📘 Chapter 4 – Moving Charges and Magnetism (Class 12 Physics)

Notes By - The Conclusion Daily

4.1 Introduction

- Electric current (moving charge) produces a **magnetic field**.
- Magnetic effects of current first observed by **Hans Christian Ørsted (1820)**.
- Magnetism and electricity are two aspects of the same phenomenon — **Electromagnetism**.
- This chapter explains how moving charges create magnetic fields and how these fields act on moving charges and currents.

4.2 Magnetic Force

Force on a moving charge in a magnetic field

- A charge qqq moving with velocity $\vec{v}$ in magnetic field $\vec{B}$ experiences a **magnetic force**:

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

- **Magnitude:**

$$F = qvBsin\theta$$

where θ = angle between $\vec{v}$ $and\ \vec{B}$

- **Direction:**
 Given by **Right-Hand Rule** — thumb = $\vec{v}$, fingers = $\vec{B}$, palm = direction of $\vec{F}$ for positive charge (opposite for negative).
- **Key properties:**
  - F=0 if charge is stationary or moves parallel to $\vec{B}$.
  - Magnetic force always **perpendicular** to $\vec{v}$ $and\ \vec{B}$
  - Does **no work** (since force ⊥ displacement ⇒ kinetic energy unchanged).

4.3 Motion in a Magnetic Field

Circular motion of charged particle

If a charge enters a **uniform magnetic field** perpendicularly:

$$qvB = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{qB}$$

- **Radius (r):** proportional to momentum (p = mv), inverse to charge and B.
- **Angular frequency:**

$$\omega = \frac{v}{r} = \frac{qB}{m}$$

- **Time period:**

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

→ Independent of velocity or radius.

Applications: Cyclotron, velocity selector, mass spectrometer.

4.4 Motion in Combined Electric and Magnetic Fields

If both electric field $\vec{E}$ and magnetic field $\vec{B}$ exist:

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

Velocity selector

- For no net deflection:

$$qE = qvB \Rightarrow v = \frac{E}{B}$$

→ Only particles with velocity v=E/Bv = E/Bv=E/B pass undeflected.

Example: Used in Thomson's e/m experiment, mass spectrometer.

4.5 Magnetic Field due to a Current Element

Biot–Savart Law

Gives magnetic field due to small current element.

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\, d\vec{l} \times \hat{r}}{r^2}$$

where

- I: current
- $\vec{dl}$: current element vector
- r: distance from element
- $\hat{r}$: unit vector from element to point

Magnitude:

$$dB = \frac{\mu_0}{4\pi}\frac{I\,dl\,\sin\theta}{r^2}$$

Direction: Perpendicular to the plane of $\vec{dl}$ and $\vec{r}$ (Right-hand rule).

4.6 Magnetic Field on the Axis of a Circular Current Loop

For a loop of radius RRR, current III, at point P on axis at distance x:

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

- **At center (x = 0):**

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

Direction: Given by Right-Hand Curl Rule — fingers along current, thumb shows B-direction (axis).

4.7 Ampere's Circuital Law

Statement:
The line integral of the magnetic field around a closed loop equals μ_0 times total current enclosed.

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I_{enclosed}$$

Use: To find B for symmetric current distributions (like solenoids, toroids).

4.8 Magnetic Field due to a Long Straight Current

For a long, straight conductor carrying current I:

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

where r = distance from wire.
Direction: Tangential (by Right-hand rule).

4.9 Magnetic Field inside a Solenoid

For an ideal solenoid of n turns per length, carrying current I:

$$B = \mu_0 n I$$

- Nearly uniform inside, zero outside (ideal case).
- **Direction:** Given by right-hand curl rule.
- Used to create strong, uniform magnetic fields.

4.10 Magnetic Field inside a Toroid

Toroid = solenoid bent into circular shape.

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

where N = total turns, r = radius to point inside core.

4.11 Force between Two Parallel Currents

Two parallel wires carrying currents I1,I2I_1, I_2I1,I2, separated by distance r:

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

- **Attractive** if currents in the same **direction**.
- **Repulsive** if currents are **opposite**.

Definition of Ampere:
1 A = current producing 2×10^{-7} N/m force between two infinitely long parallel conductors 1 m apart in vacuum.

4.12 Torque on a Current Loop in Magnetic Field

A current loop of area A, current I, placed in uniform magnetic field B experiences torque:

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

where magnetic moment $\vec{m} = I\vec{A}$

Magnitude:

$$\tau = IAB \sin \theta$$

→ Maximum when the loop plane is parallel to the field.

Application: Principle of **electric motor**.

4.13 Moving Coil Galvanometer (MCG)

Principle:
Torque on a current loop in a magnetic field is used to measure small currents.

Construction:

- Rectangular coil with N turns, area A, suspended in radial magnetic field B.
- Deflects through angle θ when current I flows.

Theory:

$$\begin{aligned} Deflecting\ torque &= NIAB \\ Restoring\ torque &= k\theta \end{aligned}$$

At equilibrium:

$$NIAB = k\theta \Rightarrow I = \frac{k}{NAB}\theta$$

$\Rightarrow I \propto \theta$

Sensitivity: Proportional to $\frac{NAB}{k}$.
Uses: Measures small currents, can be converted to voltmeter or ammeter.

4.14 Conversion of Galvanometer

To Ammeter:

- Connect low resistance (shunt) R_s in **parallel**.

$$R_s = \frac{I_g R_g}{I - I_g}$$

where I_g = full-scale deflection current, R_g = resistance of the galvanometer.

To Voltmeter:

- Connect high resistance R_v in **series**.

$$R_v = \frac{V}{I_g} - R_g$$

🧾 Key Formula Summary

Concept	Formula	Description
Magnetic force	$F = qvB\sin\theta$	Force on moving charge
Circular motion	$r = \frac{mv}{qB}$, $T = \frac{2\pi m}{qB}$	Path & time period
Velocity selector	$v = \frac{E}{B}$	No deflection condition
Biot–Savart law	$dB = \frac{\mu_0}{4\pi} \frac{I\, dl \sin\theta}{r^2}$	Field from element
Loop axis field	$B = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{\frac{3}{2}}}$	Field at axis point
Straight wire	$B = \frac{\mu_0 I}{2\pi r}$	Field near long wire
Solenoid	$B = \mu_0 nI$	Uniform field inside
Toroid	$B = \frac{\mu_0 NI}{2\pi r}$	Circular solenoid
Force per length	$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi r}$	Between parallel currents
Torque on loop	$\tau = IAB\sin\theta$	Torque due to field
Magnetic moment	$\vec{m} = I\vec{A}$	Strength of loop
Galvanometer relation	$I = \frac{k}{NAB}\theta$	Current vs deflection
Ammeter shunt	$R_s = \frac{I_g R_g}{I - I_g}$	Conversion formula
Voltmeter series	$R_v = \frac{V}{I_g} - R_g$	Conversion formula