Table of Contents

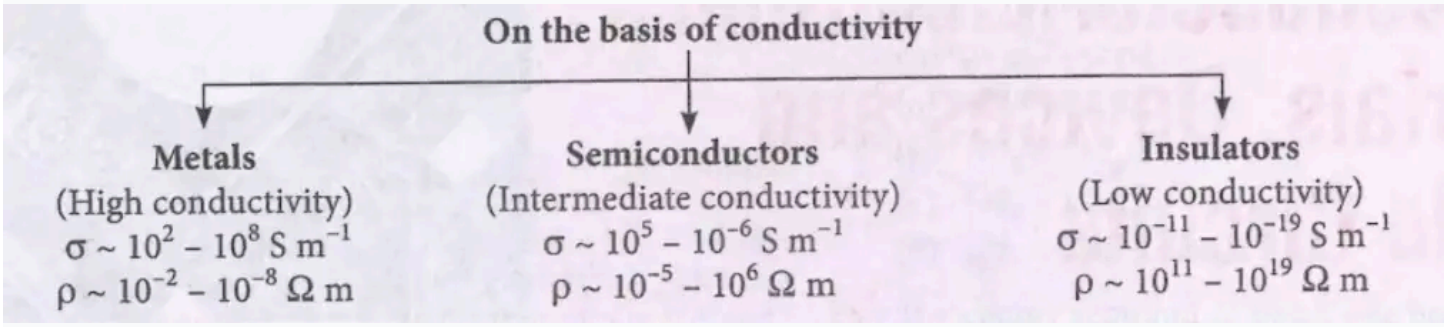
1. Introduction
2. Energy Bands of Solids
3. Energy Bands Classification
4. Hole
5. Intrinsic Semiconductor
6. Energy Band Diagram
7. Extrinsic Semiconductor
8. n-type Semiconductor
9. p-type Semiconductor
10. p-n Junction
11. Semiconductor Diode
12. Biasing of p-n Junction
13. I-V Characteristic of Diode
14. Application of Junction Diode as a Rectifier
15. Special Purpose p-n Junction Diodes
16. Photodiode
17. Light Emitting Diode
18. Solar Cell
19. Digital Electronics and Logic Gates
20. AND gate
21. NOT gate
22. NAND gate
23. NOR gate

Introduction

Overview

- Electronic circuits use devices controlling electron flow.
- Before transistors, vacuum tubes (diode, triode, tetrode, pentode) were used.
- Vacuum tubes are bulky, consume high power, operate at ~100 V, have limited life and low reliability.
- Modern solid-state semiconductors control charge carrier flow via junctions.
- Light, heat, or small voltage can change mobile charge carriers in semiconductors.
- CRT monitors replaced by LCD due to semiconductor development.

Classification of Metals, Conductors and Semiconductors



- Materials classified by electrical conductivity: Metals, Semiconductors, Insulators.
- Conductivity (σ) measures ease of electric current flow.
- Metals: High conductivity, electricity flows easily.
- Semiconductors: Medium conductivity, moderate current flow.
- Insulators: Very low conductivity, almost no current flow.
- Conductivity and resistivity (ρ) are inversely related.

Solved Examples

- **Ex 1:** Identify material type with conductivity $10^{7}\ \mathrm{S/m}$.
  - Answer: Metal (high conductivity).
- **Ex 2:** Material with conductivity $10^{-6}\ \mathrm{S/m}$ is?
  - Answer: Insulator (very low conductivity).

Practice Set

- Q1: Which material has highest conductivity?
  - A. Semiconductor
  - B. Metal
  - C. Insulator
  - D. None
- Q2: Which material has conductivity around $10^{-3}\ \mathrm{S/m}$?
  - A. Metal
  - B. Semiconductor
  - C. Insulator
  - D. Vacuum tube
- Q3: Resistivity ρ and conductivity σ relation is?
  - A. $\rho = \sigma$
  - B. $\rho = 1/\sigma$
  - C. $\rho = \sigma^2$
  - D. $\rho = \sqrt{\sigma}$

Answer Key

- Q1: B - Metals have highest conductivity.
- Q2: B - Semiconductors have medium conductivity (~10^{-3} S/m).
- Q3: B - Resistivity is inverse of conductivity: $\rho = 1/\sigma$.

