Part 1 – Semiconductor Fundamentals, Energy Bands and Semiconductor Materials

1.1 Learning Objectives

After studying this part, students will be able to:

1. Explain what a semiconductor is.
2. Distinguish between conductors, semiconductors and insulators.
3. Explain the atomic structure and covalent bonding of semiconductor materials.
4. Understand the formation of electron–hole pairs.
5. Explain the concept of holes as positive charge carriers.
6. Understand valence band, conduction band and forbidden energy gap.
7. Explain intrinsic semiconductors.
8. Understand the effect of temperature on semiconductor conductivity.
9. Define mobility, conductivity, resistivity and current density.
10. Apply the basic semiconductor formulae to numerical problems.

1.2 Introduction to Semiconductor Electronics

Semiconductor electronics is based on materials whose electrical conductivity lies between that of conductors and insulators.

The electrical properties of semiconductors can be controlled by:

- Temperature
- Addition of impurities (doping)
- Electric field
- Light
- Junction formation

The most commonly used semiconductor materials are:

- Silicon (Si)
- Germanium (Ge)

Silicon is the most widely used semiconductor material in modern electronic devices because of its suitable energy gap, thermal stability and abundant availability.

1.3 Classification of Materials According to Electrical Conductivity

Materials can broadly be classified as:

1. Conductors
2. Semiconductors
3. Insulators

1.3.1 Conductors

Conductors have a large number of free charge carriers.

Examples:

- Copper
- Aluminium
- Silver

They have very high electrical conductivity and very low electrical resistance.

1.3.2 Semiconductors

Semiconductors have electrical conductivity between that of conductors and insulators.
Examples:

- Silicon (Si)
- Germanium (Ge)

Their conductivity increases significantly when temperature increases.
Therefore, semiconductors generally have a **negative temperature coefficient of resistance**.

1.3.3 Insulators

Insulators have very few or practically no free charge carriers under ordinary conditions.
Examples:

- Glass
- Rubber
- Mica
- Plastic

Their electrical conductivity is extremely small.

1.4 Important Comparison

Property	Conductor	Semiconductor	Insulator
Electrical conductivity	Very high	Intermediate	Very low
Free charge carriers	Very large	Limited	Almost negligible
Effect of temperature	Resistance generally increases	Resistance decreases	Conductivity generally remains very low under ordinary conditions.
Temperature coefficient	Positive	Negative	Generally small
Examples	Cu, Ag, Al	Si, Ge	Glass, rubber

1.5 Semiconductor Materials

The most important elemental semiconductor materials are:

Silicon

Atomic number: **Z = 14**
Electronic configuration: **2, 8, 4**
Thus, silicon has **four valence electrons**.

Germanium

Atomic number: **Z = 32**
Electronic configuration: **2, 8, 18, 4**
Germanium also has **four valence electrons**.
Therefore, both silicon and germanium belong to **Group 14** of the periodic table.

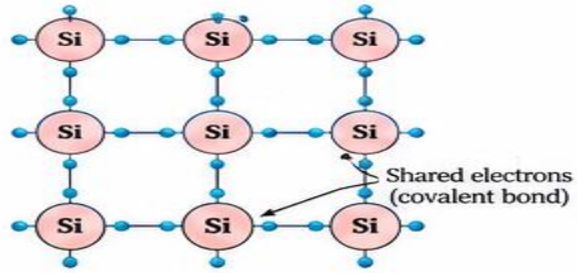
1.6 Covalent Bonding in Silicon

A silicon atom has four valence electrons.

Each silicon atom shares its four valence electrons with four neighbouring silicon atoms.
As a result, each silicon atom forms four covalent bonds.
In a pure silicon crystal:

- Each silicon atom is surrounded by four neighbouring silicon atoms.
- Electrons are shared between neighbouring atoms.
- The shared electrons participate in covalent bonds.
- At very low temperature, these electrons are strongly bound to their atoms.

Figure 14.1: Covalent Bonding in Silicon



Each Si atom shares its 4 valence electrons with four neighbouring Si atoms.

1.7 Formation of Electron–Hole Pairs

At absolute zero temperature, a pure semiconductor behaves approximately like an insulator because its electrons remain bound in covalent bonds.
When temperature increases, some covalent bonds may break.
The electron released from a broken covalent bond becomes a **free electron**.
The absence of the electron in the covalent bond is called a **hole**.
Thus, thermal energy can produce an: **electron–hole pair**
The process may be represented as:
Covalent bond + thermal energy → free electron + hole

1.8 Electron as a Charge Carrier

An electron has charge: $\mathbf{q = -e}$ where $\mathbf{e = 1.6 \times 10^{-19}\ C}$
Free electrons can move through the semiconductor crystal and contribute to electric current.

1.9 Hole as a Charge Carrier

A hole represents the absence of an electron in a covalent bond.
Although a hole is not a physical particle like an electron, it behaves as a positive charge carrier.
Effective charge of a hole: $\mathbf{q = +e}$
When a neighbouring electron moves into a vacant position, the vacancy appears to move in the opposite direction.
Thus, the motion of holes can be treated as the motion of positive charge carriers.

1.10 Electron–Hole Pair Generation

The process in which an electron–hole pair is created is called **generation**.
The reverse process is called **recombination**.

Generation

Thermal energy → electron + hole

Recombination

A free electron may combine with a hole

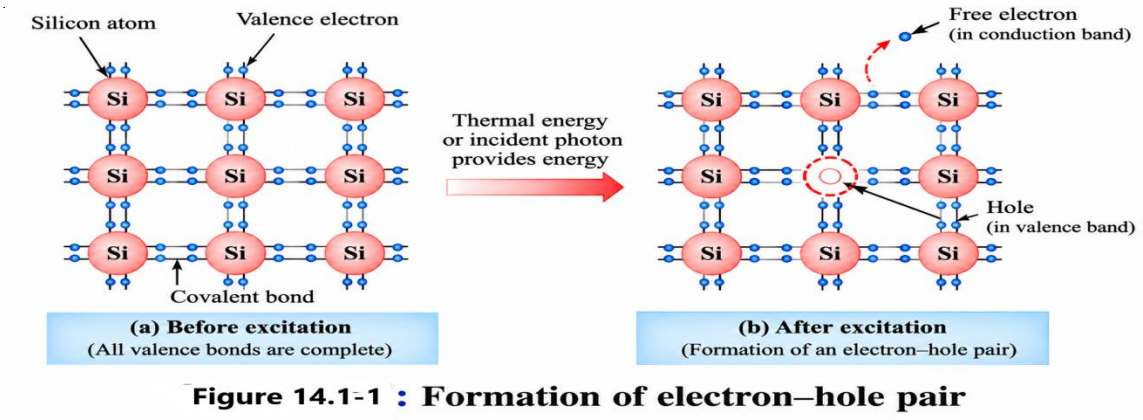


Figure 14.1-1 : Formation of electron–hole pair

Electron + hole → energy released

At thermal equilibrium, generation and recombination processes occur continuously.

1.11 Energy Band Theory

In an isolated atom, electrons occupy discrete energy levels.

When a large number of atoms come together to form a solid, these discrete energy levels split into a large number of closely spaced energy levels.

These closely spaced energy levels form **energy bands**.

The two most important bands in semiconductor physics are:

1. Valence band
2. Conduction band

Between them lies the: **Forbidden energy gap**

1.12 Valence Band

The valence band is the highest energy band that is normally occupied by electrons in a solid at absolute zero temperature.

Electrons in the valence band are associated with the bonding structure of the material.

They generally do not contribute significantly to electrical conduction unless they acquire sufficient energy.

1.13 Conduction Band

The conduction band is the energy band above the valence band.

Electrons that acquire sufficient energy to enter the conduction band become relatively free to move through the crystal.

These electrons can therefore contribute to electrical conduction.

1.14 Forbidden Energy Gap

The energy region between the valence band and conduction band in which electrons cannot normally exist is called the **forbidden energy gap**.

It is represented by: $\mathbf{E_g = E_C - E_V}$

Where: E_g = energy gap , E_C = energy at the bottom of the conduction band , E_V = energy at the top of the valence band

1.15 Energy Band Diagram

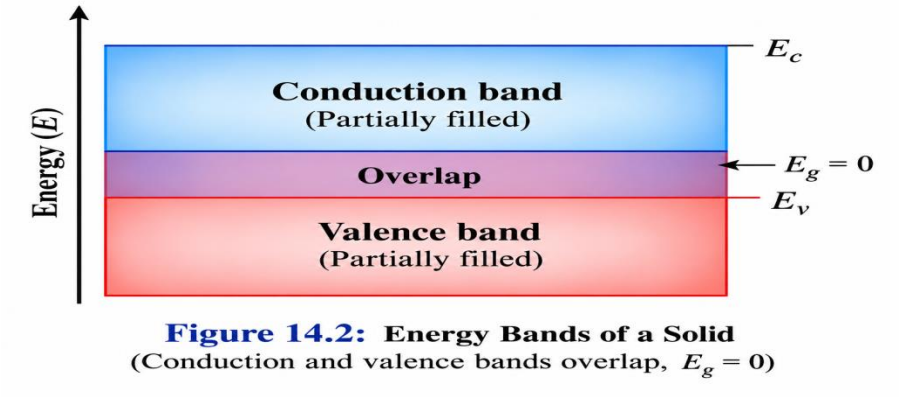


Figure 14.2: Energy Bands of a Solid
(Conduction and valence bands overlap, $E_g = 0$)

1.16 Energy Band Gap of Important Materials

Approximate band gaps at room temperature:

Silicon: Eg ≈ 1.1 eV

Germanium: Eg ≈ 0.7 eV

For comparison, insulators generally have much larger forbidden energy gaps.

1.17 Conductors, Semiconductors and Insulators from Band Theory

The electrical behaviour of a material can be understood from its energy-band structure.

Conductors

In a conductor:

- The valence band may overlap with the conduction band, or
- The conduction band may be partially filled.

Therefore, electrons can move easily.

Hence: **High electrical conductivity**

Semiconductors

In a semiconductor:

- Valence band is almost completely filled.
- Conduction band is almost empty at low temperature.
- A relatively small forbidden energy gap exists between them.

A small amount of energy can therefore excite electrons into the conduction band.

Hence: **Moderate electrical conductivity**

Insulators

In an insulator:

- Valence band is almost completely filled.
- Conduction band is almost empty.
- Forbidden energy gap is large.

Therefore, ordinary thermal energy is generally insufficient to move many electrons into the conduction band.
Hence: **Very low electrical conductivity**

1.18 Energy Band Diagram Comparison

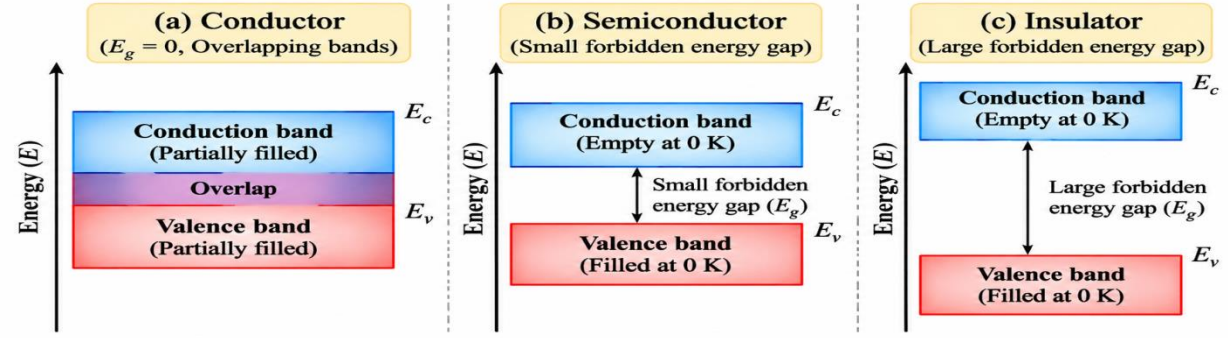


Figure 14.3: Energy Band Diagram Comparison
(Energy band diagram of conductor, semiconductor and insulator)

1.19 Intrinsic Semiconductor

A pure semiconductor without any intentionally added impurity is called an **intrinsic semiconductor**.
Examples:

- Pure silicon
- Pure germanium

In an intrinsic semiconductor: **Number of electrons = Number of holes**
Therefore: **$n = p = n_i$**
Where:

- n = electron concentration
- p = hole concentration
- n_i = intrinsic carrier concentration

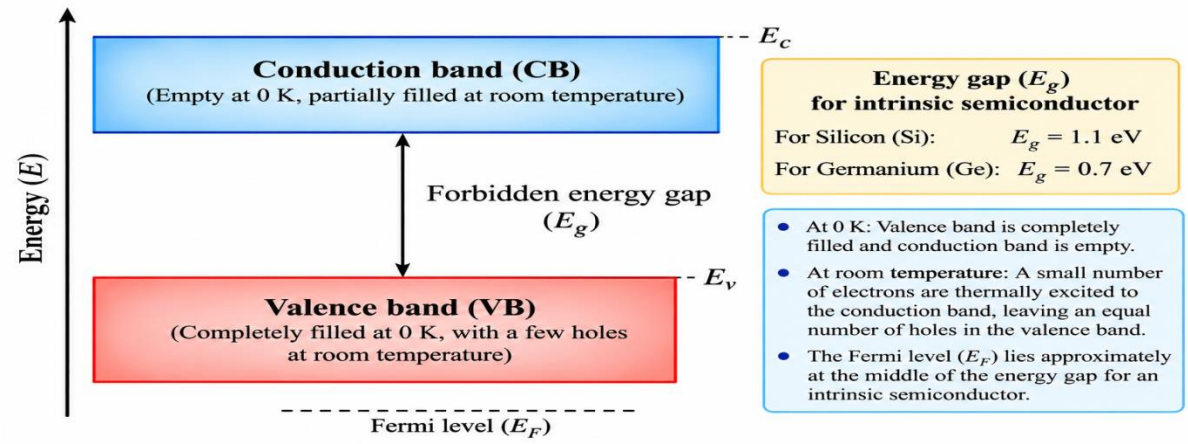


Figure 14.5: Energy band diagram of an intrinsic semiconductor
(for Si and Ge)

1.20 Intrinsic Carrier Concentration

The number of thermally generated electrons per unit volume in a pure semiconductor is called the intrinsic carrier concentration.
For an intrinsic semiconductor: **n = p**
Therefore: **$n = p = n_i$**
The product of electron and hole concentrations in a semiconductor is related to intrinsic carrier concentration by the mass-action relation, which becomes especially important for doped semiconductors**:**

$$np = n_i^2$$

This relation will be used in greater detail in Part 2.

1.21 Temperature Dependence of Semiconductor Conductivity

At low temperature, only a small number of covalent bonds are broken.
Therefore:

- Few free electrons are present.
- Few holes are present.
- Conductivity is low.

When temperature increases:

- More covalent bonds break.
- More electron–hole pairs are generated.
- Number of charge carriers increases.
- Conductivity increases.

Thus: **Temperature ↑ → Carrier concentration ↑ → Conductivity ↑**
Consequently: **Resistance ↓**
This is opposite to the usual behaviour of metallic conductors.

1.22 Negative Temperature Coefficient

For a semiconductor: **Temperature ↑ → Resistance ↓**
Therefore, semiconductors have a **negative temperature coefficient of resistance**.
For a conductor such as copper: **Temperature ↑ → Resistance ↑**
This difference is frequently tested in conceptual questions.

