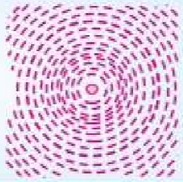
Moving Charges and Magnetism

4
Chapter

(1) MAGNETIC FIELD



- It is space around a current carrying conductor in which its magnetic effects can be felt.
- Oersted concluded that moving charges or currents produced a magnetic field in the surrounding space.

(2) LORENTZ FORCE

Mechanical force experienced by a moving charge through electric and magnetic field

$F = q\left[\vec{E} + (\vec{v}\times\vec{B})\right] = \vec{F}_{electric} + \vec{F}_{magnetic}$

- Magnetic force depends on magnitude of charge, its nature and its velocity.
- When charge is at rest, it does not experience any magnetic force.
- When charge is moving parallel to magnetic field, it does not experience any mechanical force.

(4) MOTION IN MAGNETIC FIELD

In uniform magnetic field charge particle can have three types of path.

1. Straight line: when $\vec{B} \parallel \vec{v}$
2. Circular path: $\vec{v} \perp \vec{B}$

   Perpendicular force acts as a centripetal force and produces a circular motion perpendicular to magnetic field.

   Radius of circle $r = \frac{mv}{qB}$ and $T = \frac{2\pi m}{qB}$
3. Helical path: velocity $\vec{v}$ and $\vec{B}$ are inclined at angle $\theta \neq 0,\ \theta \neq 90°,\ \theta \neq 180°$

   Velocity component along magnetic field remains unchanged, due to other component motion is circular. The combined path is helical motion.

$r = \frac{mv_{\perp}}{qB}, \omega = \frac{qB}{m}, p = \frac{2\pi m v_{\parallel}}{qB}$

(3) VELOCITY SELECTOR

When electric field and magnetic fields are crossed and velocity of particle is perpendicular to both fieldsthen particles with speed $v = \frac{E}{B}$ pass undeflected. This principle is employed in mass spectrometer.

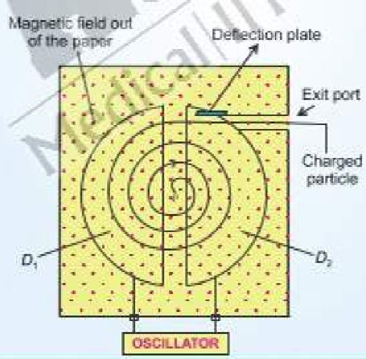
(5) CYCLOTRON

A machine to accelerate charged particles or ions to high energies cyclotron; uses both electric and magnetic field in combination to increase kinetic energy of charge particles

- Frequency of revolution of charge particle is independent of its energy.
- $f = \frac{qB}{2\pi m}$. The frequency is called cyclotron frequency.

The frequency of electric field is in resonance with cyclotron frequency. Final KE of ion

$$E_K = \frac{q^2B^2R^2}{2m},\ R = \text{radius of Dee}$$



(6) BIOT-SAVART'S LAW

- According to this law, the magnetic field at a point due to a current element of length dl carrying current I at distance r from element is

$$|d\vec{B}| = \frac{\mu I dl \sin\theta}{4\pi r^2}$$

θ is angle between $\vec{dl}$ and $\vec{r}$

(7) MAGNETIC FIELD ON AXIS OF CIRCULAR COIL

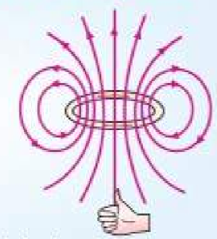
$$B = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{3/2}}$$

where R = radius of coil

x = distance along axis from centre of coil plane

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

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



Field lines form closed loop around circular wire

(8) AMPERE'S CIRCUITAL LAW

Law states $\oint_c \vec{B}\cdot\vec{dl} = \mu_0 I$, where I refers to current passing the loop through open surface S. The sign of current is determined from right hand rule.

- If B is directed along tangent to amperian loop of perimeter L and field is constant in magnitude

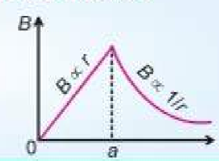
  $BL = \mu_0 I_e$

  I_e = net current enclosed by closed loop.