Memory Aids

- Metals: High σ, low ρ.
- Semiconductors: Moderate σ, moderate ρ.
- Insulators: Low σ, high ρ.

Energy Bands of Solids

Valence Band

- Contains valence electrons.
- Partially or fully filled.
- Electrons here do not conduct current.

Conduction Band

- Electrons rarely present or partially filled.
- Contains free electrons contributing to current.

Forbidden Energy Gap

- Energy gap between valence and conduction bands.
- No electrons present in this gap.
- Energy band gap formula: $E_g = h\nu = \frac{hc}{\lambda}$
- Where h = Planck's constant, c = speed of light, λ = wavelength.
- Band gap depends on temperature.

Fermi Energy

- Maximum energy of free electrons at 0 K.

Solved Examples

- **Ex 1:** Calculate band gap if $\lambda = 500\ \text{nm}$.
  - $E_g = \frac{6.63\times10^{-34}\times3\times10^{8}}{500\times10^{-9}} = 3.98 \times 10^{-19}\ \text{J} = 2.49\ \text{eV}$

Practice Set

- Q1: What is conduction band?
  - A. Filled with valence electrons
  - B. Empty or partially filled with free electrons

    - C. Energy gap
    - D. None
- Q2: Formula for energy band gap?
    - A. $E_g = h\nu$
    - B. $E_g = mc^2$
    - C. $E_g = \frac{1}{2}mv^2$
    - D. $E_g = \lambda c$
- Q3: Fermi energy is energy at?
    - A. Room temperature
    - B. Absolute zero
    - C. Melting point
    - D. Boiling point

Answer Key

- Q1: B - Conduction band has free electrons.
- Q2: A - Band gap formula is $E_g = h\nu$.
- Q3: B - Fermi energy at 0 K.

Memory Aids

- Band gap energy: $E_g = \frac{hc}{\lambda}$.
- Fermi energy max at 0 K.
- Conduction band = free electrons.

Energy Bands Classification

Metals

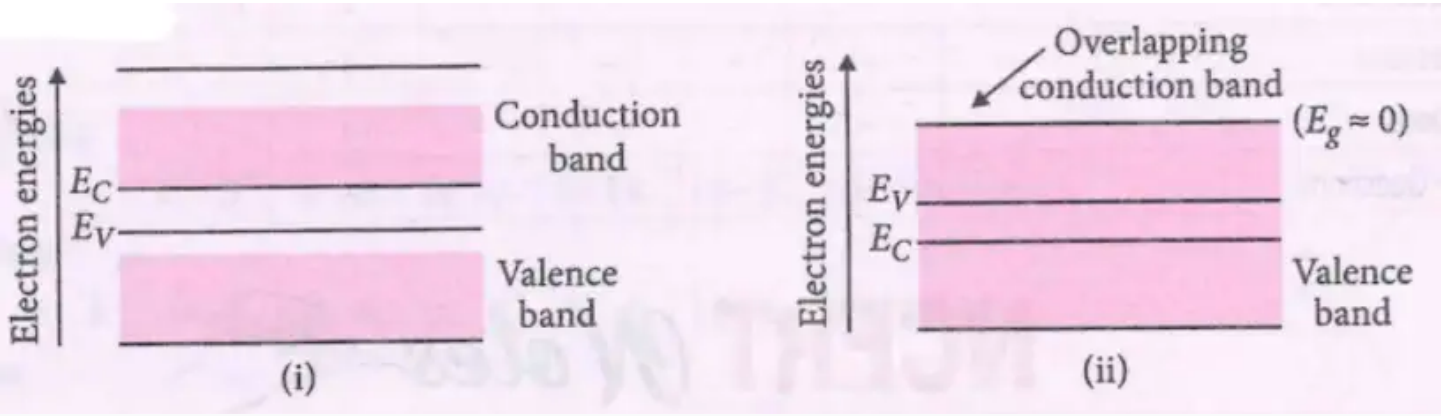
- Conduction band partially filled or overlaps valence band.
- No forbidden energy gap.