1.23 Electrical Conductivity of a Semiconductor

The conductivity of a semiconductor is due to both:

- Electrons
- Holes

The conductivity is:

$$\sigma = e(n\mu_e + p\mu_h)$$

Where:

- σ = electrical conductivity
- e = magnitude of electronic charge
- n = electron concentration
- p = hole concentration
- μ_e = electron mobility
- μ_h = hole mobility

1.24 Conductivity of an Intrinsic Semiconductor

For an intrinsic semiconductor: $\mathbf{n = p = n_i}$

Therefore: $\mathbf{\sigma_i = e\, n_i\, (\mu_e + \mu_h)}$

This is an important formula for numerical problems.

1.25 Resistivity

Electrical resistivity is the reciprocal of conductivity.

Therefore: $\mathbf{\rho = 1/\sigma}$

Using the conductivity expression: $\mathbf{\rho = 1/[e(n\mu_e + p\mu_h)]}$

For an intrinsic semiconductor: $\mathbf{\rho_i = 1/[e\, n_i\, (\mu_e + \mu_h)]}$

1.26 Mobility of Charge Carriers

Mobility describes how easily a charge carrier moves through a material under an applied electric field.

It is defined as:

$$\mu = \frac{v_d}{E}$$

Where:

- μ = mobility
- v_d = drift velocity
- E = electric field

For electrons:

$$\mu_e = \frac{v_{d_e}}{E}$$

For holes:

$$\mu_h = \frac{v_{d_h}}{E}$$

The SI unit of mobility is: $\mathbf{m^2\, V^{-1}\, s^{-1}}$

1.27 Current Density

Current density is defined as electric current per unit cross-sectional area.

$$\mathbf{J = I/A}$$

For a semiconductor: $\mathbf{J = \sigma E}$

Using the conductivity expression: $\mathbf{J = e(n\mu_e + p\mu_h)E}$

Thus, current density is contributed by both electrons and holes.

1.28 Solved Example 1 — Intrinsic Semiconductor

Problem

An intrinsic semiconductor has an electron concentration of: $\mathbf{n_i = 1.0 \times 10^{16}\ m^{-3}}$

Find the hole concentration.

Solution

For an intrinsic semiconductor: $\mathbf{n = p = n_i}$

Therefore: $\mathbf{p = 1.0 \times 10^{16}\ m^{-3}}$

Answer: **Hole concentration = $1.0 \times 10^{16}\ m^{-3}$**

1.29 Solved Example 2 — Conductivity

An intrinsic semiconductor has: $\mathbf{n_i = 2 \times 10^{16}\ m^{-3}}$
Electron mobility: $\mathbf{\mu_e = 0.14\ m^2\ V^{-1}\ s^{-1}}$
Hole mobility: $\mathbf{\mu_h = 0.05\ m^2\ V^{-1}\ s^{-1}}$
Calculate its conductivity.

Solution

For an intrinsic semiconductor: $\mathbf{\sigma_i = e\ n_i\ (\mu_e + \mu_h)}$
Substituting:

$$\mathbf{\sigma i = (1.6 \times 10^{-19})(2 \times 10^{16})(0.14 + 0.05)}$$

Or $\mathbf{\sigma_i = (1.6 \times 10^{-19})(2 \times 10^{16})(0.19)}$
Therefore: $\mathbf{\sigma_i \approx 6.08 \times 10^{-4}\ S\ m^{-1}}$

Answer: $\mathbf{\sigma_i \approx 6.08 \times 10^{-4}\ S\ m^{-1}}$

1.30 Solved Example 3 — Resistivity

If the conductivity of a semiconductor is: $\mathbf{\sigma = 2 \times 10^{-3}\ S\ m^{-1}}$, calculate its resistivity.

Solution

Since, $\mathbf{\rho = 1/\sigma}$
Therefore:

$$\mathbf{\rho = 1/(2 \times 10^{-3})}$$

Or, $\mathbf{\rho = 500\ \Omega\ m}$

Answer: $\mathbf{\rho = 500\ \Omega\ m}$

1.31 Solved Example 4 — Mobility

A charge carrier has drift velocity: $\mathbf{v_d = 2 \times 10^{-3}\ m\ s^{-1}}$ in an electric field: $\mathbf{E = 100\ V\ m^{-1}}$
Find its mobility.

Solution

Since, $\mathbf{\mu = v_d/E}$
Therefore: $\mathbf{\mu = (2 \times 10^{-3})/100}$ **Or** $\mathbf{\mu = 2 \times 10^{-5}\ m^2\ V^{-1}\ s^{-1}}$

Answer: $\mathbf{\mu = 2 \times 10^{-5}\ m^2\ V^{-1}\ s^{-1}}$

1.32 Important Conceptual Points

Point 1: A semiconductor is neither a good conductor nor a good insulator.
Point 2: Silicon and germanium have four valence electrons.
Point 3: Pure silicon and germanium are intrinsic semiconductors.
Point 4: A hole behaves as a positive charge carrier.
Point 5: Both electrons and holes contribute to semiconductor current.
Point 6: Semiconductor conductivity increases with temperature.
Point 7: A semiconductor has a relatively small forbidden energy gap.
Point 8: For an intrinsic semiconductor: $\mathbf{n = p = n_i}$
Point 9: The conductivity of a semiconductor is: $\mathbf{\sigma = e(n\mu_e + p\mu_h)}$
Point 10: The mobility of a charge carrier is: $\mathbf{\mu = v_d/E}$

1.33 NEET/JEE Quick Insights

Insight 1: For an intrinsic semiconductor: **$n = p$**
Therefore, if electron concentration is known, hole concentration is immediately known.

Insight 2: If temperature increases: **$n_i \uparrow$**
Therefore: **$\sigma \uparrow$** and: **$\rho \downarrow$**

Insight 3" For an intrinsic semiconductor: **$\sigma_i = e\, n_i\, (\mu_e + \mu_h)$**
Thus, conductivity depends on:

- Intrinsic carrier concentration
- Electron mobility
- Hole mobility

Insight 4: The current in a semiconductor is carried by **two types of charge carriers**:
Electrons + Holes

Insight 5: Remember the basic sequence: **Temperature ↑ → Electron–hole pairs ↑ → Charge carriers ↑**
→ Conductivity ↑ → Resistivity ↓
This is an excellent conceptual shortcut for MCQs.

Part 2 – Extrinsic Semiconductors, Doping, n-type/p-type Semiconductors and p-n Junction

2.1 Learning Objectives

After studying this part, students will be able to:

1. Explain the meaning of an extrinsic semiconductor.
2. Understand the purpose of doping.
3. Distinguish between donor and acceptor impurities.
4. Explain n-type and p-type semiconductors.
5. Identify majority and minority charge carriers.
6. Understand donor and acceptor energy levels.
7. Apply the mass-action law.
8. Calculate majority and minority carrier concentrations.
9. Understand charge neutrality in a doped semiconductor.
10. Explain the formation of a p-n junction.
11. Understand diffusion and drift currents.
12. Explain the depletion region and barrier potential.
13. Distinguish between forward and reverse bias of a p-n junction.

2.2 Extrinsic Semiconductor

A pure semiconductor is called an **intrinsic semiconductor**.
Its electrical conductivity can be increased and controlled by adding a very small and carefully controlled amount of suitable impurity.
Such a semiconductor is called an **extrinsic semiconductor**.
The process of adding a suitable impurity to a pure semiconductor is called **doping**.

Important idea

Pure semiconductor + controlled impurity → Extrinsic semiconductor
The purpose of doping is mainly to increase the number of charge carriers and control the electrical conductivity of the semiconductor.

2.3 Doping

Doping is the intentional addition of a very small amount of impurity to a pure semiconductor.
For silicon or germanium, the impurity concentration is much smaller than the concentration of semiconductor atoms.
The impurity atoms are generally selected from:

- Group 15 elements → donor impurities
- Group 13 elements → acceptor impurities

Doping produces two important types of extrinsic semiconductors:

1. **n-type semiconductor**
2. **p-type semiconductor**

2.4 n-type Semiconductor

An n-type semiconductor is obtained by doping a pure semiconductor with a **pentavalent impurity**.

Pentavalent atoms have five valence electrons.
Common donor impurities are:

- Phosphorus (P)
- Arsenic (As)
- Antimony (Sb)

These atoms belong to Group 15.

2.5 Formation of n-type Silicon

Consider silicon.
A silicon atom has four valence electrons and forms four covalent bonds with neighbouring silicon atoms.
Suppose a pentavalent phosphorus atom replaces one silicon atom in the crystal.
The phosphorus atom has five valence electrons.
Four of these electrons participate in covalent bonding.
The fifth electron is only weakly bound and can easily become a free electron.
Thus, one donor atom contributes approximately one additional free electron.

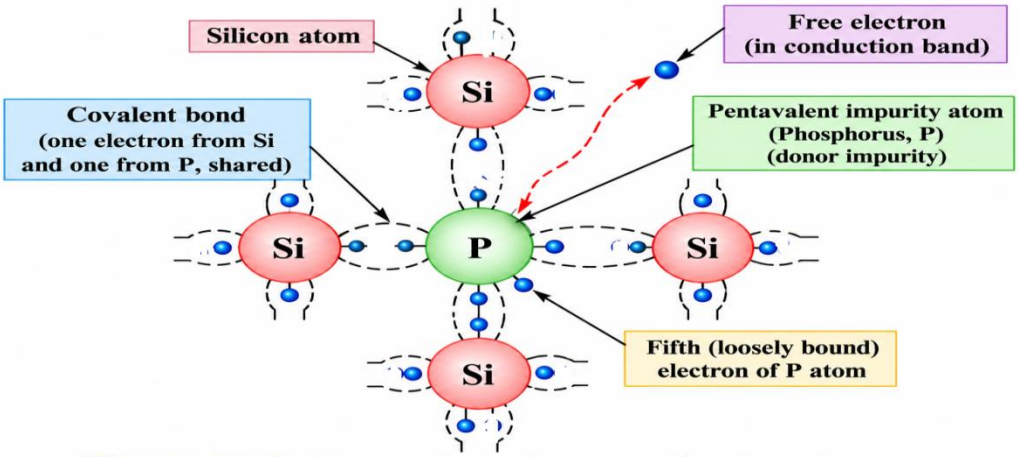


Figure 14.6: Formation of n-type Semiconductor

2.6 Donor Impurity

A pentavalent impurity is called a **donor impurity** because it donates an electron to the semiconductor.
Examples: **P, As, Sb**
The donor impurity becomes positively charged after donating its extra electron.
However, the crystal as a whole remains electrically neutral because the free electron and the ionised donor have equal and opposite charges.

2.7 Majority and Minority Carriers in n-type Semiconductor

In an n-type semiconductor:
Majority carriers: Electrons
Minority carriers: Holes
Therefore: **n > p,** where:

- n = electron concentration
- p = hole concentration

The semiconductor is called n-type because electrons are the dominant charge carriers.

2.8 Important Point About n-type Semiconductor

The term **n-type** does not mean that the semiconductor has an overall negative charge.
An n-type semiconductor is electrically neutral as a whole.
It contains:

- Negatively charged free electrons
- Positively charged ionised donor atoms

The total charge remains zero.

2.9 Donor Energy Level

The extra electron supplied by a donor impurity requires only a small amount of energy to become free.
Therefore, donor impurities introduce an energy level slightly below the conduction band.
This is called the **donor energy level**.

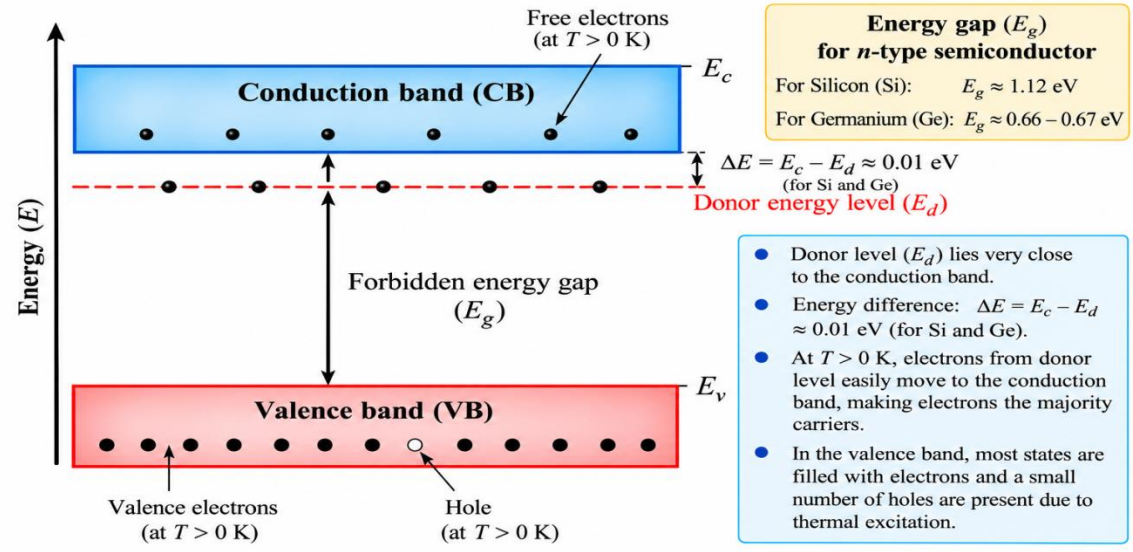


Figure 14.7: Energy band diagram of *n*-type Semiconductor
(At $T > 0$ K, showing electrons and a hole)

2.10 p-type Semiconductor

A p-type semiconductor is obtained by doping a pure semiconductor with a **trivalent impurity**.
Trivalent atoms have three valence electrons.
Common acceptor impurities are:

- Boron (B)
- Aluminium (Al)
- Gallium (Ga)
- Indium (In)

These elements belong to Group 13.

2.11 Formation of p-type Silicon

Consider a silicon crystal doped with a trivalent impurity such as boron.
The boron atom has only three valence electrons.
It can form only three complete covalent bonds with neighbouring silicon atoms.
One bond remains incomplete.
The vacant position corresponds to a **hole**.
Therefore, each acceptor impurity can produce approximately one hole.

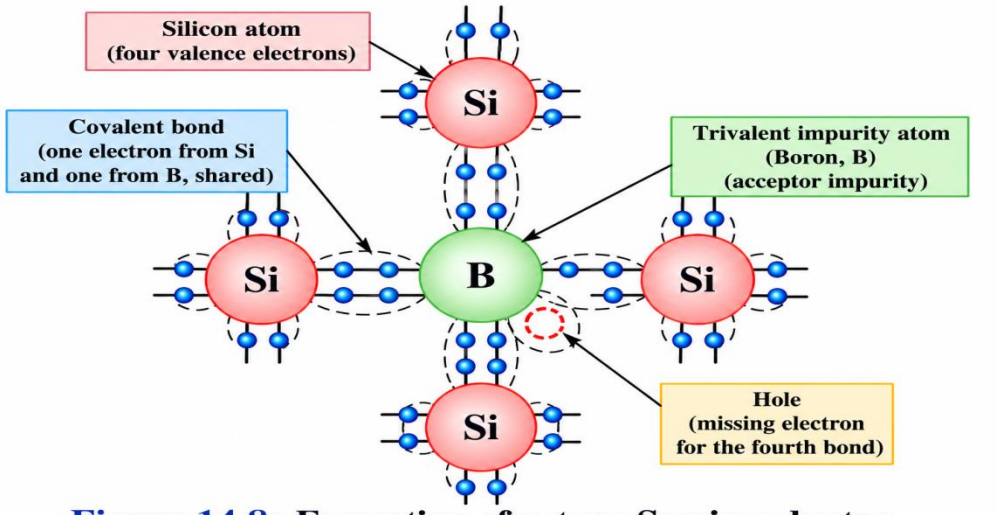


Figure 14.8: Formation of *p*-type Semiconductor

2.12 Acceptor Impurity

A trivalent impurity is called an **acceptor impurity** because it can accept an electron from a neighbouring covalent bond, thereby creating a hole.
Examples: **B, Al, Ga, In**
After accepting an electron, the acceptor atom becomes negatively charged.
Again, the semiconductor as a whole remains electrically neutral.