(9) MAGNETIC FIELD DUE TO SOLID CONDUCTOR

A long straight wire with circular cross-section of radius a

- Magnetic field in region $r < a$, $B = \left(\frac{\mu_0 I}{2\pi a^2}\right)r$
- Magnetic field in region $(r \geq a)$, $B = \frac{\mu_0 I}{2\pi r}$



⑩ MAGNETIC FIELD DUE TO A LINE CURRENT

- Magnetic field at distance *R* from straight long infinite wire carrying a current *I*.

  $B = \frac{\mu_0 I}{2\pi R}$, field lines are circles concentric with wire.

⑪ DIRECTION OF MAGNETIC FIELD

The rule is called right hand rule:

Grasp the wire in your right hand with your extended thumb pointing in the direction of the current, your fingers will curl around in the direction of magnetic field.

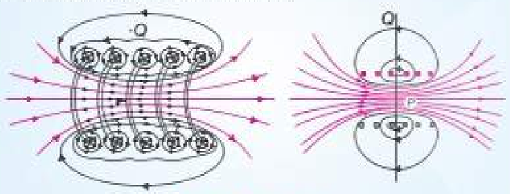
⑫ LONG SOLENOID

Magnetic field inside long solenoid (*B*)

When solenoid carries current *I* is

$B = \mu_0 nI$

n = number of turns per unit length



FOR A TOROID

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

N = total number of turns and *r* = average radius

⑬ MECHANICAL FORCE ON A CURRENT CARRYING CONDUCTOR

A current carrying conductor of straight length *L* carrying current *I* experience force

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

But if wire is of arbitrary shape

$\vec{F} = \sum i(\vec{dl} \times B)$

Summation can be converted into integration in most cases

⑭ FORCE BETWEEN CURRENT CARRYING WIRES

- Two current carrying conductors placed near each other experience magnetic forces.

  When conductors are parallel

  $F = \frac{\mu_0 I_1 I_2}{2\pi d} L$

- Force on one conductor of length *L* due to current in other at separation *d*. Parallel currents attract and antiparallel currents repel. The results are in accordance with Newton's third law.

⑮ TORQUE ON CURRENT LOOPS

- Torque on magnetic dipole

  $\tau = mB\sin\theta$

  $\tau = NIA\sin\theta$

- Any planner current loop is equivalent to magnetic dipole of dipole moment

  $m = IA$

⑯ MAGNETIC MOMENT OF REVOLVING CHARGED PARTICLES

- Magnetic moment associated with revolving electron with speed *v* in a radius of circle *r* is

  $\mu = -\frac{evr}{2}$

  and $\vec{\mu} = \frac{-e}{2m_e}\vec{J}$

Where $\vec{J}$ is angular momentum of the electron

- For electron, angular momentum is opposite in direction to magnetic moment.
- In general for any charge *q* angular momentum and magnetic moment are in same direction.

  $\frac{\mu}{J} = \frac{e}{2m}$

This is called Gyromagnetic ratio and is constant.

Minimum value of magnetic moment is called Bohr magneton

$\mu_m = 9.27 \times 10^{-24}\ \text{Am}^2$

⑰ MOVING COIL GALVANOMETER

- Torque due to radial magnetic field on loop of area *A* with *N* number of turns carrying current *I* is

  $\tau = NIAB$

- deflection on scale

  $\phi = \left(\frac{NAB}{K}\right) I$

- Quantity in bracket is constant for galvanometer. This makes linear scale
- Current sensitivity of galvanometer

  $S_i = \frac{\phi}{I} = \frac{NAB}{K}$

- Current sensitivity can be easily increased by changing *N*

⑱ GALVANOMETER CONVERSION AMMETER

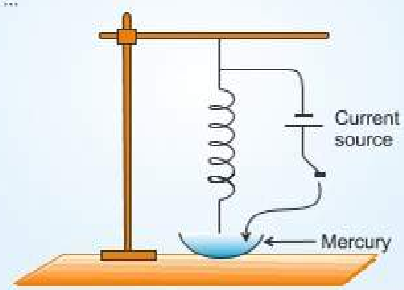
- Modification of galvanometer by connecting a low resistance in parallel.

