# Moving Charges and Magnetism - Class 12 Physics Notes

## 1. Introduction

- Moving charges create magnetic fields
- Magnetic fields exert forces on moving charges and currents
- Unit of B: Tesla (T) = N/(A·m) = Wb/m²
- No magnetic monopoles exist
- $\mu_0 = 4\pi \times 10^{-7}$ T·m/A (permeability of free space)

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## 2. Magnetic Force

**Lorentz Force:** $F = q(E + v \times B)$

**Magnetic Force:** $F = q(v \times B) = qvB \sin\theta$

**Properties:**

- Perpendicular to both v and B
- Direction: Right-hand rule
- Maximum when $\theta = 90°$: $F = qvB$
- Zero when $\theta = 0°$ or $180°$
- Does no work ($F \perp v$)

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## 3. Motion in Magnetic Field

### (a) $v \perp B$ (Perpendicular)

**Circular motion**

- **Radius:** $r = mv/(qB)$
- **Time period:** $T = 2\pi m/(qB)$
- **Frequency:** $f = qB/(2\pi m)$ (cyclotron frequency)
- **Angular velocity:** $\omega = qB/m$

### (b) $v \parallel B$ (Parallel)

**Straight line** - No force, constant velocity

### (c) v at angle θ

**Helical motion**

- $v_\parallel = v\cos\theta$ (along B)
- $v_\perp = v\sin\theta$ (perpendicular to B)
- **Radius:** $r = mv\sin\theta/(qB)$
- **Pitch:** $p = 2\pi mv\cos\theta/(qB)$

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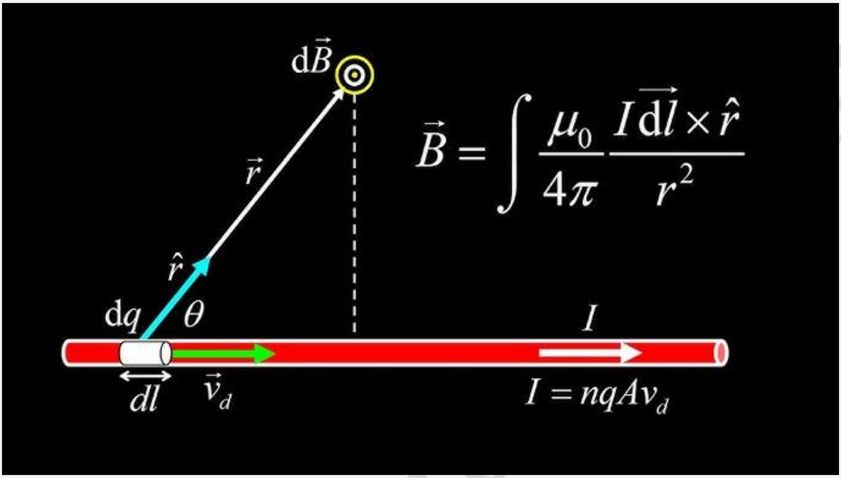
## 4. Magnetic Field Due to Current Element - Biot-Savart Law

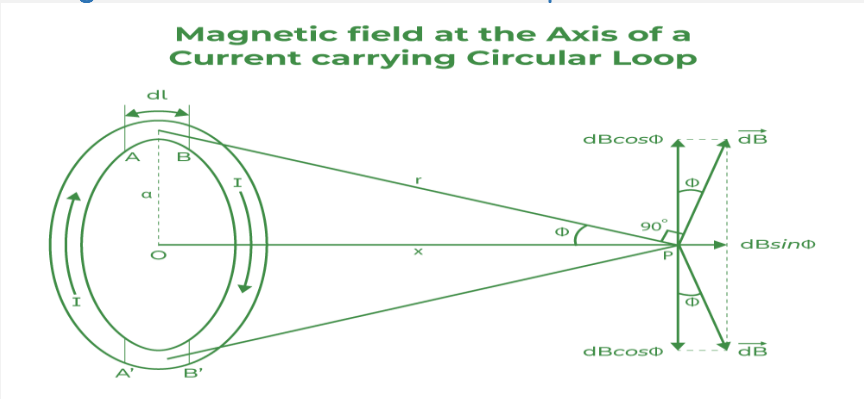



**$dB = (\mu_0/4\pi) \times (I\ dl\ \sin\theta)/r^2$**

**Vector form:** $dB = (\mu_0/4\pi) \times I(dl \times \hat{r})/r^2$

- Direction: Right-hand thumb rule
- $dB \propto I, dl, \sin\theta, 1/r^2$
- Total field: $B = \int dB$