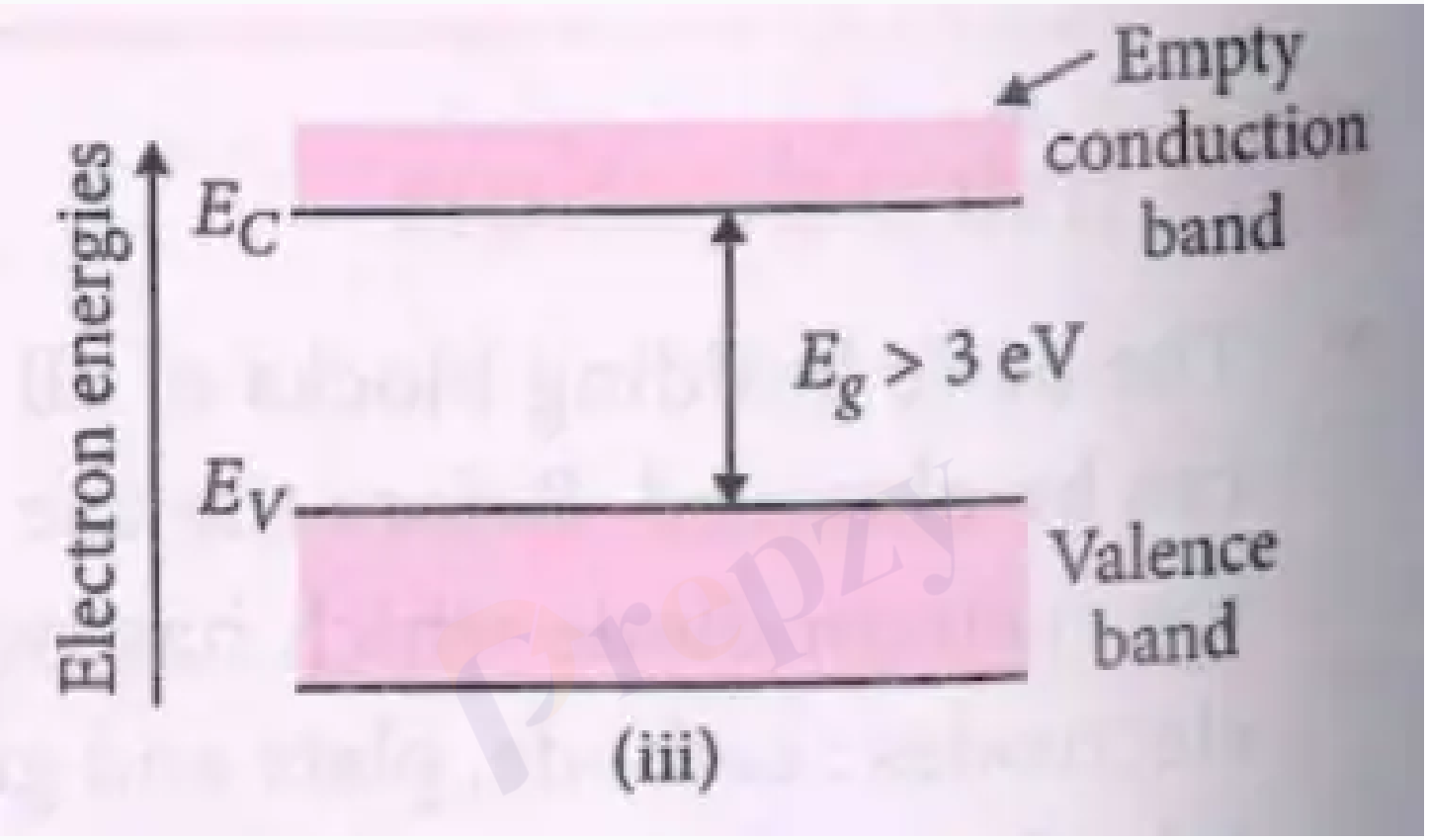
Insulators

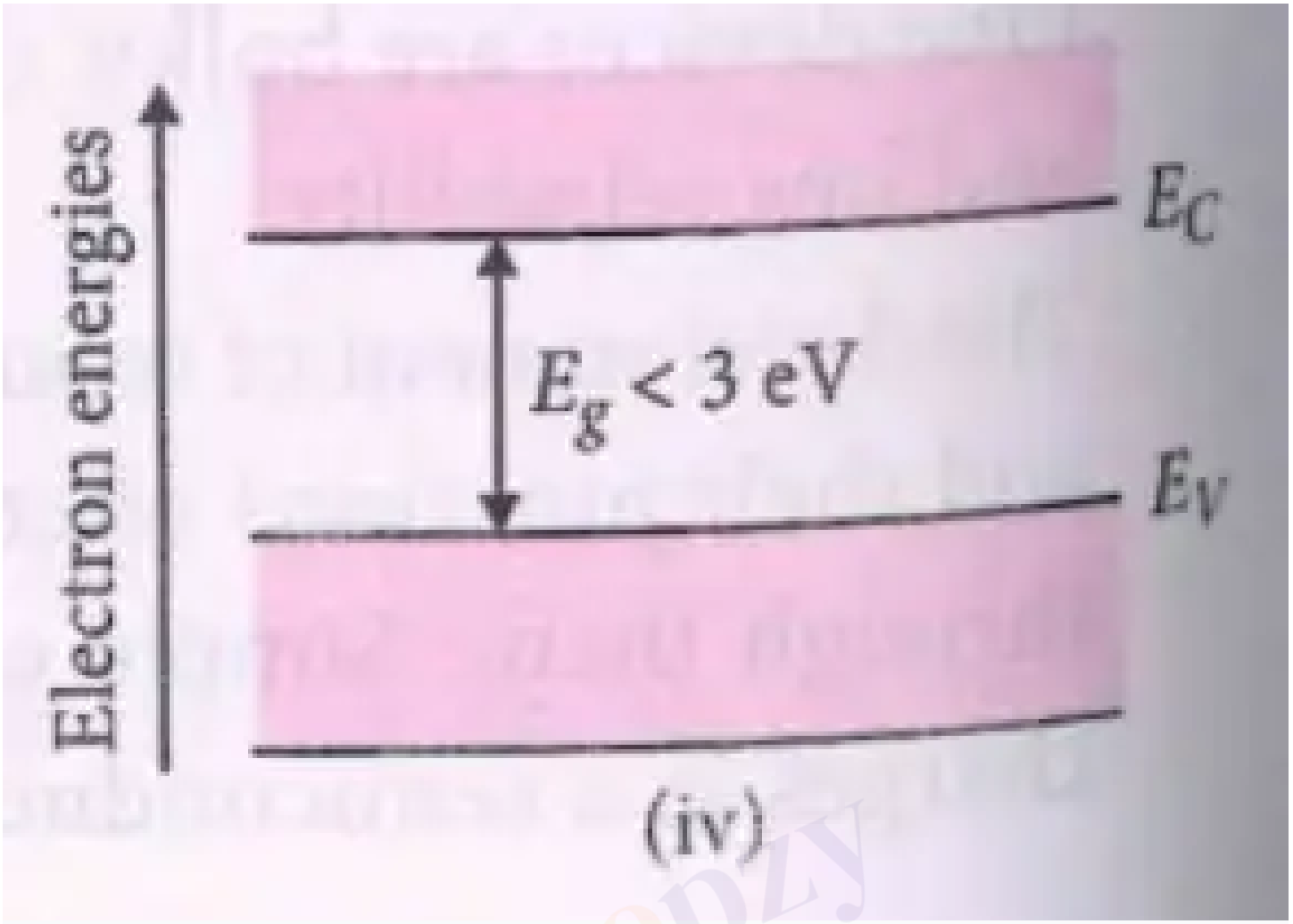
- Valence band fully filled, conduction band empty.
- Wide forbidden gap > 5 eV.