VOLTMETER

- To measure voltage across any section of circuit. It is connected in parallel. When a large resistance is in series with galvanometer, it becomes a voltmeter.

⑲ ROGET'S SPIRAL

- When current passes through spring the effect is length of parallel current produces attraction, decreasing spring length, oscillations starts and continue with tick - tick - tick ...



Sharpen Your Understanding

NCERT Based MCQs

1. A current element $\Delta l = dx\hat{i}$ (where dx = 1 cm) is placed at the origin and carries a large current of 10 A. The magnetic field on y-axis at distance of 50 cm from it is [NCERT Pg. 148]

(1) 2×10^{-8} T

(2) 2×10^{-5} G

(3) 4×10^{-8} T

(4) 3×10^{-5} G

2. Consider a tightly wound 100 turn coil of radius 12 cm carrying current of 10 A. What is magnetic field at centre of this coil. [NCERT Pg. 146]

(1) 1.2×10^{-3} T

(2) 5.2×10^{-3} T

(3) 4.6×10^{-5} T

(4) 1.9×10^{-6} T

3. A straight wire carrying current of 15 A is bent into a semicircular arc of radius 2.5 cm. The magnetic field at the centre of semicircular arc is [NCERT Pg. 150]

(1) 1.88×10^{-4} T

(2) 2.6×10^{-4} T

(3) 3.77×10^{-4} T

(4) 5.2×10^{-4} T

4. Consider a tightly wound 200 turns coil of radius 10 cm carrying current of 10 A. The magnitude of magnetic field at the centre of the coil is [NCERT Pg. 151]

(1) $2\pi \times 10^{-4}$ T

(2) $4\pi \times 10^{-3}$ T

(3) $6\pi \times 10^{-4}$ T

(4) $3\pi \times 10^{-3}$ T

5. A long straight wire of circular cross-section of radius 5 cm is carrying a steady current of 20 A, uniformly distributed over its cross-section. The magnetic field induction at 2 cm from the axis of the wire is [NCERT Pg. 149]

(1) 1.6×10^{-4} T

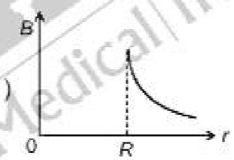
(2) 2.8×10^{-2} T

(3) 3.3×10^{-6} T

(4) 3.2×10^{-5} T

6. A long straight cylindrical wire carries current I and current is uniformly distributed across cross-section of conductor. Figures below shows a plot of magnitude of magnetic field with distance from centre of the wire. The correct graph is [NCERT Pg. 150]

(1)



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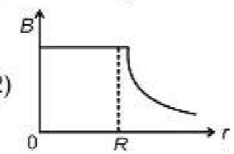

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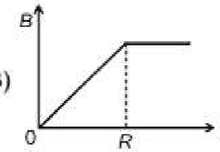

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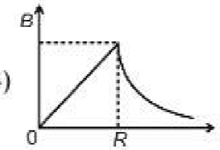

7. A closely wound solenoid 80 cm long has 5 layers of winding of 400 turns each. The diameter of solenoid is 1.8 cm. If it carries current of 8 A then magnitude of magnetic field intensity inside solenoid near its centre is [NCERT Pg. 173]

(1) 1.62×10^{-4} T

(2) 25.13×10^{-3} T

(3) 3.1×10^{-2} T

(4) 16.8×10^{-3} T

8. A circular coil of 30 turns and radius 8 cm carries a current of 6 A. It is suspended in a uniform horizontal magnetic field of 1.0 T. The field lines make an angle of 60° with the normal of the coil. The magnitude of counter torque that must be applied to prevent the coil from turning is [NCERT Pg. 169]

