Engineering Physics (2025)
Course code 25PY101
Unit 1: Metals and Semiconductors

Course Instructor:
Dr. Sreekar Guddeti
Assistant Professor in Physics
Department of Science and Humanities
Vignan's Foundation for Science, Technology and Research

October 16, 2025

Unit 1 Plan

1. Condensed matter
2. Metals
3. Classical free electron theory
4. Expression of electrical conductivity
5. Introduction to Semiconductors
6. Electrical conductivity of semiconductors
7. Hall effect
8. Concept of Panchabhuta

Unit 1 Plan

Conductivity

In a semiconductor, there are two types of charge carriers – electrons and holes. Each carrier is associated with corresponding mobility. Thus, the mobility of electrons is μ_e and that of holes is μ_h.
From the classical free electron theory, the conductivity in terms of mobility and charge density is given by

$$\sigma = ne\mu$$

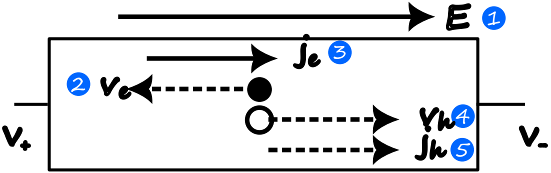
In semiconductors, there are **two channels** for conduction. Thus, the conductivity adds up and is given by

$$\sigma = ne\mu_e + pe\mu_h$$

Key Insight

Both electrons and holes contribute to conductivity

Drift motion of electrons and holes



- Under electric field, electron and hole drift motion is **anti-parallel**.

$$\mathbf{F}_e = -q_e \mathbf{E}, \qquad \mathbf{F}_h = +q_h \mathbf{E}.$$

- The sign of their charges are opposite.
- Electron and hole drift current direction is **parallel**.
- The total drift current density is given by $\mathbf{j}_{\text{drift}} = \mathbf{j}_e + \mathbf{j}_h$.
- Drift current is proportional to electric field. $\mathbf{j}_{\text{drift}} = \sigma_e \mathbf{E} + \sigma_h \mathbf{E}$
- Conductivity is written in terms of carrier density and mobility

$$\sigma_e = ne\mu_e, \qquad \sigma_h = pe\mu_h,$$

- The drift conductivity is given by

$$\sigma_{\text{drift}} = ne\mu_e + pe\mu_h$$

Intrinsic semiconductor

For the intrinsic case, the number density of electrons equals the number density of holes

$$n = p = n_i$$

Thus, the conductivity is given by

$$\sigma = n_i e\left(\mu_e + \mu_h\right)$$

Carrier density	cm^{-3}
$n_{\mathrm{i-Si}}$	10^{10}
n_{Cu}	10^{22}

Mobility	$\mathrm{cm}^2\,\mathrm{V}^{-1}\,\mathrm{s}^{-1}$
μ_e [Si]	1400
μ_h [Si]	500
μ [Cu]	40

Estimate: Conductivity of intrinsic Si

Compare it with conductivity of copper.

Key Insight

Though the carrier mobility in metals is less than in semiconductors, **very much higher** carrier density leads to higher metallic conductivity.

Extrinsic semiconductor

- n-type: Electrons are **majority** charge carriers

$$n \gg p, \quad \text{so that} \quad ne\mu_e \gg pe\mu_h$$

$$\therefore \sigma \simeq ne\mu_e$$

- p-type: Holes are **majority** charge carriers

$$p \gg n, \quad \text{so that} \quad pe\mu_h \gg ne\mu_e$$

$$\therefore \sigma \simeq pe\mu_h$$

Material	n (in cm^{-3})	σ (in $\mathrm{S\,m}^{-1}$)
i-Si	10^{10}	10^{-4}
1 ppm n-Si	10^{16}	2

Estimate: Conductivity of extrinsic n-type Si

P doping is $5 \times 10^{16}\,\mathrm{cm}^{-3}$. Compare it with conductivity of intrinsic-Si.

Key Insight

Doping of the order of 1 ppm increases conductivity of silicon by six orders of magnitude.