Semiconductors

- Valence band full, conduction band empty.
- Small forbidden gap ~1 eV (Si: 1.1 eV, Ge: 0.72 eV).
- At 0 K, behave as insulators.


Electron energies
E_C
E_V
Conduction band
Valence band
(i)
Overlapping conduction band
$(E_g \approx 0)$
Electron energies
E_V
E_C
Valence band
(ii)


Empty conduction band
Electron energies
E_C
$E_g > 3$ eV
E_V
Valence band
(iii)



Solved Examples

- **Ex 1:** Identify material with overlapping bands.
  - Answer: Metal.
- **Ex 2:** Material with band gap 1.1 eV?
  - Answer: Silicon (semiconductor).

Practice Set

- Q1: Which has no band gap?
  - A. Metal
  - B. Semiconductor
  - C. Insulator
  - D. None
- Q2: Band gap of insulator is?
  - A. < 1 eV
  - B. ~1 eV
  - C. > 5 eV
  - D. 0 eV
- Q3: Band gap of germanium?
  - A. 0.72 eV
  - B. 1.1 eV
  - C. 5 eV
  - D. 0 eV

Answer Key

- Q1: A - Metals have overlapping bands, no gap.
- Q2: C - Insulators have band gap > 5 eV.
- Q3: A - Germanium band gap is 0.72 eV.

Memory Aids

- Metal: Overlapping bands, no gap.
- Insulator: Large gap > 5 eV.
- Semiconductor: Small gap ~1 eV.

Hole

Definition and Properties

- Positive charge carrier in semiconductors.
- Created when electron leaves covalent bond.
- Charge equal in magnitude to electron but positive.
- Mobility less than electron.

Solved Examples

- **Ex 1:** What charge does a hole carry?
  - Answer: Positive charge equal to electron charge.

Practice Set

- Q1: Hole is?
  - A. Negative charge carrier
  - B. Positive charge carrier
  - C. Neutral particle
  - D. Electron
- Q2: Hole mobility compared to electron is?
  - A. Greater
  - B. Equal
  - C. Smaller
  - D. Zero
- Q3: Hole is created when?
  - A. Electron breaks covalent bond
  - B. Electron recombines
  - C. Electron moves in conduction band
  - D. Electron is created

Answer Key

- Q1: B - Hole carries positive charge.
- Q2: C - Hole mobility is smaller than electron.
- Q3: A - Hole created when electron leaves covalent bond.

Memory Aids

- Hole = positive charge carrier.
- Mobility: electron > hole.
- Created by electron leaving bond.

Intrinsic Semiconductor

Definition and Examples

- Pure semiconductor without impurities is intrinsic semiconductor.
- Examples: Silicon (Si), Germanium (Ge).

Carrier Concentration

- Electron density in conduction band, n_e.
- Hole density in valence band, n_h.
- Intrinsic carrier concentration, n_i.
- In intrinsic semiconductor, $n_e = n_h = n_i$.

Current in Intrinsic Semiconductor

- Electrons and holes move in opposite directions under electric field.
- Total current, $I = I_e + I_h$, where I_e is electron current, I_h is hole current.
- Current formula: $I = n_i e A (v_e + v_h)$, where A is cross-sectional area, v_e, v_h are drift velocities.