2.13 Majority and Minority Carriers in p-type Semiconductor

In a p-type semiconductor:
Majority carriers: Holes
Minority carriers: Electrons
Therefore: **p > n**
The semiconductor is called p-type because holes are the dominant charge carriers.

2.14 Important Point About p-type Semiconductor

A p-type semiconductor is **not positively charged as a whole**.
The positive holes are balanced by negatively charged ionised acceptor atoms.
Therefore: **Overall charge = zero**
This point is important in conceptual questions.

2.15 Acceptor Energy Level

An acceptor impurity introduces an energy level slightly above the valence band.
This is called the **acceptor energy level**.
An electron from the valence band can easily move to this acceptor level.
The vacancy left behind behaves as a hole.

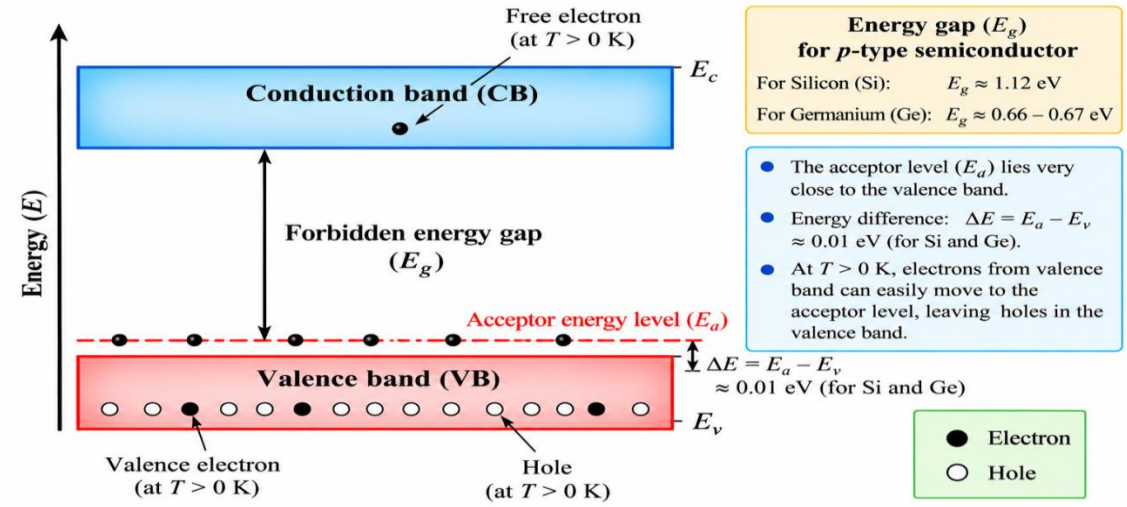


Figure 14.9: Energy band diagram of *p*-type Semiconductor
(At $T > 0$ K, showing electrons and holes)

2.16 Comparison of n-type and p-type Semiconductors

Property	n-type	p-type
Impurity	Pentavalent	Trivalent
Examples	P, As, Sb	B, Al, Ga, In
Impurity type	Donor	Acceptor
Majority carriers	Electrons	Holes
Minority carriers	Holes	Electrons
Donor/acceptor level	Near conduction band	Near valence band
Conductivity mainly due to	Electrons	Holes

2.17 Carrier Concentration in an n-type Semiconductor

Let the donor concentration be: $\mathbf{N_D}$
If the donors are completely ionised and the intrinsic carrier concentration is relatively small, then approximately:

$$\mathbf{n \approx N_D}$$

Since electrons are majority carriers:
From Mass-action law,

$$\mathbf{p = n_i^2 / n}$$

Therefore:

$$\mathbf{p \approx n_i^2 / N_D}$$

Thus: In **n-type semiconductor:**

$$\mathbf{n \approx N_D}$$

And

$$p \approx n_i^2/N_D$$

2.18 Carrier Concentration in a p-type Semiconductor

Let the acceptor concentration be: N_A
If the acceptors are completely ionised:

$$p \approx N_A$$

Since holes are majority carriers: $n = n_i^2/p$
Therefore:

$$n \approx n_i^2/N_A$$

Thus: In **p-type semiconductor:** $p \approx N_A$ **and** $n \approx n_i^2/N_A$

2.19 Mass-Action Law

For a semiconductor in thermal equilibrium: $np = n_i^2$
This is called the **mass-action law**.
It is valid for both intrinsic and extrinsic semiconductors under thermal equilibrium conditions.

For intrinsic semiconductor

Since: $n = p = n_i$
We obtain: $np = n_i^2$

For n-type semiconductor:

$$n \approx N_D$$

Therefore:

$$p \approx n_i^2/N_D$$

For p-type semiconductor: $p \approx N_A$

Therefore:

$$n \approx n_i^2/N_A$$

2.20 Charge Neutrality

Although an extrinsic semiconductor contains charged carriers and ionised impurities, the semiconductor as a whole remains electrically neutral.
The general charge-neutrality condition is:

$$n + N_A^- = p + N_D^+$$

Where:

- n = electron concentration
- p = hole concentration
- N_A = acceptor concentration
- N_D = donor concentration

This relation is useful when both donor and acceptor impurities are present.

2.21 Effect of Doping on Conductivity

Doping increases the concentration of charge carriers.
Therefore, conductivity increases.
The general conductivity equation is: $\sigma = e(n\mu_e + p\mu_h)$
For an n-type semiconductor, electron concentration is much larger than hole concentration, so electron conduction dominates.

For a p-type semiconductor, hole concentration is much larger than electron concentration, so hole conduction dominates.

2.22 Fermi Level — Basic Idea

The **Fermi level** is an important energy reference used to describe the distribution of electrons among available energy states.
For an intrinsic semiconductor, the Fermi level lies approximately near the middle of the forbidden energy gap.
In an n-type semiconductor: The Fermi level shifts closer to the conduction band.
In a p-type semiconductor: The Fermi level shifts closer to the valence band.

2.23 Formation of a p-n Junction

A **p-n junction** is formed when a p-type region and an n-type region are created in the same semiconductor crystal.
The boundary separating the p-type and n-type regions is called the **p-n junction**.

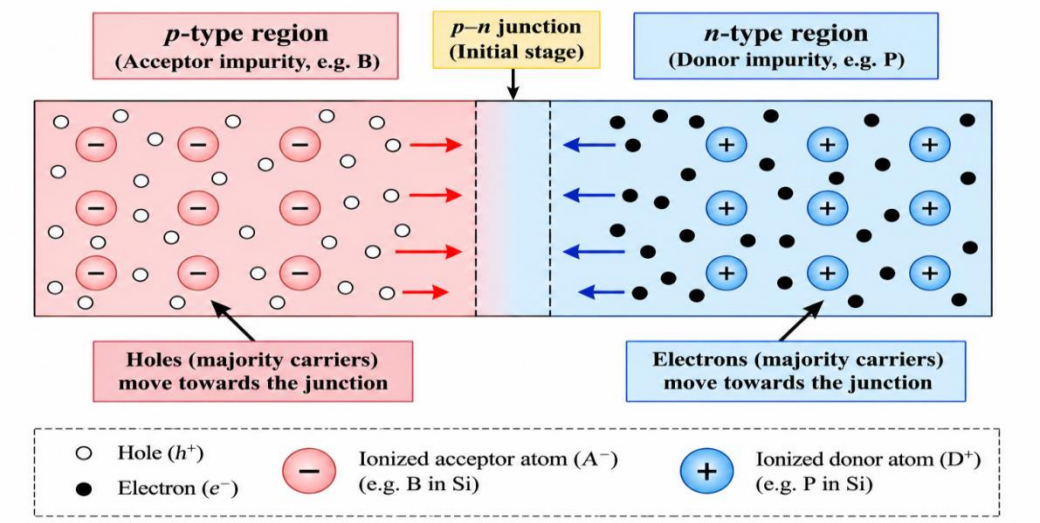


Figure 14.10: Formation of a *p–n* junction

2.24 Diffusion of Charge Carriers

Immediately after the p-n junction is formed, there is a large concentration difference across the junction.
Therefore:

- Holes diffuse from p-side to n-side.
- Electrons diffuse from n-side to p-side.

This movement occurs because particles tend to move from a region of higher concentration toward a region of lower concentration.
This process is called **diffusion**.

2.25 Formation of the Depletion Region

As electrons move from the n-side toward the p-side, they leave behind positively charged donor ions on the n-side.
Similarly, holes moving from the p-side toward the n-side leave behind negatively charged acceptor ions on the p-side.
Thus, near the junction, a region develops that contains almost no mobile charge carriers.
This region is called the: **Depletion region**
It is also called the: **Space-charge region**

2.26 Space Charge in the Depletion Region

The depletion region contains approximately:

- Negative acceptor ions on the p-side
- Positive donor ions on the n-side

These fixed ions create an electric field across the junction.
The electric field is directed approximately: **n-side → p-side** because the electric field points from positive charge toward negative charge.

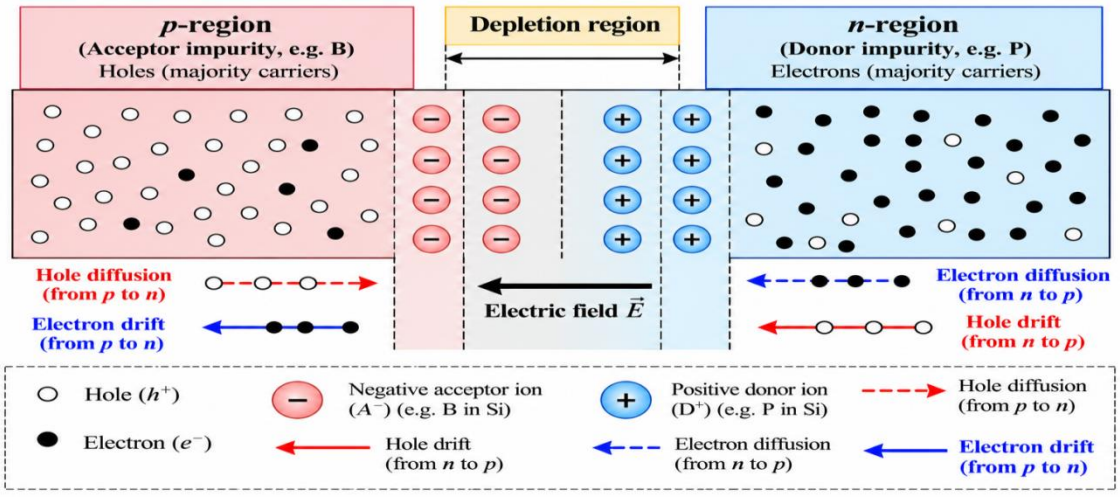


Figure 14.11: Depletion Region and Electric Field

2.27 Barrier Potential

The electric field in the depletion region opposes further diffusion of majority carriers.
As a result, a potential difference develops across the depletion region.
This potential difference is called the: **Barrier potential**
It acts as a potential barrier against the further diffusion of majority carriers.
Typical approximate values at room temperature are:

Silicon : $V_B \approx 0.7$ V

Germanium: $V_B \approx 0.3$ V

These are typical approximate values, not exact fixed values for every diode.
These are useful approximate values for basic numerical and conceptual problems.

2.28 Diffusion Current

The movement of majority charge carriers due to the concentration gradient produces **diffusion current**.

Therefore:

- Holes diffuse from p → n.
- Electrons diffuse from n → p.

The resulting diffusion current tends to increase the separation of charge near the junction.

2.29 Drift Current

The electric field established in the depletion region causes minority carriers to move across the junction.

This produces **drift current**.

At thermal equilibrium: **Diffusion current = Drift current**

Therefore: **Net current = 0**

This is an important concept.

2.30 Equilibrium at a p-n Junction

At equilibrium:

- Diffusion tendency exists because of the carrier concentration difference.
- The electric field in the depletion region produces drift.
- Drift opposes further diffusion.
- Diffusion current and drift current balance each other.

Therefore: **I diffusion = I drift** and hence: **I net = 0**

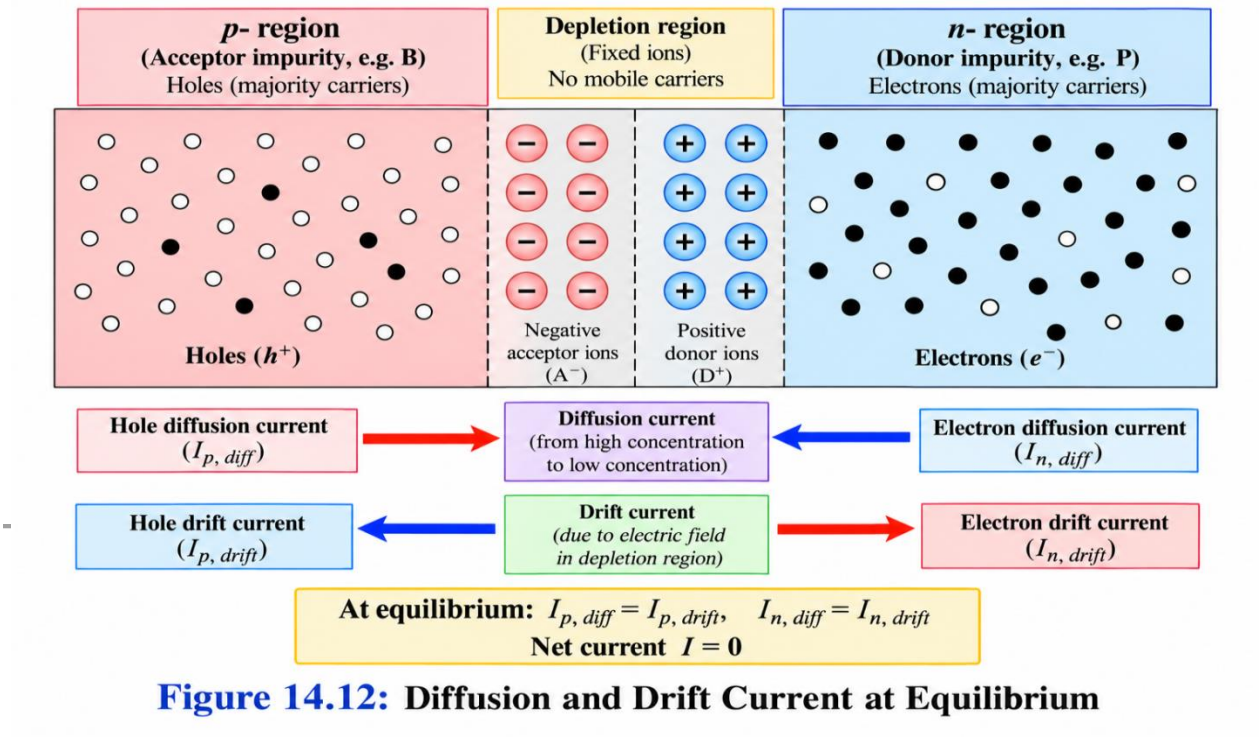


Figure 14.12: Diffusion and Drift Current at Equilibrium

2.31 Solved Example 1 — n-type Semiconductor

An n-type semiconductor has donor concentration: $N_D = 5 \times 10^{22}\ m^{-3}$ and intrinsic carrier concentration: $n_i = 2 \times 10^{16}\ m^{-3}$
Find the electron and hole concentrations.

