Moving Charges And Magnetism

Moving Charges

- Moving charges produce magnetic field around them.
- SI unit of magnetic field is Tesla T.

Lorentz Force

- It is the force experienced by a charged particle moving in a space where both electric and magnetic fields exist.
- $\vec{F} = q\vec{E} + q\left(\vec{v} \times \vec{B}\right)$
- Where,
  - $q\vec{E}$ = Force due to electric field
  - $q\left(\vec{v} \times \vec{B}\right)$ = Force due to magnetic field$magnetic force$

Magnetic force on a charged particle

- It is opposite on negative charge than that on positive charge.
- It vanishes, if v and $B$are parallel or anti-parallel
- Magnetic force is zero, if charge is at rest.

Magnetic force on a current carrying conductor

A straight conductor of length l and carrying a steady current I experiences a force F in a uniform external magnetic field B, $\vec{F} = I\left(\vec{l} \times \vec{B}\right)$

Motion of a charged particle in a uniform magnetic field

- In a uniform magnetic field B, a charge q executes a circular orbit in a plane normal to B.
- The magnetic force acts as the centripetal force.
- $q\left(\vec{v} \times \vec{B}\right) = \frac{mv^2}{r}$

If $\vec{v}$and $\vec{B}$ are at right angles, then radius of the circular orbit, $r = \frac{mv}{Bq}$

- Time period T, $T = \frac{2\pi m}{qB}$
- Frequency of rotation, $\omega = \frac{Bq}{m}$

Motion of a charged particle in combined electric and magnetic field

- Generally, a charged particle moves in a spiral path when the magnetic and electric field are combined.

- **Velocity selector**
  - The magnetic and the electric field are perpendicular to each other.
  - At a certain velocity at which the the net force due to the magnetic and the electric field is zero, we have:

    $qvB = qE or\, v = \frac{E}{B}$

Cyclotron

- It works on the principle that the frequency of revolution of a charged particle is not dependent on the energy.
- The electric and the magnetic field are used in combination to increase the energy.
- **Cyclotron frequency:**

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

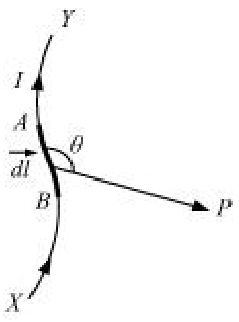
Limitations of Cyclotron

- It cannot accelerate uncharged particles like neutrons.
- There is a limit of speed beyond which a charged particle cannot be accelerated by a cyclotron.
- It cannot produce highly energetic particles with energy of the order of 500 MeV.

Right-Hand Thumb Rule

According to this rule, if we grasp the current-carrying wire in our right hand such that our thumb points in the direction of current, then the direction in which our fingers encircle the wire will tell the direction of the magnetic field lines around the wire.

The Biot–Savart Law



According to this law, the magnetic field is proportional to the current and element length and inversely proportional to the square of the distance.

$dB = \frac{I dl \sin\theta}{r^2}$

Magnetic field due to a current-carrying circular coil

At the centre, it is calculated to be equal to B.

$$B = \frac{\mu_0 n I}{r}$$

Here,
n = Number of turns in the coil
I = Current flowing through the circular coil
r = Radius of the coil

- The magnetic field at a point on the axis of a circular current-carrying coil is given by

$$B = \frac{\mu_0 n I r^2}{2\left(r^2+x^2\right)^{\frac{3}{2}}}$$

Here,
n = Number of turns in the coil
I = Current flowing through the circular coil
r = Radius of the coil
x = Distance of the point from the centre of the coil

Ampere's circuital law

- The line integral of magnetic field induction $\vec{B}$ around a closed path in vacuum is equal to m_0 times the total current *I* threading it.

$$\int \vec{B}.\mathrm{d}\vec{l} = \mu_0 n I$$

Applications of Ampere's circuital law

- Magnetic field (*B*) due to a long straight conductor carrying current is given by $B = \frac{\mu_0}{4\pi}\left(\frac{2\mathrm{I}}{r}\right)$.