Conductivity and Resistivity

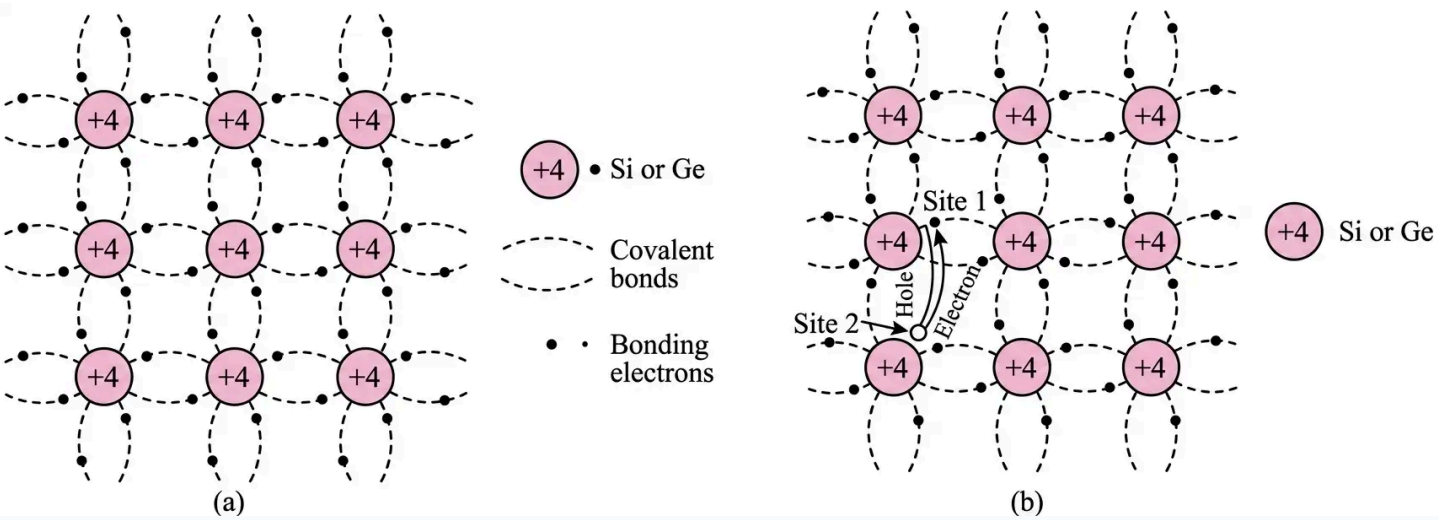
- Conductivity, $\sigma = n_i e (\mu_e + \mu_h)$, where μ_e, μ_h are mobilities of electrons and holes.
- Resistivity, $\rho = \frac{1}{\sigma} = \frac{1}{e n_i (\mu_e + \mu_h)}$.

Temperature Effect

- Increasing temperature increases electron-hole pair density.
- Conductivity increases with temperature.
- Resistivity decreases with temperature.
- Semiconductors have negative temperature coefficient of resistance.

Crystal Structure and Hole Motion

- Si or Ge atoms form covalent bonds with 4 neighbors (+4 core charge).
- At low temperature, all bonds intact.
- Electron movement creates holes that appear to move through the lattice.



Solved Examples

- **Ex 1:** Calculate conductivity if $n_i = 1 \times 10^{16}$ m^{-3}, $\mu_e = 0.14$ m^2/V·s, $\mu_h = 0.05$ m^2/V·s, and $e = 1.6 \times 10^{-19}$ C.
  - $\sigma = n_i e(\mu_e + \mu_h) = 1 \times 10^{16} \times 1.6 \times 10^{-19} \times (0.14 + 0.05) = 3.04 \times 10^{-3}$ S/m.
- **Ex 2:** Find resistivity ρ from above data.
  - $\rho = 1/\sigma = 1/3.04 \times 10^{-3} = 329.0\ \Omega$·m.