Solution

For an n-type semiconductor: $\approx N_D$
Therefore: $n = 5 \times 10^{22}\ m^{-3}$
Using: $np = n_i^2$
We get: $p = n_i^2/n$ **Or** $p = (2 \times 10^{16})^2/(5 \times 10^{22})$ **Or** $p = 8 \times 10^9\ m^{-3}$

Answer:

Electron concentration $= 5 \times 10^{22}\ m^{-3}$
Hole concentration $= 8 \times 10^9\ m^{-3}$

2.32 Solved Example 2 — p-type Semiconductor

A p-type semiconductor has: $N_A = 4 \times 10^{22}\ m^{-3}$ and: $n_i = 2 \times 10^{16}\ m^{-3}$
Find the minority electron concentration.

Solution

For a p-type semiconductor: $p \approx N_A$
Therefore: $p = 4 \times 10^{22}\ m^{-3}$
Using: $np = n_i^2$
We get: $n = n_i^2/p$
Or, $n = (2 \times 10^{16})^2/(4 \times 10^{22})$ **Or** $n = 1 \times 10^{10}\ m^{-3}$

Answer: Minority electron concentration $= 1 \times 10^{10}\ m^{-3}$

2.33 Solved Example 3 — Identifying Semiconductor Type

A semiconductor has: $n = 8 \times 10^{21}\ m^{-3}$ and: $p = 2 \times 10^{16}\ m^{-3}$
Determine whether it is n-type or p-type.

Solution

Since: $n > p$
That is, electrons are the majority carriers.
Therefore, the semiconductor is: **n-type**

2.34 Solved Example 4 — Bias Identification

A p-n junction has its p-side connected to the positive terminal of a battery and its n-side connected to the negative terminal. Determine the type of bias.

Solution

For forward bias: $p \rightarrow +$ **and** $n \rightarrow -$
Therefore, the junction is: **Forward biased**

2.35 Important Conceptual Points

Point 1: Doping does not make the semiconductor electrically charged overall.
Point 2: Pentavalent impurities produce n-type semiconductors.
Point 3: Trivalent impurities produce p-type semiconductors.
Point 4: Electrons are majority carriers in n-type semiconductors.

Point 5: Holes are majority carriers in p-type semiconductors.
Point 6: Donor level lies close to the conduction band.
Point 7: Acceptor level lies close to the valence band.
Point 8: The depletion region contains very few mobile charge carriers.
Point 9: At equilibrium: **Diffusion current = Drift current**
Point 10: Forward bias reduces the depletion width.
Point 11: Reverse bias increases the depletion width.
Point 12: An n-type semiconductor is not negatively charged overall.
Point 13: A p-type semiconductor is not positively charged overall.

2.36 NEET/JEE Quick Insights

Shortcut 1 — Identify the type

Pentavalent → n-type → electrons majority
Trivalent → p-type → holes majority

Shortcut 2 — Minority carrier concentration

For n-type: **p =** $\boldsymbol{n_i^2/n}$
For p-type: **n =** $\boldsymbol{n_i^2/p}$

Shortcut 3 — Doping effect

More donor doping generally means: **n** ↑ and: **p** ↓
More acceptor doping generally means: **p** ↑ and: **n** ↓
While the mass-action relation remains: $\boldsymbol{np = n_i^2}$ under thermal equilibrium.

Shortcut 4 — p-n junction

Remember the sequence:
Diffusion → Fixed ions → Depletion region → Electric field → Barrier potential

---

Shortcut 5 — Biasing

Forward bias → depletion width decreases → current increases
Reverse bias → depletion width increases → current remains very small under normal conditions

---

Part 3 – p-n Junction Diode, Biasing, Rectifiers and Zener Diode

3.1 Learning Objectives

After studying this part, students will be able to:

1. Explain the construction and working of a p-n junction diode.
2. Identify the anode and cathode of a diode.
3. Explain forward and reverse biasing.
4. Understand the V-I characteristics of a p-n junction diode.
5. Define cut-in or knee voltage.
6. Distinguish between static and dynamic resistance.
7. Explain rectification.
8. Understand half-wave and full-wave rectification.
9. Calculate average and RMS values of rectifier output.
10. Understand ripple and rectifier efficiency.
11. Explain bridge and centre-tapped full-wave rectifiers.
12. Understand the purpose of a capacitor filter.
13. Explain the working of a Zener diode.
14. Understand Zener breakdown and voltage regulation.
15. Solve numerical problems based on diode circuits, rectifiers and Zener regulators.

3.2 p-n Junction Diode

A **p-n junction diode** is a semiconductor device formed by joining p-type and n-type regions of a semiconductor crystal.

A diode allows current to flow predominantly in one direction.

The two terminals of a diode are:

- **Anode (A)** — connected to the p-side
- **Cathode (K)** — connected to the n-side

Therefore: **p-side → Anode and n-side → Cathode**

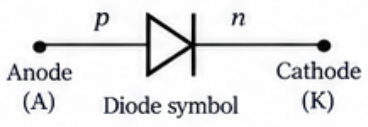
3.3 Diode Symbol

The circuit symbol of a p-n junction diode consists of an anode and a cathode.

The vertical line in the standard diode symbol represents the **cathode**.

In circuit diagrams, the cathode is often identified by a bar or line.

$I(\mu A)$



3.4 Biasing of a p-n Junction Diode

Biasing means: Applying an external potential difference across a p-n junction.

There are two types:

1. Forward bias
2. Reverse bias

3.5 Forward Bias of a p-n Junction

A p-n junction is said to be **forward biased** when:

- p-side is connected to the positive terminal of the battery.
- n-side is connected to the negative terminal.

Thus: **p → + and n → −**

Forward bias reduces the depletion-layer width and lowers the effective barrier potential.
Therefore, majority carriers can cross the junction more easily.

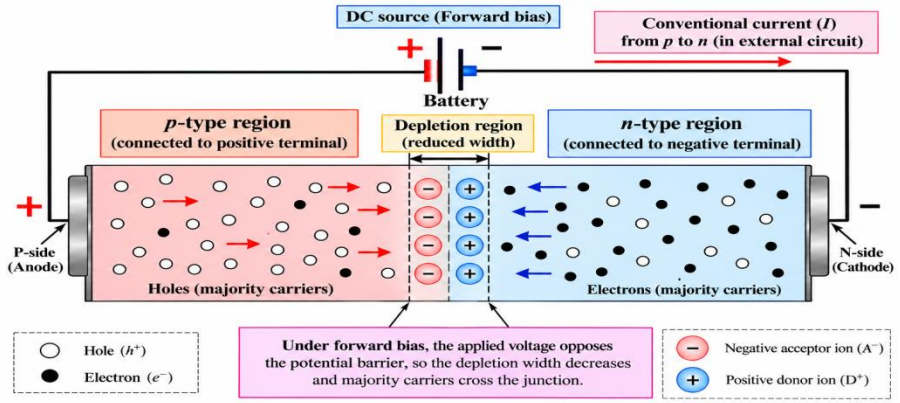


Figure 14.13: Forward Bias of a $p-n$ Junction

3.6 Reverse Bias of a p-n Junction

A p-n junction is said to be **reverse biased** when:

- p-side is connected to the negative terminal.
- n-side is connected to the positive terminal.

Thus: **p → − and n → +**

Reverse bias increases the depletion-layer width and increases the effective barrier potential.
Therefore, majority carriers are strongly prevented from crossing the junction.
Only a very small reverse current due mainly to minority carriers flows under normal conditions.

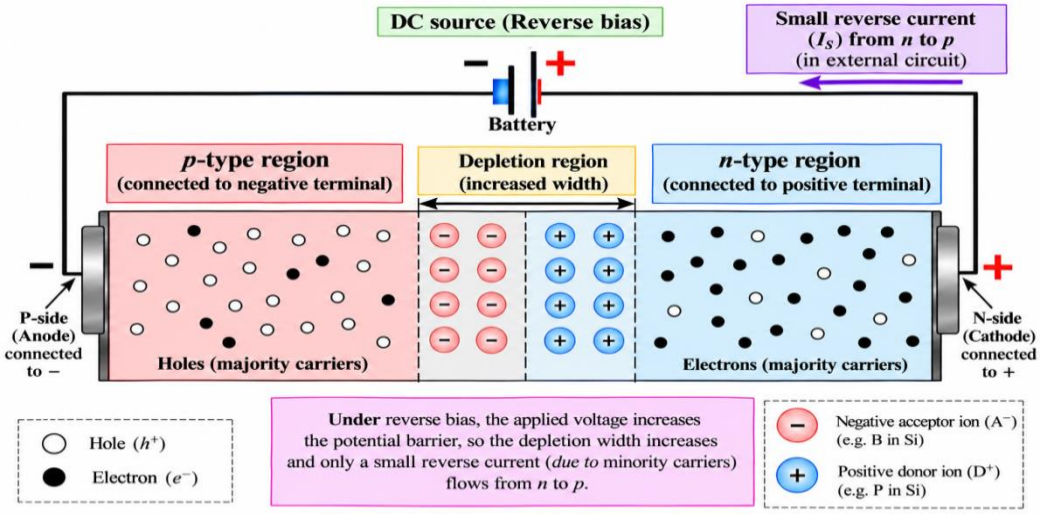


Figure 14.14: Reverse Bias of a $p-n$ Junction

3.7 Forward Bias versus Reverse Bias

Feature	Forward Bias	Reverse Bias
p-side connection	Positive	Negative
n-side connection	Negative	Positive
Depletion width	Decreases	Increases
Barrier potential	Decreases	Increases
Majority carrier movement	Easier	Strongly restricted
Current	Large after sufficient forward voltage	Very small under normal conditions

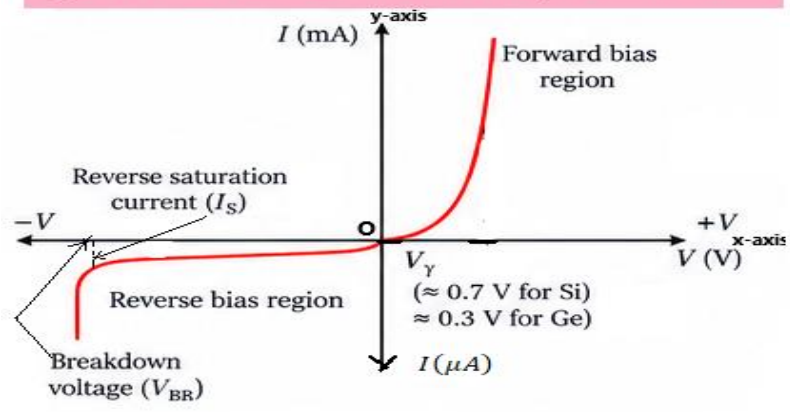
3.8 V-I Characteristics of a p-n Junction Diode

The relationship between diode current and applied voltage is called the **V-I characteristic**.
It has two regions:

1. Forward-bias region
2. Reverse-bias region

- Breakdown region

Figure 14.15: I-V characteristics Curve of a p-n Junction diode



3.9 Forward Characteristic

Initially, the forward current is very small.
As the applied voltage approaches the barrier-related threshold, the current begins to increase rapidly.
The voltage at which the forward current begins to rise appreciably is called the: **Cut-in voltage** or **Knee voltage**
Approximate values:
Silicon: $V_k \approx 0.7$ V
Germanium: $V_k \approx 0.3$ V
These are approximate practical values.

3.10 Reverse Characteristic

In reverse bias:

- The current is very small.
- It is mainly due to minority charge carriers.
- The reverse current remains approximately constant over a certain range of reverse voltage.

This small current is called the: **Reverse saturation current**
If the reverse voltage is increased sufficiently, the current rises sharply.
This is called: **Breakdown**

3.11 Diode Equation

For an idealized practical p-n junction diode, the current-voltage relation can be represented by the diode equation:

$$I = I_0 e^{\frac{V}{\eta V_T} - 1}$$

This is Shockley diode equation.
Where:

- I = diode current
- I_0 = reverse saturation current
- V = applied voltage
- η = ideality factor
- V_T = thermal voltage

At room temperature: **$V_T \approx 26$ mV**
The ideality factor η depends on the diode and its operating conditions.
This equation is mainly useful for advanced numerical treatment.

3.12 Static Resistance of a Diode

The DC or static resistance at a particular operating point is: **R = V/I**
It is obtained from the ratio of voltage to current at that point.

3.13 Dynamic Resistance

Dynamic resistance is the small-signal resistance around a particular operating point.
It is: **$r_d = \Delta V/\Delta I$**
For a smooth characteristic:

$r_d = dV/dI$

Dynamic resistance is important when studying small variations in diode voltage and current.

3.14 Rectification

The process of converting alternating current (AC) into unidirectional or pulsating direct current (DC) is called **rectification**.
A diode is suitable for rectification because it conducts predominantly in one direction.
The main types are:

1. Half-wave rectifier
2. Full-wave rectifier

3.15 Half-Wave Rectifier

A half-wave rectifier uses one diode to convert only one half-cycle of an AC input into a pulsating DC output.

During one half-cycle:

- Diode is forward biased.
- Current flows through the load.

During the opposite half-cycle:

- Diode is reverse biased.
- Current is approximately zero.

Thus, only one half of the input waveform appears across the load.

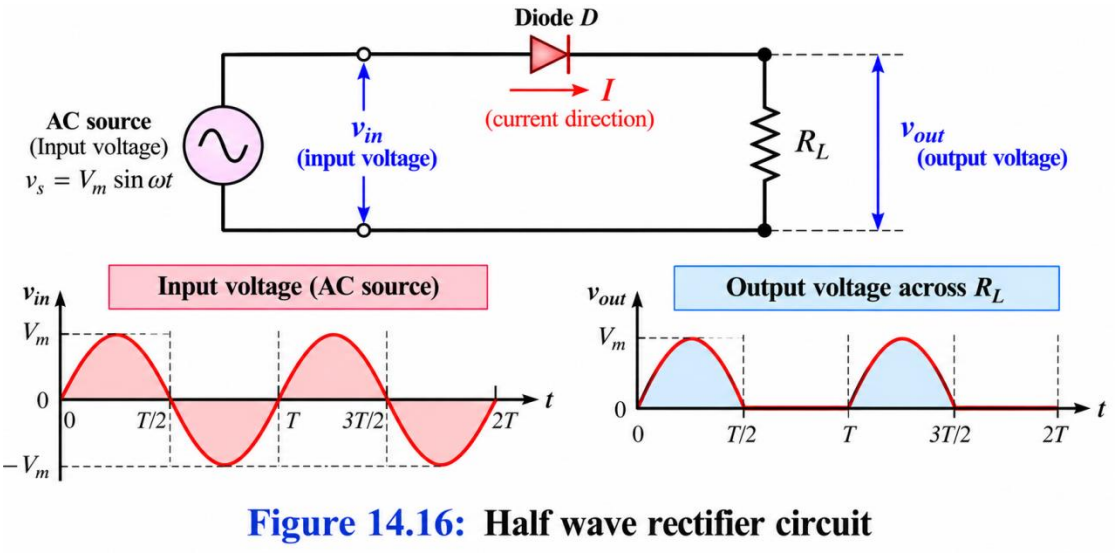


Figure 14.16: Half wave rectifier circuit

3.16 Input and Output Waveforms of Half-Wave Rectifier

The input is sinusoidal AC.

The output contains only one set of half-cycles.

3.17 Average or DC Current of Half-Wave Rectifier

Let the peak load current be: **Im**

Then the average current over a complete cycle is: $\boldsymbol{I_{dc} = I_m/\pi}$

3.18 RMS Current of Half-Wave Rectifier

The RMS current is: $\boldsymbol{I_{rms} = I_m/2}$

3.19 Average and RMS Voltage of Half-Wave Rectifier

If the peak voltage is V_m:

Then: $\boldsymbol{V_{dc} = V_m/\pi}$ and: $\boldsymbol{V_{rms} = V_m/2}$

These formulas are for the ideal half-wave rectifier.

