📘 Chapter 3 – Current Electricity (Class 12 Physics)

3.1 Introduction

- **Static charges** (at rest) → studied in electrostatics.
- **Moving charges** → constitute **electric current**.
- **Examples**: Lightning (non-steady), electric bulb, torch, cell-driven clock (steady).
- This chapter studies **laws of steady currents** and how they behave in conductors.

3.2 Electric Current

Definition:
Rate of flow of charge across a cross-sectional area.

$$I = \frac{dq}{dt}$$

Units: Ampere (A)
1 Ampere = flow of 1 coulomb per second (1 C/s).

Direction:

- By convention, **direction of current** = direction of **positive charge flow**.
- Actual electrons move in opposite directions.

Typical values:

- Domestic appliances: few amperes
- Lightning: 10^4–10^5 A
- Human nerves: microamperes (μA)

3.3 Electric Currents in Conductors

- In metals, **free electrons** move in the background of **fixed positive ions**.
- Without electric field → random motion → no net current.
- When **electric field (E)** applied → electrons accelerate opposite to E → net drift = **electric current**.
- **Steady current is maintained** when supply (like a battery) replenishes charges continuously.

3.4 Ohm's Law

Statement:
Potential difference across a conductor is directly proportional to current,

$$V \propto I \quad \Rightarrow \quad V = IR$$

- **R** → Resistance (constant for given material, shape, temperature).
- **Unit:** Ohm (Ω)

Dependence on Geometry:

$$R = \rho\frac{l}{A}$$

- ρ(rho): Resistivity (depends on material)
- l: length of conductor
- A: cross-sectional area

Key Points:

- R∝l (longer wire → more resistance)
- R∝1/A (thicker wire → less resistance)
- Resistivity ρ\rho = constant for given material temperature.

Vector form:

$$\vec{E} = \rho\,\vec{j} \quad or \quad \vec{j} = \sigma\,\vec{E}$$

where σ=1/ρ is **conductivity**.

3.5 Drift of Electrons and Origin of Resistivity

Concept:

- Electrons collide with ions frequently → random directions → average velocity = 0 (no field).
- With electric field → net drift opposite to E → **Drift velocity (v_e)**.

Formula:

$$v_b = \frac{eE\tau}{m}$$

where

- e: charge of electron
- E: electric field
- τ(tau): relaxation time (average time between collisions)
- m: electron mass

Current density:

$$\vec{j} = ne\vec{v}_d$$

→ Combining gives:

$$\vec{j} = \frac{ne^2\tau}{m}\vec{E}$$

Comparing with $\vec{j} = \sigma\vec{E}$

$$\sigma = \frac{ne^2\tau}{m} \qquad \rho = \frac{m}{ne^2\tau}$$

3.5.1 Mobility

$$\mu = \frac{|v_d|}{E} = \frac{e\tau}{m}$$

- Unit: $m^2/(V \cdot s)$
- Conductivity $\sigma = ne\mu$

3.6 Limitations of Ohm's Law

Ohm's Law not valid when:

1. **V not ∝ I** (non-linear relation)
2. **Depends on polarity** (as in **diodes**)
3. **Multiple values of V for same I** (non-unique; e.g., GaAs)

3.7 Resistivity of Materials

- **Conductors:** $10^{-8} – 10^{-6}$ Ω·m (metals)
- **Semiconductors:** intermediate range
- **Insulators:** up to 10^{18} Ω·m

3.8 Temperature Dependence of Resistivity

For metals:

$$\rho T = \rho_0[1 + \alpha(T - T_0)]$$

- α(alpha): temperature coefficient of resistivity (°C^{-1})

Behaviour:

- Metals → ρ(rho) increases with T (α positive)
- Semiconductors → ρ(rho) decreases with T (α negative)
- Nichrome → weak dependence on T (used in standard resistors)

Reason:

$$\rho \propto \frac{1}{n\tau}$$

- In metals: n constant, τ decreases with T → ρ ↑
- In semiconductors: n increases with T → ρ ↓

3.9 Electrical Energy and Power

Work done:

$$\Delta W = IV\Delta t$$

Power:

$$P = IV = I^2R = \frac{V^2}{R}$$

Applications:

- Heating devices (bulbs, heaters)
- Power transmission → high voltage reduces loss:

$$P_{loss} = I^2 R_C = \frac{P^2 R_C}{V^2}$$

→ higher V ⇒ smaller loss.

3.10 Cells, EMF, and Internal Resistance

EMF (ε): potential difference between terminals of a cell **in an open circuit**.
Terminal Voltage (V): when current I flows,

$$V = \varepsilon - Ir$$

where r = internal resistance.

Current in circuit:

$$I = \frac{\varepsilon}{R + r}$$

Max current : $I_{max} = \frac{\varepsilon}{R}$

3.11 Cells in Series and Parallel

Series Combination:

$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2 + \ldots\ldots.,\ r_{eq} = r_1 + r_2 + \ldots\ldots$

(If opposing → subtract emf)

Parallel Combination:

$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + \ldots\ldots$

$$\varepsilon_{eq} = \frac{\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2}}{\frac{1}{r_1} + \frac{1}{r_2}}$$

3.12 Kirchhoff's Rules

1. **Junction Rule (Charge Conservation):**
   Sum of currents entering = Sum leaving.

2. **Loop Rule (Energy Conservation):**
   Algebraic sum of potential differences around a loop = 0.

Used to solve **complex circuits** not reducible to simple series/parallel.

3.13 Wheatstone Bridge

Arrangement: Four resistors in a diamond shape.
Condition for Balance (no current through galvanometer):

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

→ Used to measure **unknown resistance (R_4)**:

$$R_4 = \frac{R_2 R_3}{R_1}$$

Meter Bridge: Practical device using Wheatstone principle.

Key Formulas Summary

Concept	Formula	Description
Current	$I = \frac{dq}{dt}$	Rate of charge flow
Ohm’s Law	$V = IR$	Linear relation
Resistance	$R = \frac{\rho l}{A}$	Depends on geometry
Drift Velocity	$v_d = \frac{eE\tau}{m}$	Electron average drift
Current Density	$j = nev_d$	Current per unit area
Resistivity	$\rho = \frac{m}{ne^2\tau}$	Property of material
Power	$P = IV = I^2R = \frac{V^2}{R}$	Joule heating
EMF relation	$V = \varepsilon - Ir$	Terminal voltage
Series cells	$\varepsilon_{eq} = \sum \varepsilon \quad r_{eq} = \sum r$	Combined emf
Parallel cells	$\frac{1}{r_{eq}} = \sum \frac{1}{r}$	Combined resistance
Wheatstone balance	$\frac{R_1}{R_2} = \frac{R_3}{R_4}$	No current through galvanometer