Practice Set

- Q1: What is the relation between electron and hole densities in intrinsic semiconductor?
  - A) $n_e > n_h$
  - B) $n_e < n_h$
  - C) $n_e = n_h = n_i$
  - D) None of these
- Q2: Conductivity σ of intrinsic semiconductor depends on?
  - A) Carrier concentration and mobility
  - B) Only carrier concentration
  - C) Only mobility
  - D) Temperature only
- Q3: If intrinsic carrier concentration doubles, what happens to conductivity?
  - A) Halves
  - B) Doubles
  - C) Quadruples
  - D) No change

Answer Key

- Q1: C - Electron and hole densities are equal in intrinsic semiconductor.
- Q2: A - Conductivity depends on carrier concentration and their mobilities.
- Q3: C - Conductivity $\sigma = n_i e(\mu_e + \mu_h)$, doubling n_i doubles σ, so quadruples conductivity.

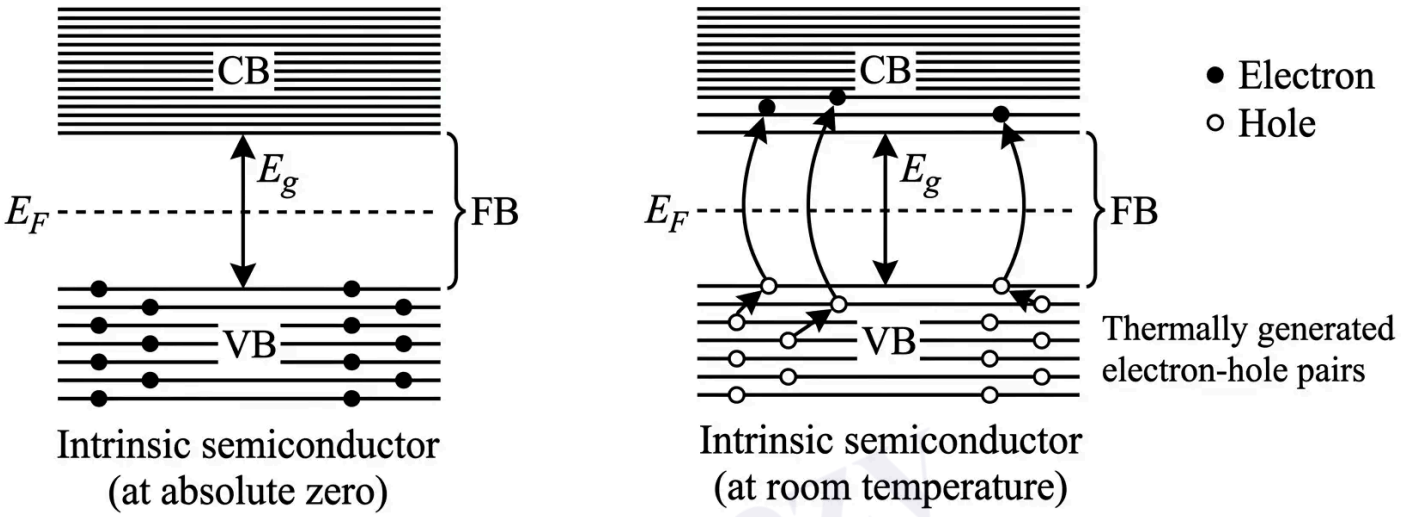
Memory Aids

- Intrinsic: Pure, no impurities.
- $n_e = n_h = n_i$ always equal.
- Conductivity $\sigma = n_i e(\mu_e + \mu_h)$.
- Resistivity inversely proportional to conductivity.
- Conductivity increases with temperature.

Energy Band Diagram

Band Structure at Different Temperatures

- At $T = 0$ K, valence band (VB) full, conduction band (CB) empty.
- Intrinsic semiconductor behaves like insulator at 0 K.
- At $T > 0$ K, electrons gain thermal energy, jump from VB to CB.
- Equal number of holes created in VB.
- Electrons occupy lowest energy levels in CB.
- Number of electrons in CB equals number of holes in VB.