3.20 Rectification Efficiency of Half-Wave Rectifier

Rectification efficiency is:

$$\eta = \text{DC output power / AC input power} \times 100\%$$

For an ideal half-wave rectifier:

$$\eta_{max} \approx 40.6\%$$

Thus, the maximum theoretical efficiency is approximately: **40.6%**

3.21 Ripple Factor of Half-Wave Rectifier

Ripple factor is:

$$r = \text{AC component of output / DC component of output}$$

For an ideal half-wave rectifier:

$$r \approx 1.21$$

A smaller ripple factor means a smoother DC output.

3.22 Output Frequency of Half-Wave Rectifier

For a half-wave rectifier, if the input frequency is f:

$$f_{out} = f$$

The output contains one pulse for each input cycle.

3.23 Full-Wave Rectifier

A full-wave rectifier converts both half-cycles of the AC input into output current flowing through the load in the same direction.

Two common arrangements are:

1. Centre-tapped full-wave rectifier
2. Bridge rectifier

3.24 Centre-Tapped Full-Wave Rectifier

A centre-tapped full-wave rectifier uses:

- Centre-tapped transformer
- Two diodes
- Load resistance

During the positive half-cycle:

- One diode conducts.

During the negative half-cycle:

- The other diode conducts.

In both cases, current through the load has the same direction.

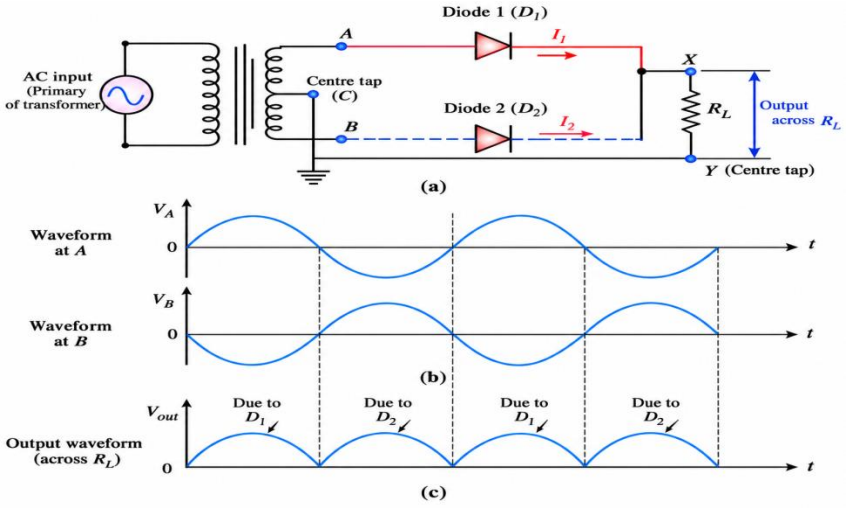


Figure 14.17: Centre-Tapped Full-Wave Rectifier Circuit

3.25 Bridge Rectifier

A bridge rectifier uses four diodes arranged in a bridge configuration.
During each half-cycle, two diodes conduct and the other two remain reverse biased.
The load current remains in the same direction during both half-cycles.

3.26 Input and Output Waveforms of Full-Wave Rectifier

The output of a full-wave rectifier contains both half-cycles converted into the same polarity.
Therefore, the output has twice the frequency of the input.

3.27 Average Current of Full-Wave Rectifier

For peak load current Im:

$$I_{dc} = 2I_m/\pi$$

3.28 RMS Current of Full-Wave Rectifier

$$Irms = Im/\sqrt{2}$$

3.29 Average and RMS Voltage

For peak voltage Vm:

$$V_{dc} = 2Vm/\pi$$
$$Vrms = Vm/\sqrt{2}$$

3.30 Rectification Efficiency of Full-Wave Rectifier

For an ideal full-wave rectifier: $\eta_{max} \approx 81.2\%$
This is approximately twice the efficiency of the ideal half-wave rectifier.

3.31 Ripple Factor of Full-Wave Rectifier

For an ideal full-wave rectifier: $r \approx 0.482$
Therefore, the full-wave rectifier provides a smoother output than the half-wave rectifier.

3.32 Output Frequency of Full-Wave Rectifier

For input frequency f:

$$f_{out} = 2f$$

This occurs because both half-cycles contribute to the output.

3.33 Peak Inverse Voltage (PIV)

Peak inverse voltage is the maximum reverse voltage that a diode can withstand without breakdown in a rectifier circuit.

For an ideal centre-tapped full-wave rectifier:

$$PIV = 2V_m$$

Where, Vm is the peak voltage across one half of the transformer secondary.

For an ideal bridge rectifier:

$$PIV = V_m$$

Where, Vm is the peak secondary voltage across the bridge input.

Important: The definition of V_m must be identified from the circuit before applying a PIV formula.

3.34 Comparison of Half-Wave and Full-Wave Rectifiers

Quantity	Half-Wave	Full-Wave
Diodes	1	2 or 4
Average current	I_m/π	$2I_m/\pi$
RMS current	$I_m/2$	$I_m/\sqrt{2}$
Maximum efficiency	40.6%	81.2%
Ripple factor	1.21	0.482
Output frequency	f	2f
Output smoothness	Lower	Higher

3.35 Capacitor Filter

The output of a rectifier is pulsating DC.

A capacitor filter is used to reduce the variation or ripple in the output voltage.

A capacitor is connected across the load.

The capacitor:

- Charges when rectifier output rises.
- Discharges through the load when the rectifier output falls.
- Therefore, it reduces the variation in output voltage.

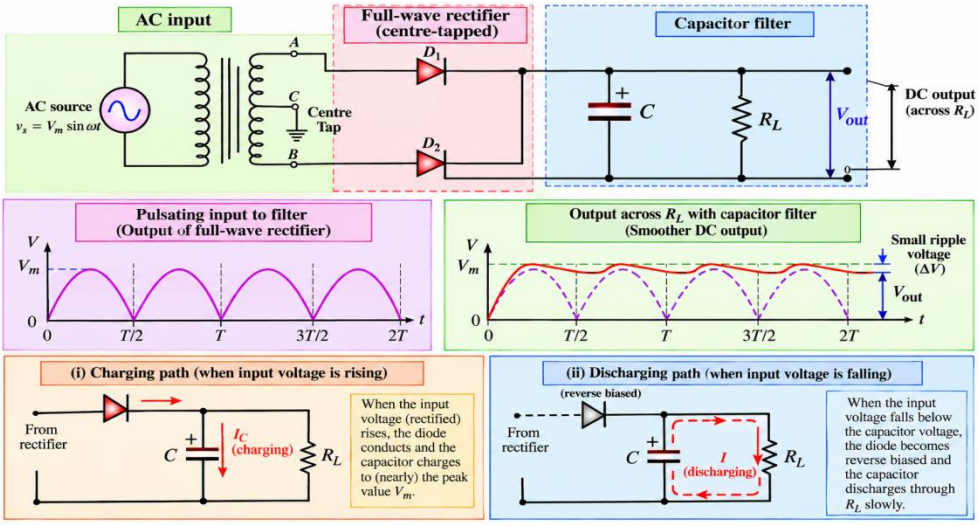


Figure 14.18: Capacitor Filter Cuircuit

3.36 Ripple with Capacitor Filter

The approximate ripple voltage decreases when:

- Capacitance increases.
- Load resistance increases.
- Rectification frequency increases.

A useful proportional relation is:

$$V_{ripple} \approx \frac{I_L}{f_r C}$$

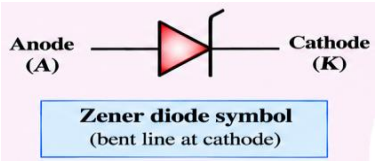
Where:

- I_L = load current
- f_r = ripple frequency
- C = filter capacitance

Thus: **C ↑ → Ripple ↓** and: **f ↑ → Ripple ↓**

3.37 Zener Diode (Not in CBSE Board Examination)

A **Zener diode** is a specially designed p-n junction diode intended to operate in the reverse-breakdown region.



It is widely used for:

- Voltage regulation
- Reference voltage generation
- Protection circuits

Unlike an ordinary diode, a Zener diode is designed to operate safely in its specified breakdown region.

3.38 Zener Diode Characteristics

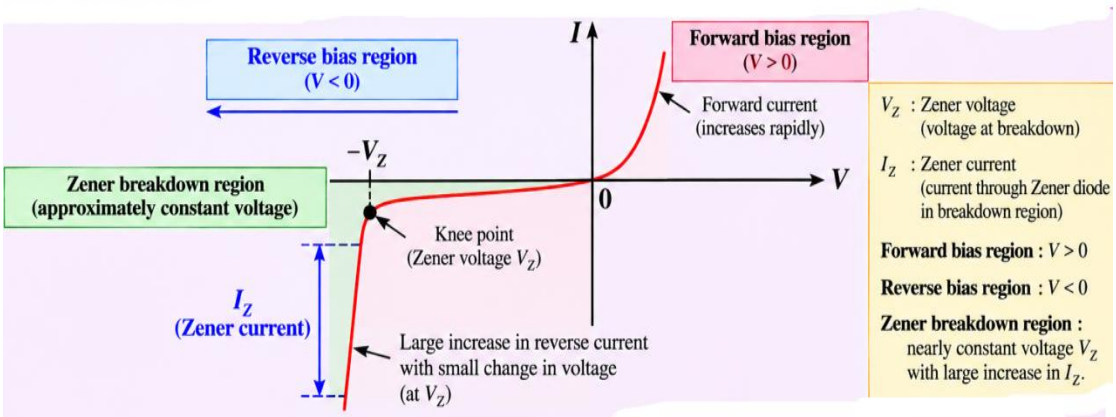


Figure 14.19 (a): V-I Characteristic Curve of zener Diode

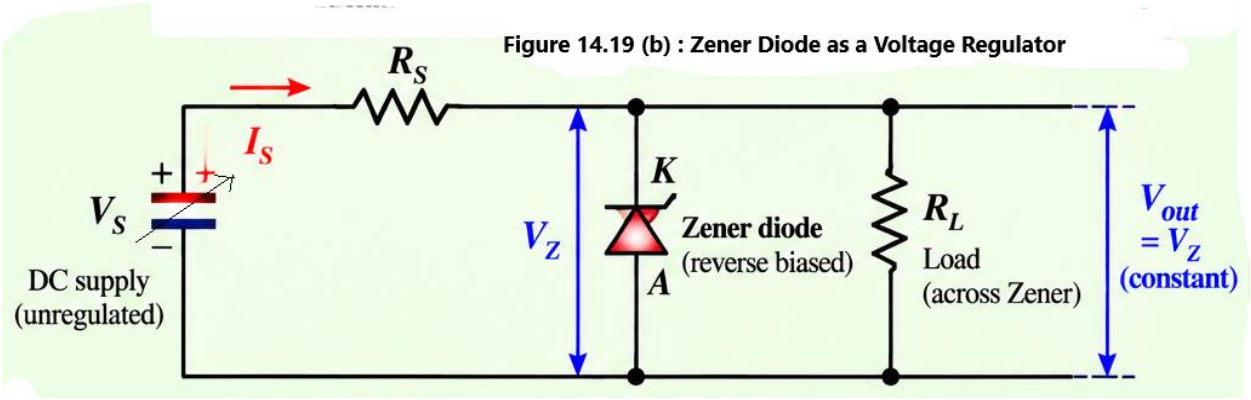
3.39 Zener Breakdown

When a sufficiently large reverse voltage is applied to a Zener diode, the reverse current increases sharply while the voltage across the diode changes only slightly.
The corresponding voltage is called:
Zener voltage, V_Z
The diode can maintain an approximately constant voltage across itself over its specified operating-current range.

3.40 Zener Diode as a Voltage Regulator

A Zener diode is connected in reverse bias across the load.
A series resistor is used to limit current.

Figure 14.19 (b) : Zener Diode as a Voltage Regulator



3.41 Working of a Zener Voltage Regulator

When the input voltage changes within the permissible range, the Zener diode adjusts its current so that the output voltage remains approximately constant.
Therefore: **$V_{out} \approx V_Z$**

The current through the series resistor is: $\mathbf{I_S = (Vin - V_Z)/R_S}$
This current divides between the Zener diode and the load: $\mathbf{I_S = I_Z + I_L}$
Where:

- I_S = series current
- I_Z = Zener current
- I_L = load current

3.42 Zener Power

The power dissipated by the Zener diode is: $\mathbf{P_Z = V_Z I_Z}$
The Zener diode must operate within its specified maximum power rating.

3.43 Conditions for Proper Zener Regulation

For proper voltage regulation:

- The Zener diode must operate in its breakdown region.
- Zener current must remain within the specified operating range.
- Series resistor must limit current.
- Zener power must not exceed its rated value.

3.44 Solved Example 1 — Diode Resistance

A diode has a forward voltage of: **V = 0.7 V** and current: **I = 10 mA**
Find its static resistance.

Solution

$R = V/I$ Or $R = 0.7/(10 \times 10^{-3})$ Or $R = 70\ \Omega$

Answer: Static resistance = 70 Ω

3.45 Solved Example 2 — Half-Wave Rectifier

A half-wave rectifier has peak current: **Im = 2 A**
Find the average current.

Solution

$$\mathbf{I\ dc = Im/\pi}$$

Or

$$\mathbf{I\ dc = 2/\pi}$$

Or

$$\mathbf{I\ dc \approx 0.637\ A}$$

Answer: I dc ≈ 0.637 A

3.46 Solved Example 3 — Full-Wave Rectifier

A full-wave rectifier has peak current: **Im = 2 A**
Find its average current.

Solution

$$I_{dc} = 2Im/\pi$$

Or,

$$I_{dc} = 4/\pi$$

Or,

$$I_{dc} \approx 1.273\ A$$

Answer: $I_{dc} \approx 1.273\ A$

3.47 Solved Example 4 — Zener Regulator

A Zener regulator has: **Vin = 15 V, V_Z = 9 V, R_S = 300 Ω**
Find the series current.

Solution

$$I_S = (V_{in} - V_Z)/R_S$$

Or,

$$I_S = (15 - 9)/300$$

Or,

$$I_S = 6/300 = 0.02\ A$$

Therefore: $I_S = 20\ mA$

Answer: Series current = 20 mA

3.48 Solved Example 5 — Zener Current

Suppose the previous circuit has a load current: **I_L = 10 mA**
Using: **$I_S = I_Z + I_L$**
We obtain: **$I_Z = I_S - I_L$**
Therefore, **$I_Z = 20 - 10$**
Or, **I_Z = 10 mA**
Answer: Zener current = 10 mA

3.49 Solved Example 6 — Zener Power

For: **V_Z = 9 V and**: **I_Z = 10 mA, calculate** Zener power.

