.

10. (i) **(b):** As $B = \frac{\mu_0 nI}{2} = \frac{(4\pi \times 10^{-7}) \times 800 \times 1.6}{2}$
$= 8 \times 10^{-4}\ \text{T}$

(ii) **(c):** Magnetic field at one end of a solenoid carrying current is $B = \frac{\mu_0 nI}{2}$

Magnetic field inside the solenoid is uniform and is given by $B_c = \mu_0 nI$

(iii) **(d):** Magnetic field inside a long solenoid with an iron core inside it is $B = \mu nI$

But $\mu = \mu_0(1 + \chi) \quad \therefore \quad B = \mu_0(1 + \chi)nI$

(iv) **(c):** A solenoid of length l and having n turns carries a current I in anticlockwise direction. The magnetic field is $\frac{\mu_0 nI}{l}$. Its direction will be along the axis of solenoid.

(v) **(d)**

11. **(a):** A voltmeter is always connected in parallel. This has a large resistance.

12. **(b):** Magnetic field lines can be entirely confined to the core of a toroid because toroid has no ends. It can confine the field within its core. A straight solenoid has two ends. If the entire flux were confined between these ends, the flux throughout the cross-section at each end would be non-zero.

13. **(c):** An ammeter is a low resistance galvanometer. It is used to measure the current in amperes. To measure the current of a circuit, the ammeter is connected in series in the circuit so that the current to be measured must pass through it. Since, the resistance of ammeter is low, so its inclusion in series in the circuit does not change the resistance and hence the main current in the circuit.

14. **(b)**

15. **(a):** The magnetic field at the centre of circular coil is given by .

$$B = \frac{\mu_0}{4\pi}\frac{2\pi nI}{a}$$

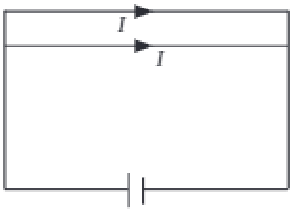
So if current through coil is doubled then magnetic field is $B' = 2B$.

The magnetic field also get doubled. The magnetic field is directly proportional to the current in conductor.

16. **(d):** When a charged particle moves perpendicular to magnetic field, it experiences a force which changes the direction of motion of the particle without changing the magnitude of velocity of the particle. Hence kinetic energy remains constant but momentum of electron changes.

17. (a): If the wires are twisted together, they can be modelled as a single wire carrying current in the opposite directions. In this model, no magnetic field is induced in the wires which does not affect adjacent circuits.

18. (b): The wires are parallel to each other but the direction of current in it is in same direction so they attract each other. If the current in the wires is in opposite direction then wires repel each other. When the currents are in opposite directions, the magnetic forces are reversed and the wires repels each other.



19. (c): Since $dB \propto \sin\theta$, where θ is angle between the direction of the flow of current and the line joining the elementary portion to the observation point which is zero in this case, so the magnetic field is also zero (because $\sin\theta$ is equal to zero).

20. (d) : When current flows through a solenoid, the currents in the various turns of the solenoid are parallel and in the same direction. Since the currents flowing through parallel wires in the same direction lead to force of attraction between them, the turns of the solenoid will also attract each other and as a result,the solenoid tends to contract.

21. (c): In a conductor, the average velocity of electrons is zero. Hence no current flows through the conductor. Hence, no force acts on this conductor.

22. (c): When charged particle enters the uniform field they makes angle θ with the field. Then its path is decided by combined effect of two component of velocity. $v\cos\theta$ parallel to the field. Due to the parallel field the charge will follow a linear path and due to the perpendicular component ($v\sin\theta$) of the field will be circular. This results in a helical path whose axis is parallel to the parallel component of the field.

23. (c): When current is straight, it means the current is passing through a straight conductor, the magnetic field produced due to current through a straight conductor is in the form of concentric circular magnetic lines of force whose centres lie on the linear conductor and are in a plane perpendicular to the plane of linear conductor. It means the magnetic field is circular.

24. (d): The force experienced by a charge particle in a magnetic field is given by,

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

which is independent of mass. As q, v and B are same for both the electron and proton, hence both will experience same force.

25. (a)

26. (d): In a non-uniform magnetic field, a torque and a net force both act on the dipole. If magnetic field is uniform, net force on dipole would be zero.

27. (a): Magnetic moment $= \dfrac{\text{joule}}{\text{tesla}} = \dfrac{W}{B} = \dfrac{W}{F/qv}$

$$= \frac{Wqv}{F} = \frac{[\mathrm{ML^2T^{-2}}][\mathrm{AT}][\mathrm{LT^{-1}}]}{[\mathrm{MLT^{-2}}]}$$

$$= \mathrm{AL}^2 = \text{amp m}^2$$

28. (c): When a charged particle is moving in a uniform magnetic field, it experiences a force in a direction perpendicular to its direction of motion. Due to which the speed of the charged particle remains unchanged and hence its kinetic energy remains same.

29. (d): The radius of curvature of a charged particle in a magnetic field is given by, $r = \dfrac{mv}{qB} = \dfrac{\sqrt{2mK.E.}}{qB}$

i.e. $r \propto \sqrt{K.E.}$ when kinetic energy is halved, the radius is reduced to $\left(\dfrac{1}{\sqrt{2}}\right)$ times its initial value.

30. (d): A charge, whether stationary or in motion, produces an electric field around it. If it is in motion, then in addition to the electric field, it also produces a magnetic field, because moving charges produce magnetic field in the surrounding space.