(1) 3.133 N m

(2) 0.236 N m

(3) 30.8 N m

(4) 35 N m

9. In a chamber, a uniform magnetic field of 1.2 T is maintained. An electron is shot into the field with a speed of 3.2×10^6 m s^{-1} normal to the field. The radius of circular orbit in which it starts circular path is
($m_e = 9.1 \times 10^{-31}$ kg) [NCERT Pg. 169]
(1) 15.16 μm
(2) 6.27 μm
(3) 12.42 μm
(4) 22.4 μm

10. Two moving coil galvanometers M_1 and M_2 have the following particulars. N_1 = 30, B_1 = 0.25 T, $A_1 = 7.2 \times 10^{-3}$ m^2, G_1 = 10Ω and N_2 = 60, B_2 = 0.50 T, $A_2 = 1.8 \times 10^{-3}$ m^2, G_2 = 5Ω respectively. The spring constants are identical to both galvanometers. The ratio of their current sensitivity is [NCERT Pg. 173]
(1) 1 : 1
(2) 2 : 1
(3) 4 : 1
(4) 1 : 4

11. A toroid ring has inner radius 21 cm and outer radius 23 cm in which 4400 turns of wire are wound. If the current in the wire is 10 A, then magnetic field inside the core of the toroid will be [NCERT Pg. 170]
(1) 4.4×10^{-4} T
(2) 4×10^{-2} T
(3) 6.6×10^{-4} T
(4) 12.6×10^{-3} T

12. Two concentric circular coils *X* and *Y* of radius 20 cm and 25 cm respectively lie in the same vertical plane. Coil *X* has 40 turns and coil *Y* has 100 turns. If coil *X* and *Y* carries currents of 18 A each but in opposite sense, the net magnetic field due to the coils at their centre is [NCERT Pg. 170]
(1) 3.12×10^{-4} T
(2) 1.2×10^{-5} T
(3) 7.2×10^{-4} T
(4) 2.26×10^{-3} T

13. A galvanometer has resistance of 60 Ω. It is converted in to an ammeter by connecting a shunt resistance of 1.2 Ω. Its range becomes [NCERT Pg. 172]
(1) 68
(2) 50
(3) 51
(4) 60

14. To convert a galvanometer into a voltmeter of large range, we connect a resistance with galvanometer. The resistance [NCERT Pg. 165]
(1) Is connected in parallel and of higher value
(2) Is connected in series and of lower value
(3) Is connected in parallel and of lower value
(4) Is connected in series and of higher value

15. Magnetic moment associated with an electron moving at speed *v* in a circular orbit of radius *r* is (in magnitudes) [NCERT Pg. 162]
(1) evr
(2) $\frac{evr}{2}$
(3) $\frac{evr}{4}$
(4) $\frac{ev^2}{2r}$

16. The horizontal component of earth's magnetic field at a certain place is 3.2×10^{-5} T and field is directed from south to North. A long straight conductor is carrying a current of 3 A. What is force per unit length experienced by it when it is placed on horizontal table and current in wire is from west to east? [NCERT Pg. 156]
(1) 9.6×10^{-5} Nm^{-1}, upwards
(2) 9.6×10^{-5} Nm^{-1}, downwards
(3) 3.6×10^{-5} Nm^{-1}, upwards
(4) 9.6×10^{-5} Nm^{-1}, horizontal

17. Two long straight parallel wires *A* and *B* carrying current of 20 A and 10 A is same direction are separated by a distance of 5 cm. The force of 15 cm section of wire *B* is [NCERT Pg. 173]
(1) 1.5×10^{-3} N, attractive
(2) 1.6×10^{-4} N, repulsive
(3) 1.2×10^{-3} N, attractive
(4) 1.2×10^{-4} N, attractive

18. A cyclotron's oscillatory frequency is 10 MHz. What should be the operating magnetic field for accelerating deuterons? [NCERT Pg. 146]

(1) 0.96 T (2) 1.52 T

(3) 0.46 T (4) 1.32 T

19. A charge $q = 1.6 \times 10^{-12}$ C moving with speed of v m s^{-1} crosses electric field $|\vec{E}| = 6 \times 10^4$ Vm^{-1} and magnetic field $|\vec{B}| = 1.2$ T. The electric field and magnetic fields are crossed and velocity v is also perpendicular to both. If the charge particle crosses both fields undeflected, the value of v is [NCERT Pg. 140]