Solution

$P_Z = V_Z I_Z$
Or, **$P_Z = 9 \times 10 \times 10^{-3}$** **Or,** **$P_Z$ = 0.09 W**
Answer: P_Z = 90 mW

3.50 Important Conceptual Comparisons

Ordinary Diode vs Zener Diode

Ordinary Diode	Zener Diode
Mainly used in forward conduction	Designed for reverse-breakdown operation
Reverse breakdown is normally avoided	Reverse breakdown is the intended operating region
Used in rectification and switching	Used mainly for voltage regulation/reference
Not normally operated at breakdown	Operated within specified Zener-current range

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Half-Wave vs Full-Wave

Remember: **Half-wave → one half-cycle**
Full-wave → both half-cycles
Therefore: **f out = f** for half-wave and **f out = 2f** for full-wave

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3.51 NEET/JEE Quick Insights

Shortcut 1: Remember the rectifier sequence: **Half-wave:** Idc = Im/π; Irms = Im/2; $\eta_{max} \approx$ 40.6%; r ≈ 1.21; f out = f; **Full-wave:** I dc = 2Im/π, Irms = Im/√2; $\eta_{max} \approx$ 81.2%; r ≈ 0.482; f out = 2f

Shortcut 2: For a Zener regulator: **V out ≈ V_Z**

Then calculate: **$I_S = (Vin - V_Z)/R_S$** and: **$I_Z = I_S - I_L$;** Finally check: **$P_Z = V_Z I_Z$**

Shortcut 3: For diode resistance: **Static:** R = V/I; **Dynamic:** $r_d = \Delta V/\Delta I$

PART 4 – TRANSISTOR: STRUCTURE, WORKING, CHARACTERISTICS, AMPLIFIER AND SWITCH (Not in CBSE Board Examination)

4.1 Learning Objectives

After studying this part, you should be able to:

- Understand the structure and working of a Bipolar Junction Transistor (BJT).
- Distinguish between NPN and PNP transistors.
- Explain transistor action and current components.
- Understand the three transistor configurations: CB, CE and CC.
- Derive the relations between α and β.
- Understand the input and output characteristics of a transistor.
- Explain the active, cut-off and saturation regions.
- Understand a transistor as an amplifier.
- Explain phase reversal in a common-emitter amplifier.
- Understand a transistor as an electronic switch.
- Solve numerical problems involving transistor currents and current gains.

4.2 Bipolar Junction Transistor (BJT)

A **Bipolar Junction Transistor (BJT)** is a three-layer, three-terminal semiconductor device used mainly for:

1. Signal amplification
2. Electronic switching
3. Oscillation and signal processing

The word **bipolar** indicates that both electrons and holes participate in current conduction.
A transistor has three semiconductor regions:

- **Emitter (E)**
- **Base (B)**
- **Collector (C)**

The corresponding junctions are:

- Emitter–Base Junction (E–B)
- Collector–Base Junction (C–B)

4.3 Structure of a Transistor

A BJT is formed by joining three semiconductor regions.
There are two types:

NPN transistor

N-type → P-type → N-type

PNP transistor

P-type → N-type → P-type
Thus:
NPN: Emitter – Base – Collector
PNP: Emitter – Base – Collector

The three regions have different doping levels.

Region	Doping	Main purpose
Emitter	Heavily doped	Supplies majority charge carriers
Base	Very lightly doped and very thin	Controls transistor action
Collector	Moderately doped The collector is generally physically larger than the emitter because it has to dissipate more heat.	Collects charge carriers

Important Point

The base is:

- very thin,
- lightly doped,
- physically located between emitter and collector.

This structure allows most carriers injected by the emitter to reach the collector.

4.4 NPN and PNP Transistors

NPN Transistor

An NPN transistor consists of: **N-type emitter – P-type base – N-type collector**
The majority carriers are **electrons**.

PNP Transistor

A PNP transistor consists of: **P-type emitter – N-type base – P-type collector**
The majority carriers are **holes**.

Memory Tip

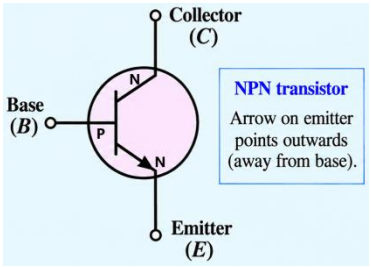
NPN → electrons are the main carriers.
PNP → holes are the main carriers.

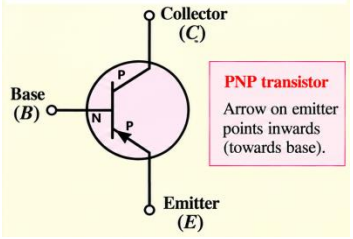
4.5 Transistor Symbol

The transistor has three terminals:

- Emitter (E)
- Base (B)
- Collector (C)

The **arrow is always present on the emitter**.





Arrow rule

NPN → Arrow Not Pointing IN
PNP → Arrow Pointing IN
The arrow indicates the direction of conventional current through the emitter.

4.6 Transistor Biasing

For normal transistor operation, the two junctions are biased differently.
For operation in the **active region**:

- Emitter–base junction → Forward biased
- Collector–base junction → Reverse biased

This condition is essential for transistor amplification.

Active-mode biasing

For an NPN transistor:

- Base is positive relative to emitter.
- Collector is more positive than base.

For a PNP transistor:

- Base is negative relative to emitter.
- Collector is more negative than base.

4.7 Working of an NPN Transistor

Consider an NPN transistor operating in the active region.
The emitter-base junction is forward biased.
Therefore, electrons are injected from the heavily doped emitter into the thin base.
Since the base is very thin and lightly doped:

- only a small fraction of electrons recombine with holes in the base,
- most electrons pass through the base,
- these electrons are attracted towards the collector because the collector-base junction is reverse biased.

Thus:
Emitter supplies electrons → Base controls a small fraction → Collector collects most electrons.
The small base current controls a much larger collector current.
This is the basic principle of transistor amplification.

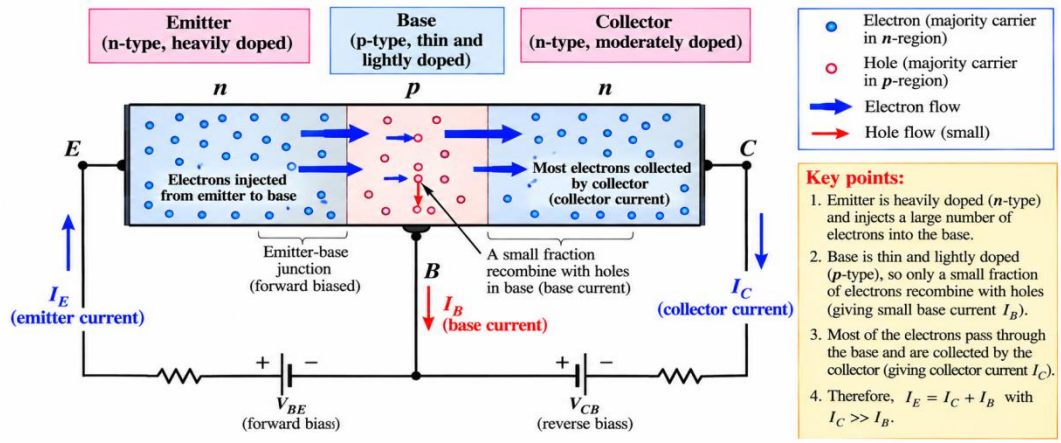


Figure 14.21: Transistor Action in an NPN Transistor

4.8 Transistor Current Components

The emitter current consists of:

- Collector current
- Base current

Therefore,

$$I_E = I_C + I_B$$

Where:

I_E = emitter current
I_C = collector current
I_B = base current
Since the base is thin and lightly doped: **I_C is much larger than I_B.**
Usually, **$I_E > I_C >> I_B$**

4.9 Current Gain in Common-Base Configuration

The current gain in common-base configuration is represented by **α (alpha)**.
It is defined as:

$$\alpha = I_C / I_E$$

Since $I_C < I_E$,
Therefore, $\alpha < 1$
For a practical transistor:

$$\alpha \approx 0.95 \text{ to } 0.99$$

Using:

$$I_E = I_C + I_B$$

We can write: $I_C = \alpha I_E$
Therefore: $I_B = I_E - I_C$ **and** $I_B = I_E (1 - \alpha)$

4.10 Current Gain in Common-Emitter Configuration

The current gain in common-emitter configuration is represented by **β (beta)**.
It is defined as:

$$\beta = I_C / I_B$$

Since I_C is much larger than I_B,

β is generally much greater than 1.

Typical values may range from about 20 to several hundred, depending on the transistor.

4.11 Relation Between α and β

We know: $\alpha = I_C / I_E$ --------- **(1)**
And,

$$\beta = I_C / I_B \text{ ---------- (2)}$$

Also,

$$I_E = I_C + I_B \text{ ---------(3)}$$

Dividing equation (1) by equation (2), we get

$$\frac{\alpha}{\beta} = \frac{I_B}{I_E} = \frac{I_B}{I_C + I_B} = \frac{1}{\frac{I_C}{I_B} + 1} = \frac{1}{1 + \beta}$$

Therefore,

$$\alpha = \beta / (1 + \beta)$$

Hence,

$$\beta = \alpha / (1 - \alpha)$$

Important Formula Box

$\alpha = \beta / (1 + \beta)$
$\beta = \alpha / (1 - \alpha)$
These two relations are very important for numerical problems.

4.12 Example 1 – Relation Between α and β

A transistor has: **α = 0.98.** Find β.
Using: **β = α / (1 − α) Or,** β = 0.98 / (1 − 0.98), Or β = 0.98 / 0.02; Or **β = 49**
Answer: β = 49

4.13 Example 2 – Finding Collector Current

A transistor has β = 100 and base current: **I_B = 20 μA,** Find collector current.
Using: **$\beta = I_C / I_B$**
Therefore,

$I_C = \beta I_B$ Or $I_C = 100 \times 20\ \mu A$ or **I_C = 2 mA**

4.14 Transistor Configurations

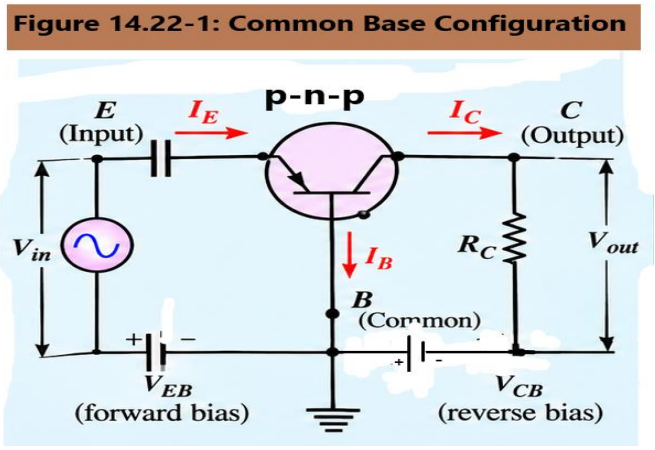
A transistor can be connected in three basic configurations:

1. **Common-Base (CB)**
2. **Common-Emitter (CE)**
3. **Common-Collector (CC)**

The term **common** refers to the terminal that is common to both the input and output circuits.

Configuration	Common terminal	Input	Output
CB	Base	Emitter	Collector
CE	Emitter	Base	Collector
CC	Collector	Base	Emitter

4.15 Common-Base (CB) Configuration



In the CB configuration:

- Base is common to input and output.
- Input is applied between emitter and base.
- Output is taken between collector and base.

The current gain is: **$\alpha = I_C / I_E$**
Since α < 1, the CB configuration has **current gain less than unity**.
However, it can provide significant voltage gain.

Main features

- Low input resistance
- High output resistance
- Current gain < 1
- No phase reversal between input and output voltage

4.16 Common-Emitter (CE) Configuration

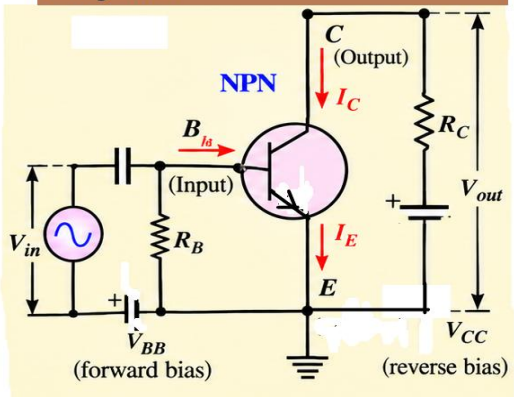
In the CE configuration:

- Emitter is common to input and output.
- Input is applied between base and emitter.
- Output is taken between collector and emitter.

The current gain is: **$\beta = I_C / I_B$**
Since β is generally much greater than 1, the CE configuration provides high current gain.

The CE configuration is widely used for amplification.

Figure14.22-2: Common Emitter Configuration

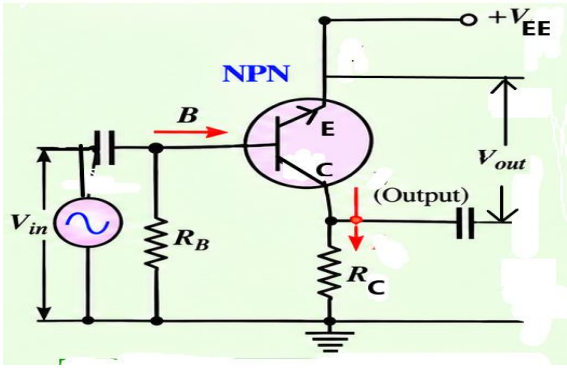


Main features

- Moderate input resistance
- High output resistance
- High current gain
- High voltage gain
- High power gain
- **180° phase reversal between input and output voltage**

4.17 Common-Collector (CC) Configuration

Figure 14.22-3: Common Collector Configuration



In the CC configuration:

- Collector is common.
- Input is applied between base and collector.
- Output is taken between emitter and collector.

It is also called an **emitter follower**.

Main features

- High input resistance
- Low output resistance
- High current gain
- Voltage gain approximately equal to 1
- No phase reversal

The CC configuration is commonly used for impedance matching.

4.18 Comparison of Transistor Configurations

Property	CB	CE	CC
Common terminal	Base	Emitter	Collector
Current gain	Less than 1	High	High
Voltage gain	High	High	Approximately 1
Input resistance	Low	Moderate	High
Output resistance	High	High	Low
Phase reversal	No	180°	No
Typical application	High-frequency circuits	Amplifiers	Buffer/impedance matching

4.19 Common-Emitter Characteristics

The CE configuration is the most commonly used configuration for transistor amplification.
It has two important characteristics:

1. Input characteristic

It represents the relationship between: $\mathbf{I_B}$ **and** $\mathbf{V_{BE}}$ at constant $\mathbf{V_{CE}}$.
The curve resembles the forward characteristic of a p-n junction diode because the emitter-base junction is forward biased.

2. Output characteristic

It represents the relationship between: **I_C and V_{CE}** at constant **I_B**.
The output characteristic is divided into different operating regions.

Figure 14.22-4: CE Input Characteristics Curve

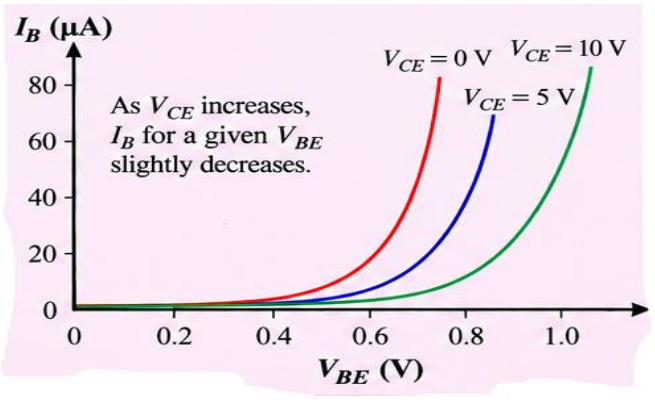
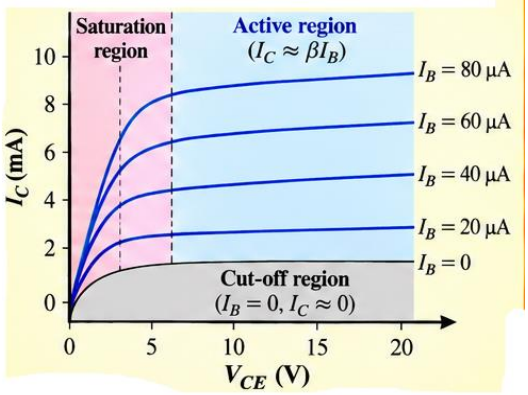


Figure 14.22-5: CE Output Characteristics Curve



4.20 Regions of Operation of a Transistor

The CE output characteristic contains three important regions:

1. Cut-off region

In this region: $I_B \approx 0$; $I_C \approx 0$; (This is ideal approximation. There may be leakage current in practical case)
Both junctions are effectively reverse biased.
The transistor is **OFF**.