## 5. Magnetic Field on Axis of Circular Loop




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

**At center (x = 0):** $B = \mu_0 I/(2R)$

For N turns: $\mathbf{B = \mu_0 NI/(2R)}$

**Far from loop (x >> R):** $B = \mu_0 M/(2\pi x^3)$, where $M = IA$

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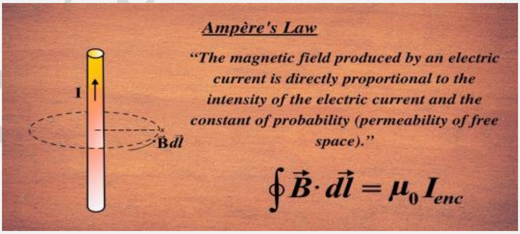
## 6. Ampere's Circuital Law



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

- Line integral of B around closed path = $\mu_0$ × net current through path
- Useful for symmetric configurations
- Analogous to Gauss's law

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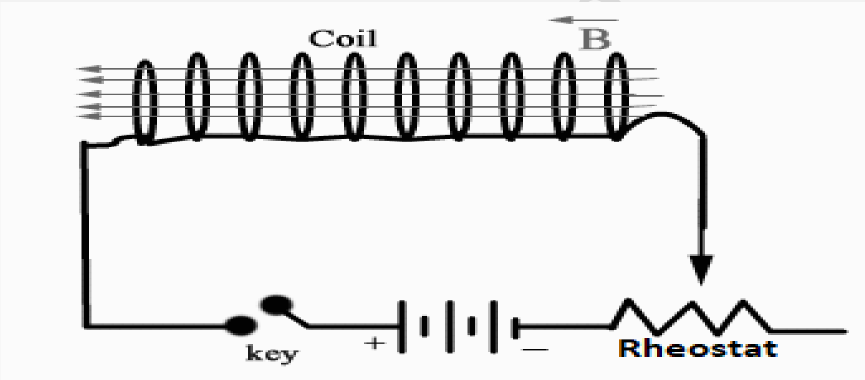
## 7. Solenoid



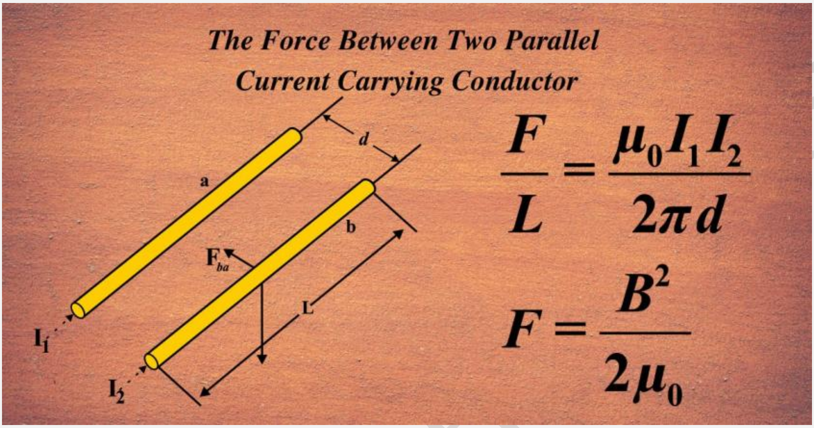

**$B = \mu_0 nI = \mu_0 NI/L$**

Where n = N/L (turns per unit length)

**Properties:**

- Uniform field inside, parallel to axis
- Field outside ≈ 0
- At ends: $B = \mu_0 nI/2$
- Acts like bar magnet

## 8. Force Between Two Parallel Currents

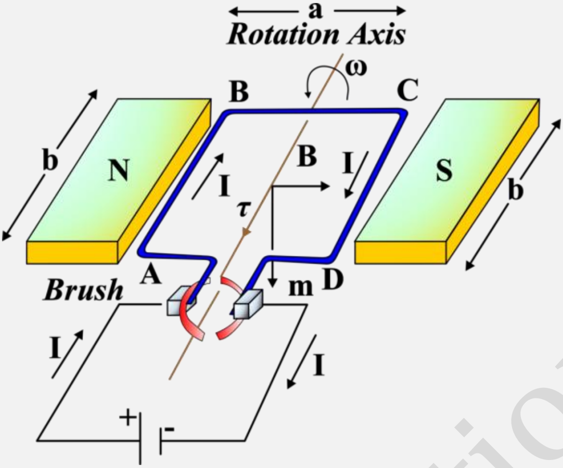



**$F/L = \mu_0 I_1 I_2/(2\pi d)$**

- Same direction currents: **Attractive**
- Opposite direction currents: **Repulsive**