(1) 7.2×10^5

(2) 7.2×10^4

(3) 5×10^5

(4) 5×10^4

20. A proton is moving with speed of 2×10^5 m s^{-1} enters a uniform magnetic field $B = 1.5$ T. At the entry velocity vector makes an angle of 30° to the direction of the magnetic field. The pitch of helical path it describes is nearly [NCERT Pg. 138]

(1) 6.25 mm

(2) 4.37 mm

(3) 7.25 mm

(4) 1.67 mm

Thinking in Context

1. Earth's natural magnetic field is about ______ tesla and that on the surface of a neutron star is about ______ tesla. [NCERT Pg. 135]

2. Magnetic field exerts a mechanical force on current carrying wire $\vec{F}$ = ______, where $\vec{l}$ is conductor length with a direction identical to current I. [NCERT Pg. 136]

3. The product of μ and ε has relation with speed v of electromagnetic wave in a medium and $\mu\varepsilon$ = ______. [NCERT Pg. 136]

4. If magnetic field is parallel to positive y axis and a positive charge particle is moving along positive x-axis, it will experience Lorentz force along ______. [NCERT Pg. 137]

5. In uniform magnetic $\vec{B}$, when a charge particle has motion directed perpendicular to field, particle will move on ______ and work done by magnetic force is ______. [NCERT Pg. 138]

6. When a charged particle enters perpendicular in a uniform magnetic field, magnitude of its angular velocity will be independent of the ______. [NCERT Pg. 138]

7. When electric field and magnetic field are perpendicular to each other and also perpendicular to velocity of a charged particle, then electric and magnetic force are in ______ directions. [NCERT Pg. 140]

8. Cyclotron uses the concept that frequency of revolution of the charged particle in magnetic field is independent of its ______. [NCERT Pg. 140]

9. In a cyclotron, under perpendicular magnetic field $\vec{B}$ (uniform) and radius of Dee R, maximum kinetic energy gained by an ion of charge q and mass m is ______. [NCERT Pg. 141]

10. The electrostatic field is produced by a scalar source, namely, electric charge. The magnetic field is produced by a vector source namely ______. [NCERT Pg. 143]

11. A current element is placed at origin along +x-axis. The observation point where magnetic field is desirable is along +y axis, then magnetic field is directed along ______ axis. [NCERT Pg. 144]

12. Magnetic field due to a long current carrying wire at finite distance is directly proportional to ______ and inversely proportional to ______. [NCERT Pg. 148]

13. There exists a simple rule to determine the direction of magnetic field due to a long wire. This rule is called _______. [NCERT Pg. 149]

14. A long straight wire of circular cross-section is carrying steady current. The current is uniformly distributed over the cross-section of wire. The magnitude of magnetic field on the axis of wire is ______. [NCERT Pg. 149-150]

15. A solenoid consists of a long wire wound in the form of helix where neighbouring turns are closely packed. The field outside the solenoid is ______ and field inside the solenoid is parallel to axis and ______. [NCERT Pg. 151]

16. Toroid can act like magnetic container and are expected to play key role in ______, an equipment for plasma confinement in fusion power reactors. [NCERT Pg. 153]

17. Two current carrying wires placed near each other can exert mechanical forces on each other. When two straight wires are held parallel it can be observed that parallel currents ______ and antiparallel currents ______ each other. [NCERT Pg. 155]

18. One ampere is the value of that steady current which when maintained in each of two long, straight, parallel conductors of negligible cross-section, and placed one metre apart in vacuum, would produce on each of these conductors a force equal to ______ newton per metre of length. [NCERT Pg. 155]

19. Dimensions of magnetic moment are ______ and its SI unit is _______. [NCERT Pg. 158]

20. Voltage sensitivity is defined as the deflection per unit _______. [NCERT Pg. 163]

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