2. Active region

In this region:

- Emitter-base junction → Forward biased
- Collector-base junction → Reverse biased

Approximately: **$I_C = \beta I_B$**
The transistor operates as an **amplifier**.

3. Saturation region

In this region:

- Both junctions are forward biased.
- Collector current does not increase significantly with further increase in base current because the transistor is in saturation.

The transistor is **fully ON**.

4.21 Working of a CE Amplifier

Suppose an AC input signal is applied at the base.
During the positive half-cycle:

- Base current increases.
- Collector current increases.
- Voltage drop across collector resistance increases.
- Collector voltage decreases.

During the negative half-cycle:

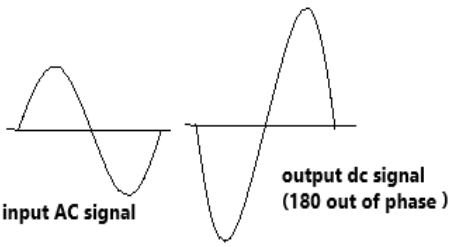


Figure 14.22-6: Transistor CE input/output waveform

- Base current decreases.
- Collector current decreases.
- Voltage drop across collector resistance decreases.
- Collector voltage increases.

Therefore, the output voltage changes in the opposite direction to the input voltage.
Hence, the CE amplifier produces a:
180° phase difference between input and output voltage.

4.22 Voltage Gain of an Amplifier

Voltage gain is defined as:

Av = Vout / Vin

Where: Av = voltage gain; Vout = output voltage; Vin = input voltage;
For an amplifier:
|Av| > 1, if the output voltage amplitude is greater than the input voltage amplitude.
For a CE amplifier, the voltage gain can be negative because of phase reversal.

4.23 Current Gain

Current gain is: **Ai = Iout / Iin**
For a transistor in CE configuration: **Ai ≈ β**
for the transistor current relation, although the overall circuit current gain depends on the complete amplifier circuit.

4.24 Power Gain

Power gain is approximately: **A_P = Pout / Pin**
For voltage and current gains:

$$A_P = |A_v| \times |A_i|$$

Thus, an amplifier can provide substantial power gain.

4.25 Transistor as an Electronic Switch

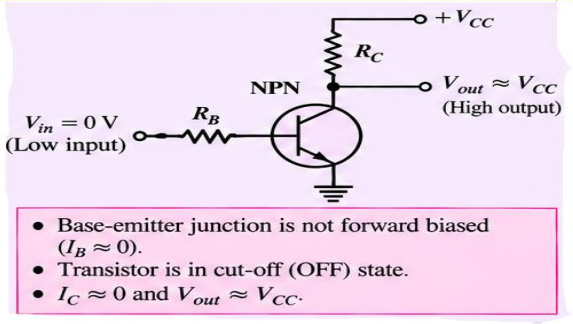
A transistor can also work as an electronic switch.
It operates mainly in two regions:

Cut-off region → OFF

Saturation region → ON

This switching property is fundamental to digital electronics and computer circuits.

Figure 14.23-1: Transistor as an OFF Switch



4.26 Transistor as an OFF Switch

When the base current is approximately zero: **$I_B \approx 0$**
Therefore, **$I_C \approx 0$**
The transistor is in the **cut-off region**.
It behaves approximately like an open switch.

Condition:

Base drive absent → Transistor OFF

4.27 Transistor as an ON Switch

When sufficient base current is supplied:

- transistor enters saturation,
- collector current becomes large,
- collector-emitter voltage becomes small.

For a silicon transistor, a typical saturation value is approximately:

V_{CE} (sat) ≈ 0.1–0.3 V

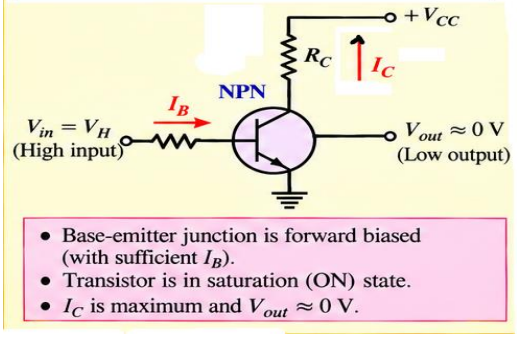
The exact value depends on the transistor and operating conditions.

The transistor behaves approximately like a closed switch.

Condition:

Base drive sufficient → Transistor ON

Figure 14.23-2: Transistor as an ON switch



4.28 Transistor as an Amplifier

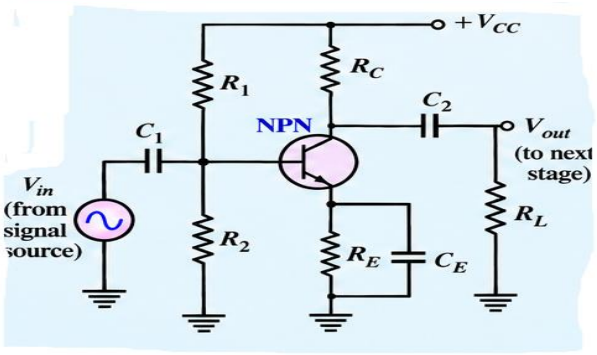
One of the most important applications of a transistor is **amplification**.

A transistor amplifier converts a small input signal into a larger output signal by using energy supplied by an external DC source.

In a CE amplifier:

- A small AC signal is applied to the base.
- The resulting change in base current produces a larger change in collector current.
- This produces a larger voltage variation across the collector load.

Figure 12.23-3: Transistor as an Amplifier



4.29 Transistor Switch Summary

Condition	Region	Transistor state	Switch equivalent
I_B ≈ 0	Cut-off	OFF	Open switch
Sufficient I_B	Saturation	ON	Closed switch

This principle is used extensively in:

- Digital circuits
- Logic gates
- Microprocessors
- Computer systems
- Electronic control systems

4.30 Transistor Biasing and Q-Point

For amplifier operation, the transistor must be properly biased.
The **Q-point (Quiescent Point)** is the operating point of the transistor when no input signal is applied.
It is generally specified by: $\mathbf{I_{CQ}}$ **and** $\mathbf{V_{CEQ}}$
A suitable Q-point allows the transistor to amplify the input signal with minimum distortion.
If the Q-point is poorly selected, one part of the amplified signal may enter:

- cut-off region, or
- saturation region.

This causes **signal distortion**.

4.31 Solved Example – Transistor Currents

A transistor has: $\beta = 99$ and $I_B = 50\ \mu A$, Find I_C and I_E.

Step 1: Collector current

$$I_C = \beta I_B = 99 \times 50\ \mu A = \mathbf{4.95\ mA}$$

Step 2: Emitter current

$$I_E = I_C + I_B = 4.95\ mA + 0.05\ mA = \mathbf{5.00\ mA}$$

Answer: $\mathbf{I_C = 4.95\ mA}$ **and** $\mathbf{I_E = 5.00\ mA}$

4.32 Solved Example – Finding α

A transistor has: $\beta = 49$, Find α.
Using: $\alpha = \beta / (1 + \beta) = 49 / 50 = \mathbf{0.98}$

4.33 Solved Example – Finding Base Current

A transistor has: $I_C = 5\ mA$ and $\beta = 100$. Find I_B.
Using: $\beta = I_C / I_B$
Therefore,

$$I_B = I_C / \beta = 5\ mA / 100 = \mathbf{0.05\ mA}$$

Therefore, $\mathbf{I_B = 50\ \mu A}$

4.34 Important Exam Points

1. A transistor has three terminals: **Emitter, Base and Collector**.
2. The emitter is heavily doped.
3. The base is thin and lightly doped.
4. The collector is moderately doped.
5. In active operation:
    - E-B junction is forward biased.
    - C-B junction is reverse biased.
6. The fundamental current relation is: $\mathbf{I_E = I_C + I_B}$
7. α is the current gain in CB configuration.
8. β is the current gain in CE configuration.
9. CE configuration is widely used for amplification.
10. CE amplifier produces **180° phase reversal**.
11. Cut-off region corresponds to transistor **OFF**.

12. Saturation region corresponds to transistor **ON**.
13. Active region is used for **amplification**.
14. The Q-point determines the operating condition of an amplifier.

4.35 NEET/JEE Quick Insights

Shortcut 1:

If β is given: $\mathbf{I_C = \beta I_B}$

Shortcut 2:

If α is given: $\boldsymbol{\beta = \alpha/(1 - \alpha)}$

Shortcut 3:

If β is very large: $\mathbf{I_E \approx I_C}$

Shortcut 4:

Remember the operating regions: **Cut-off → OFF; Active → Amplification**
Saturation → ON

Shortcut 5:

For CE configuration: **Current gain is high + phase reversal = 180°**

4.36 Quick Revision Table

Concept	Key Point
BJT	Three-layer semiconductor device
Terminals	Emitter, Base, Collector
NPN carriers	Electrons
PNP carriers	Holes
Emitter	Heavily doped
Base	Thin and lightly doped
Collector	Moderately doped
Active mode	E-B forward, C-B reverse
Current relation	$I_E = I_C + I_B$
CB gain	α
CE gain	β
α	I_C / I_E
β	I_C / I_B
α–β relation	$\alpha = \beta/(1+\beta)$
CE amplifier	180° phase reversal
Cut-off	OFF
Active	Amplifier
Saturation	ON
Q-point	Quiescent operating point

PART 5 – LOGIC GATES AND DIGITAL ELECTRONICS (Not in CBSE board examination)

5.1 Learning Objectives

After studying this part, you should be able to:

- Understand the difference between analog and digital signals.
- Explain binary logic and logic levels.
- Understand the operation of basic logic gates.
- Construct and interpret truth tables.
- Derive Boolean expressions for different gates.
- Understand NAND and NOR as universal gates.
- Explain XOR and XNOR gates.
- Apply De Morgan's laws.
- Simplify simple Boolean expressions.
- Analyse basic digital logic circuits.
- Solve Board, NEET and JEE-level conceptual questions involving logic gates.

5.2 Analog and Digital Signals

Electronic signals can broadly be classified into:

1. **Analog signals**
2. **Digital signals**

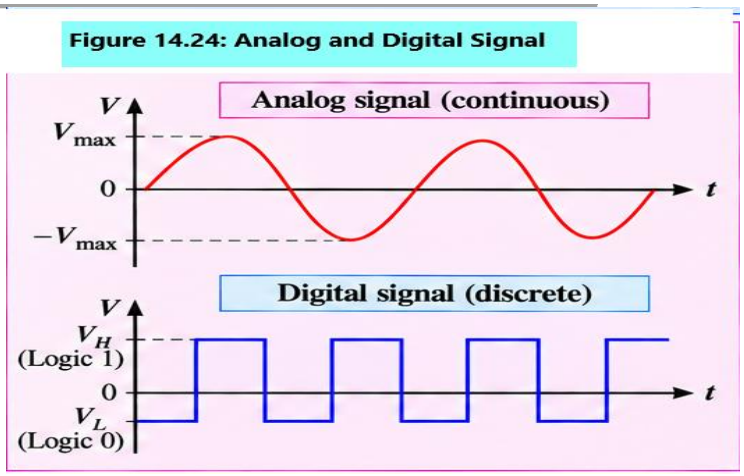


Figure 14.24: Analog and Digital Signal

Analog Signal

An analog signal varies continuously with time.

Examples:

- Sound signal
- Temperature variation
- Microphone output
- Conventional audio signal

Digital Signal

A digital signal has discrete values.

In binary digital electronics, only two logic states are generally used:

Logic 0 → LOW

Logic 1 → HIGH

Thus, digital electronics is based on the manipulation of binary information.

5.3 Binary Number System

The binary system uses only two digits:

0 and 1

These two values can represent two different electrical states.

For example:

- 0 → LOW voltage
- 1 → HIGH voltage

The exact voltage ranges corresponding to LOW and HIGH depend on the logic family and circuit technology.

Important Point
Logic 0 and logic 1 represent **logical states**, not necessarily exactly 0 V and a fixed voltage in every digital circuit.

5.4 Logic Gate

A **logic gate** is an electronic circuit that performs a logical operation on one or more input signals to produce a single output.
The basic logic gates are:

- NOT
- AND
- OR
- NAND
- NOR
- XOR
- XNOR

Each gate is represented by a standard circuit symbol and a Boolean expression.

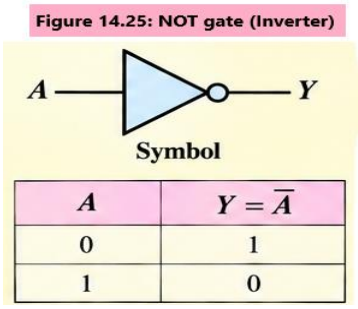
5.5 NOT Gate

The NOT gate has:

- One input
- One output

It performs logical inversion.
If the input is 0, output is 1.
If the input is 1, output is 0.
Therefore: $Y = \overline{A}$
Read as: **Y = NOT A**

Truth Table



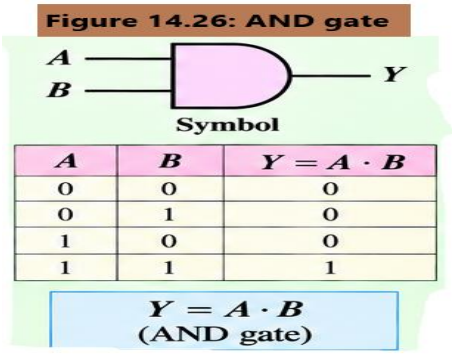
A	$Y = \overline{A}$
0	1
1	0

Key Point
A NOT gate is also called an **inverter**.

5.6 AND Gate

The AND gate generally has two or more inputs.
For a two-input AND gate: **Y = A · B**
The output is 1 only when **all inputs are 1**.

Truth Table



A	B	$Y = A \cdot B$
0	0	0
0	1	0
1	0	0
1	1	1

$Y = A \cdot B$
(AND gate)

Memory Rule
AND → All inputs must be 1 to produce output 1.

5.7 OR Gate

For a two-input OR gate: **Y = A + B**
The output is 1 when **at least one input is 1**.

Figure 14.27: OR gate



Symbol

A	B	$Y = A + B$
0	0	0
0	1	1
1	0	1
1	1	1

$Y = A + B$
(OR gate)

Memory Rule
OR → Any one input being 1 can produce output 1.

Truth Table

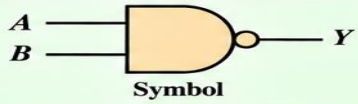
5.8 NAND Gate

A NAND gate is an AND gate followed by a NOT gate.
Therefore:

$$Y = \overline{A \cdot B}$$

The output is 0 only when **both inputs are 1**.

Truth Table



Symbol

A	B	$Y = \overline{A \cdot B}$
0	0	1
0	1	1
1	0	1
1	1	0

$Y = \overline{A \cdot B}$
(NAND gate)

Memory Rule
NAND = NOT of AND

5.9 NOR Gate

A NOR gate is an OR gate followed by a NOT gate.
Therefore: $Y = \overline{A + B}$
The output is 1 only when **both inputs are 0**.