**Definition of Ampere:** Two parallel wires 1m apart carrying 1A each experience force of $2\times10^{-7}$ N/m

## 9. Torque on Current Loop




**$\tau = NBIA \sin\theta = MB \sin\theta$**

Where:

- M = NIA (magnetic dipole moment)
- θ = angle between B and normal to loop

**Properties:**

- τ_max = MB (when θ = 90°)
- τ = 0 (when θ = 0° or 180°)
- Tends to align loop perpendicular to B

**Potential Energy:** $U = -MB \cos\theta$

**Work done:** $W = MB(\cos\theta_1 - \cos\theta_2)$

## 10. Magnetic Dipole

**Magnetic Moment:** M = NIA

- Direction: Perpendicular to loop (right-hand rule)
- Unit: $A \cdot m^2$

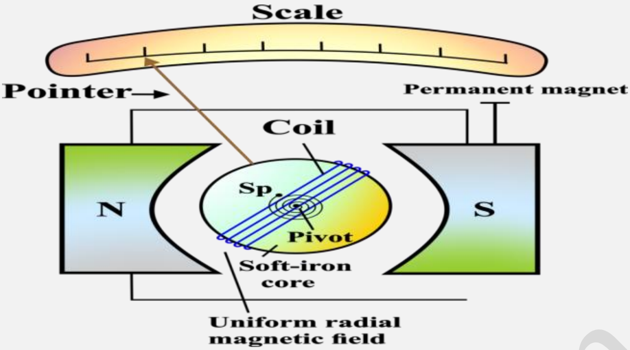
**Field of dipole (far field):**

- On axis: $B = \mu_0 M/(2\pi x^3)$
- On equator: $B = \mu_0 M/(4\pi x^3)$

**Torque:** $\tau = M \times B = MB \sin\theta$

**Energy:** $U = -M \cdot B = -MB \cos\theta$

## 11. Moving Coil Galvanometer




**Principle:** Torque on current-carrying coil in magnetic field

**Components:**

- Coil (N turns, area A) on soft iron core
- Radial magnetic field (B)
- Spring (restoring torque)
- Pointer and scale

**Working:**

- Deflecting torque: $\tau_d = NBIA$
- Restoring torque: $\tau_r = k\phi$
- At equilibrium: $\boldsymbol{\phi = (NBA/k)I}$
- $\boldsymbol{I \propto \phi}$ (linear scale)

**Current Sensitivity:** $I_s = \varphi/I = NBA/k$

**Voltage Sensitivity:** $V_s = \varphi/V = NBA/(kR)$

## 12. Conversion of Galvanometer

### (a) To Ammeter

**Add low resistance (shunt S) in parallel**

$$S = I_g G/(I - I_g)$$

Where:

- $I_g$ = full scale current of galvanometer
- G = galvanometer resistance
- I = desired range

Properties:

- Low resistance device
- Connected in series in circuit

### (b) To Voltmeter

**Add high resistance (R) in series**

$$R = (V/I_g) - G$$

Where V = desired voltage range

Properties:

- High resistance device
- Connected in parallel in circuit

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## Key Formulas

| **Concept** | **Formula** |
|---|---|
| **Magnetic force** | $F = qvB \sin\theta$ |
| **Circular motion radius** | $r = mv/(qB)$ |
| **Time period** | $T = 2\pi m/(qB)$ |
| **Cyclotron frequency** | $f = qB/(2\pi m)$ |
| **Pitch** | $p = 2\pi mv \cos\theta/(qB)$ |
| **Biot-Savart law** | $dB = (\mu_0/4\pi)(I\ dl \sin\theta)/r^2$ |
| **Circular loop (center)** | $B = \mu_0 NI/(2R)$ |
| **Circular loop (axis)** | $B = \mu_0 IR^2/[2(R^2+x^2)^\wedge(3/2)]$ |
| **Ampere's law** | $\oint B\cdot dl = \mu_0 I$ |
| **Solenoid** | $B = \mu_0 nI$ |
| **Force between wires** | $F/L = \mu_0 I_1 I_2/(2\pi d)$ |

| Concept | Formula |
|---|---|
| **Torque on loop** | $\tau = NBIA \sin\theta = MB \sin\theta$ |
| **Magnetic moment** | $M = NIA$ |
| **Potential energy** | $U = -MB \cos\theta$ |
| **Galvanometer** | $\phi = (NBA/k)I$ |
| **Ammeter shunt** | $S = I_gG/(I-I_g)$ |
| **Voltmeter resistance** | $R = V/I_g - G$ |

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## Important Constants

- $\mu_0 = 4\pi \times 10^{-7}$ T·m/A
- 1 Tesla = $10^4$ Gauss