Here, *r* = radius and *I* = current

Solenoid

- It consists of an insulating long wire closely wound in the form of a helix.
- The magnetic field induction at a point as well as inside a solenoid is given by $B = \mu_0 n I$.
  Here, *n* is the number of turns of the solenoid and *I* is the current flowing in the solenoid.

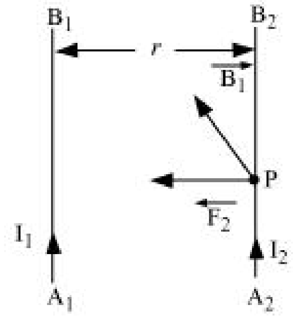
Toroid

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

The magnetic field (*B*) due to a toroid is given by $B = \frac{\mu_0 n I}{2\pi r}$.

Here, *r* = radius, *I* = current and *N* = no. of turns of the toroidal coil

Force between two parallel conductors carrying current



- Two linear parallel conductors carrying currents in the same direction attract each other.
- Two linear parallel conductors carrying currents in opposite directions repel each other.

Torque on a current carying loop

- A loop carrying current when placed in a uniform magnetic field experiences a torque that is given by
  - $\vec{\tau} = \vec{m} \times \vec{B}$
- Magnetic moment of a loop of area A carrying current I is given by $m = IA$.
- Direction of magnetic moment is determined by the right hand thumb rule . If we curl the fingers of the right hand inthedirectuion of the current the fdirection of the thumb gives the direction of the magnetic moment.
- DC motor works on this principle
  - It consists of a commutator that reverses the direction of the current after every half rotation
  - The direction of the force on the conductors of current carrying loop is determined by Fleming's left hand loop

Current carrying loop as magnetic dipole

Its upper face has current flowing in anti-clockwise direction. It has North polarity.
Its lower face has current flowing in clockwise direction. It has South polarity.
Magnetic dipole moment of current loop (*M*) is given by $M = NIA$.

Magnetic dipole moment of a revolving electron

An electron is in uniform circular motion in an orbit around nucleus constitutes current.

The current in atom has a magnetic dipole momentμ associated with it.

Magnetic dipole moment of revolving electron is given by $\mu = \frac{e}{2m} l$

where *l* = the angular momentum of the electron around the nucleus

e = charge on electron

m = mass of electron

Minimum value of the magnetic moment is given by μ_{min}

$\mu_{min} = \frac{eh}{4\pi m}$

μ_{min} is also known as Bohr magneton.

Moving Coil Galvanometer

- Its working is based on the fact that when a current carrying coil is placed in a magnetic field, it experiences a torque that deflects the coil connected with the pointer.
- The suspension wire provides the restoring or control torque.
- The relation between deflection θ and current I is given by $I = \frac{k}{NBA}\theta$.
    - $\frac{k}{NBA} = G$ is the galvanometer constant.
    - Current sensitivity $= \frac{NAB}{k}$
    - Voltage sensitivity = $\frac{NAB}{k}\frac{1}{R}$
- **Conversion of a Galvanometer into an Ammeter**
    - It can be converted into an ammeter by introducing a shunt resistance (r_s) of small value in parallel with it.
- **Conversion of a Galvanometer into a Voltmeter**
    - It can be converted into a voltmeter by introducing a series resistance of large value in series with it.
- **Advantages of a Moving Coil Galvanometer**
    - It is not affected by the Earth's magnetic field.
    - It has a high value of torque-weight ratio.
    - It is highly accurate and reliable.
    - Its scales are uniform.

- Sensitivity of moving coil galvanometer is given by $S = \left(\frac{NBA}{C}\right)$.

  Here,
  N = number of turns in the coil
  B = magnetic field
  A = area of the rectangular coil
  C = twist constant of the suspension wire

- Fractional error in a galvanometer is given by $\frac{dI}{I} = \frac{d\theta}{\theta}$.