Truth Table



Symbol

A	B	$Y = \overline{A + B}$
0	0	1
0	1	0
1	0	0
1	1	0

$Y = \overline{A + B}$
(NOR gate)

Memory Rule
NOR = NOT of OR

5.10 XOR Gate

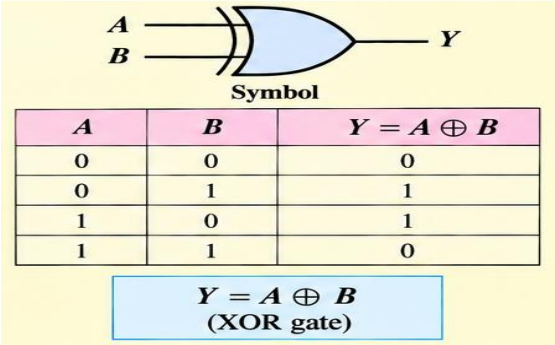
XOR means **Exclusive OR**.
For two inputs:

$$Y = \bar{A}B + A\bar{B}$$

The output is 1 when the two inputs are **different**.

Memory Rule
XOR → Different inputs give 1.

Truth Table



A	B	$Y = A \oplus B$
0	0	0
0	1	1
1	0	1
1	1	0

$Y = A \oplus B$
(XOR gate)

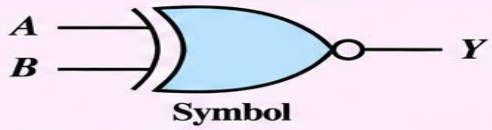
5.11 XNOR Gate

XNOR means **Exclusive NOR**.
It is the complement of XOR.
Therefore: **$Y = AB + \bar{A}\bar{B}$**
The output is 1 when the two inputs are **the same**.

Truth Table

Memory Rule
XNOR → Same inputs give 1.

Figure 14.28: XNOR gate ((Exclusive NOR)



A	B	$Y = A \oplus B$
0	0	1
0	1	0
1	0	0
1	1	1

$Y = A \oplus B$
(XNOR gate)

5.12 Complete Truth Table of Basic Gates

A	B	AND	OR	NAND	NOR	XOR	XNOR
0	0	0	0	1	1	0	1
0	1	0	1	1	0	1	0
1	0	0	1	1	0	1	0
1	1	1	1	0	0	0	1

For the NOT gate:

A	NOT A
0	1
1	0

5.13 Boolean Algebra

Boolean algebra is a mathematical system used to analyse and simplify digital logic circuits.
The variables in Boolean algebra normally have only two possible values:
0 and 1
The two basic operations are:

- OR → +
- AND → ·

The complement is represented by a bar.
For example: $\bar{A}$ means NOT A.

5.14 Basic Boolean Laws

Identity Laws

$$A + 0 = A$$

$$A \cdot 1 = A$$

Null Laws

$$A + 1 = 1$$

$$A \cdot 0 = 0$$

Idempotent Laws

$$A + A = A$$

$$A \cdot A = A$$

Complement Laws

$$A + \bar{A} = 1$$

$$A \cdot \bar{A} = 0$$

Involution Law

$$\bar{\bar{A}} = A$$

5.15 Commutative Laws

OR

$$A + B = B + A$$

AND

$$A \cdot B = B \cdot A$$

The order of variables does not affect the result.

5.16 Associative Laws

OR

$$A + (B + C) = (A + B) + C$$

AND

$$A(BC) = (AB)C$$

These laws allow regrouping of variables.

5.17 Distributive Laws

AND over OR

$$A(B + C) = AB + AC$$

OR over AND

$$A + BC = (A+B)(A+C)$$

The second relation is particularly useful in Boolean simplification.

5.18 De Morgan's First Law

De Morgan's first law states:

$$\overline{(A + B)} = \overline{A} \cdot \overline{B}$$

In words:

The complement of OR is equal to the AND of the complements.

Thus:

NOT (A OR B) = NOT A AND NOT B

5.19 De Morgan's Second Law

De Morgan's second law states:

$$\overline{A \cdot B} = \overline{A} + \overline{B}$$

In words: **The complement of AND is equal to the OR of the complements.**

Thus: **NOT (A AND B) = NOT A OR NOT B**

Exam Tip

De Morgan's laws are extremely useful for converting NAND and NOR circuits and simplifying Boolean expressions.

5.20 Simplification Example 1

Simplify: **Y = A + AB**

Take A common:

Y = A (1+B)

Since: **1+B = 1**

Therefore: **Y = A**

Hence,

A + AB = A

5.21 Simplification Example 2

Simplify: **Y = A + $\overline{A}$B**

Using distributive law:

$$Y = (A + \overline{A})(A + B)$$

Since:

$$A + \overline{A} = 1$$

Therefore:

Y = A+B

5.22 Universal Logic Gates

A **universal gate** is a logic gate from which all other basic gates can be constructed.

The two universal gates are:

1. **NAND**
2. **NOR**

This is an important examination concept.

Figure 14.29: NAND gate as Universal gate

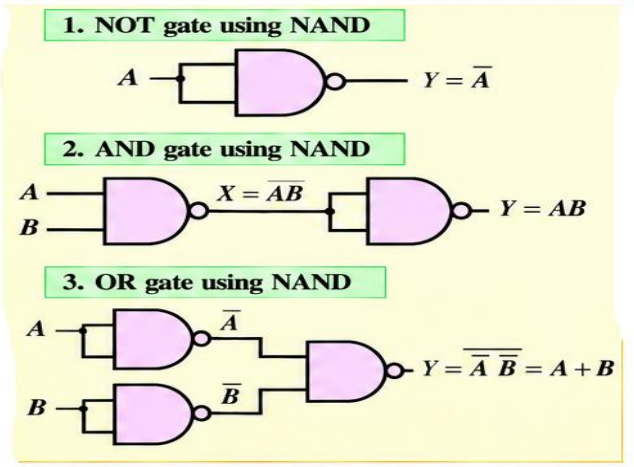
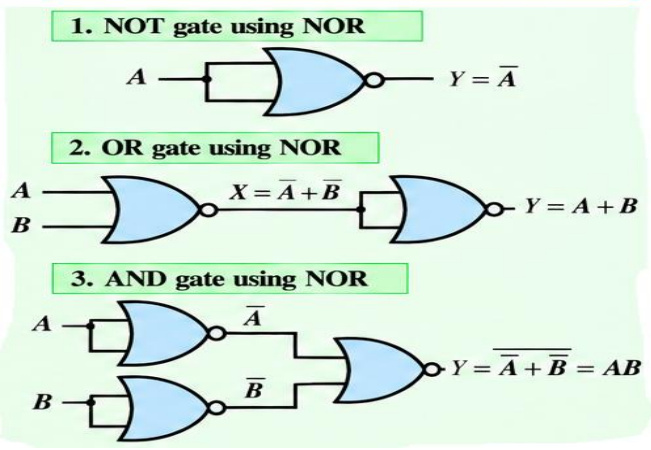


Figure 14.30: NOR gate as Universal gate



5.23 NAND Gate as NOT Gate

Connect the two inputs of a NAND gate together.
Thus: $\mathbf{Y = \overline{A.A}}$
Since: $\mathbf{A \cdot A = A}$
Therefore: $\mathbf{Y = \bar{A}}$
Hence, a NAND gate can be used as a NOT gate.

5.24 NAND Gate as AND Gate

First obtain: $\mathbf{X = \overline{A.B}}$
Then pass X through another NAND gate configured as a NOT gate.
Therefore: $\mathbf{Y = \bar{X}}$
Hence:

$$\mathbf{Y = AB}$$

Thus, NAND gates can be used to construct an AND gate.

5.25 NAND Gate as OR Gate

Using De Morgan's law:

$$A + B = \overline{(\bar{A} \cdot \bar{B})}$$

Therefore:

- First obtain $\bar{A}$ using a NAND gate.
- Obtain $\bar{B}$ using another NAND gate.
- NAND the two outputs.

The final output is:

$$\mathbf{Y = A+B}$$

Thus, NAND gates can construct an OR gate.

5.26 NOR Gate as NOT Gate

Connect both inputs of a NOR gate together.
Then: $\mathbf{Y = \overline{A + A}}$
Since:

$$\mathbf{A+A = A}$$

Therefore:

$$\mathbf{Y = \overline{A}}$$

Thus, a NOR gate can function as a NOT gate.

5.27 NOR Gate as OR Gate

First obtain:

$$\mathbf{X = \overline{A + B}}$$

Then invert X using another NOR gate.
Therefore:

$$\mathbf{Y = \overline{X}}$$

Hence:

$$\mathbf{Y = A+B}$$

Thus, NOR gates can construct an OR gate.

5.28 NOR Gate as AND Gate

Using De Morgan's law:

$$\boldsymbol{AB = \left(\overline{\overline{A} + \overline{B}}\right) = \overline{\overline{AB}}}$$

Therefore:

- Invert A using a NOR gate.
- Invert B using another NOR gate.
- Apply these outputs to another NOR gate.

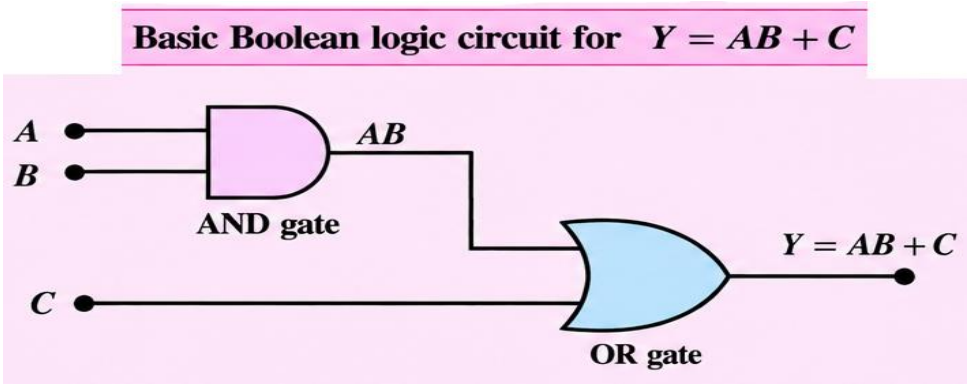
The final output is:

$$\mathbf{Y = AB}$$

Thus, NOR gates can construct an AND gate.

5.29 Logic Circuit Example

Consider the Boolean expression: **Y = AB + C**
The circuit can be constructed in two stages:
Stage 1: Apply A and B to an AND gate: **X = AB**
Stage 2: Apply X and C to an OR gate: **Y = X+C**
Therefore: **Y = AB+C**
This illustrates how a Boolean expression can be directly converted into a logic circuit.



5.30 Example – Determining Output

Consider:

$$Y = AB + C$$

If:

$$A = 1, B = 0, C = 1$$

Then:

$$AB = 1 \times 0 = 0$$

Therefore:

$$Y = 0 + 1 = 1$$

Answer: Y = 1

5.31 XOR and XNOR – Important Comparison

Feature	XOR	XNOR
Meaning	Exclusive OR	Exclusive NOR
Output 1 when	Inputs are different	Inputs are same
Expression	$\bar{A}B + A\bar{B}$	$AB + \bar{A}\bar{B}$
00	0	1
01	1	0
10	1	0
11	0	1

Also:

XNOR = NOT(XOR)

5.32 Digital Logic and Transistors

Modern digital circuits are constructed using semiconductor devices such as transistors.

A transistor can operate as a switch:

- Cut-off → OFF
- Saturation → ON

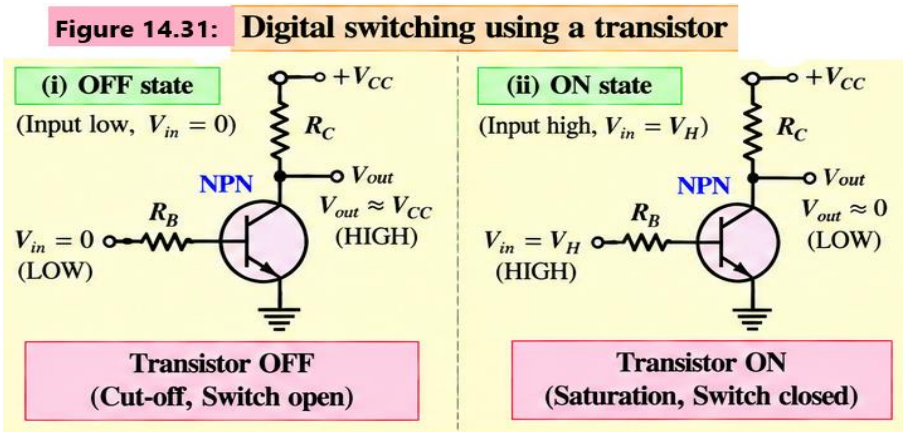
These two switching states correspond naturally to binary logic:

OFF → 0

ON → 1

Large numbers of transistor-based switching circuits can therefore be combined to form:

- Logic gates
- Flip-flops
- Registers
- Memory circuits
- Processors
- Digital control systems



5.33 Applications of Digital Electronics

Digital electronics is used in:

- Computers
- Smartphones
- Digital watches
- Calculators
- Digital cameras
- Communication systems
- Medical instruments
- Industrial automation
- Microcontrollers
- Microprocessors
- Memory systems
- Control systems

5.34 Solved Example – NAND Gate (NOT AND)

For a NAND gate:

$$Y = \overline{AB}$$

If: **A = 1 and B = 1**
Then: **AB = 1**
Therefore: **Y = 0**
Answer: Y = 0

5.35 Solved Example – NOR Gate

For a NOR gate:

$$Y = \overline{(A + B)}$$

If:

A = 0 and B = 0

Then:

A+B = 0

Therefore:

Y = 1

Answer: Y = 1

5.36 Solved Example – XOR Gate

For an XOR gate:

$$Y = \bar{A}B + A\bar{B}$$

If: **A = 1, B = 0**

Then: $\bar{A} = 0$

$\bar{B} = 1$

Therefore: $Y = (0)(0) + (1)(1) = 1$

Answer: Y = 1

5.37 NEET/JEE Quick Insights

Shortcut 1: For two-input gates:

AND → only 1 1 gives 1
OR → only 0 0 gives 0
NAND → only 1 1 gives 0
NOR → only 0 0 gives 1
XOR → different inputs give 1
XNOR → same inputs give 1

Shortcut 2: Remember the universal gates:

Both NAND and NOR gates are universal gates.

NAND + NOR = Universal Gates

Shortcut 3: Complement of XOR:

$$XNOR = \overline{XOR}$$

Shortcut 4: De Morgan:

OR + bar → AND of bars
AND + bar → OR of bars

5.38 Master Truth Table

A	B	AND	OR	NAND	NOR	XOR	XNOR
0	0	0	0	1	1	0	1
0	1	0	1	1	0	1	0
1	0	0	1	1	0	1	0
1	1	1	1	0	0	0	1

5.39 Final Chapter-14 Revision – Semiconductor Electronics

The complete chapter can now be remembered through the following sequence:

Semiconductor → Doping → n-type/p-type → p-n Junction → Diode → Rectifier → Zener Diode → Transistor → Amplifier → Switch → Logic Gates → Digital Electronics

Five Core Ideas

1. Semiconductor

Its conductivity lies between that of conductors and insulators.

2. p-n Junction

Formation of a depletion region and barrier potential is the basis of diode operation.

3. Diode
It allows current mainly in one direction and is used for rectification and voltage regulation.

4. Transistor
A small base current controls a much larger collector current, enabling amplification and switching.

5. Logic Gates
Digital circuits process binary information using logical operations.

Final Master Concept

Semiconductor devices provide the physical foundation of modern electronics: diodes control and convert electrical signals, transistors provide amplification and switching, and combinations of transistor-based switching circuits form the logic gates used in digital electronic systems.