Solved Examples

- **Ex 1:** At 0 K, what is the conductivity of intrinsic semiconductor?
  - Zero, as no free electrons in conduction band.
- **Ex 2:** Why does conductivity increase with temperature?
  - Thermal energy excites electrons to conduction band, increasing free carriers.

Practice Set

- Q1: At 0 K, intrinsic semiconductor behaves as?
  - A) Conductor
  - B) Insulator
  - C) Semiconductor
  - D) Superconductor
- Q2: What causes holes in valence band?
  - A) Electron excitation to conduction band
  - B) Electron recombination
  - C) Impurity doping
  - D) None of these
- Q3: Number of electrons in conduction band equals?
  - A) Number of holes in valence band
  - B) Number of atoms
  - C) Number of impurities
  - D) Zero

Answer Key

- Q1: B - At 0 K, no free electrons, acts as insulator.
- Q2: A - Holes created by electron excitation to conduction band.
- Q3: A - Electrons in CB equal holes in VB.

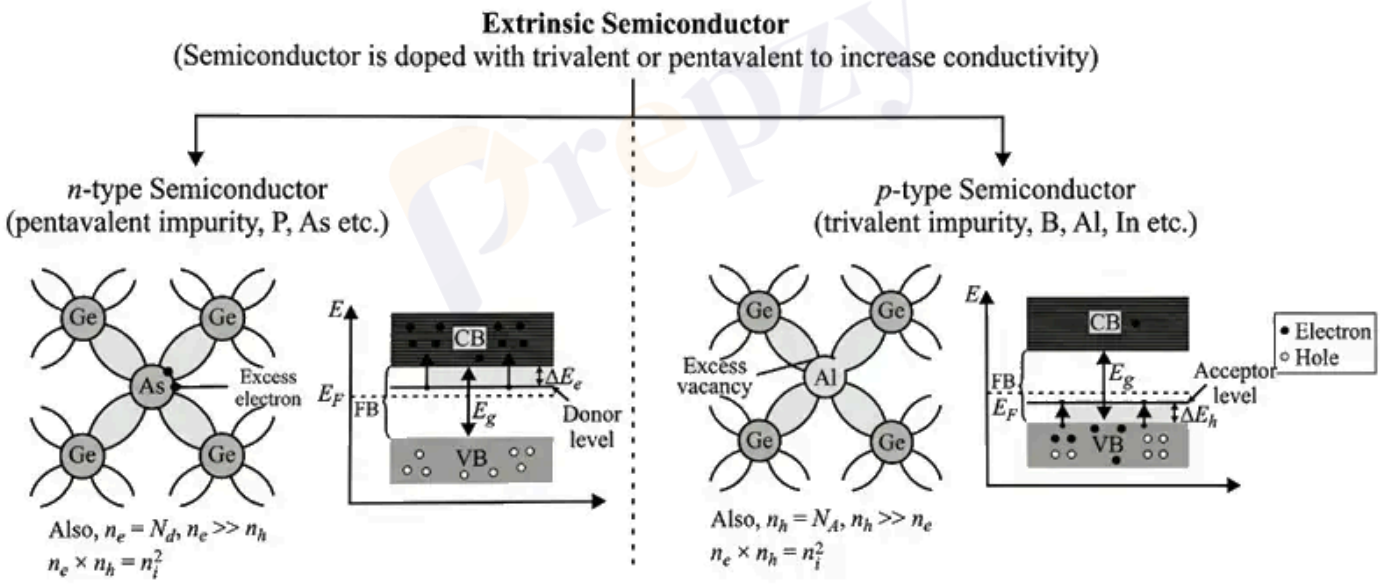
Memory Aids

- At 0 K, no conduction.
- Thermal energy creates electron-hole pairs.
- Electron-hole pairs enable conductivity.

Extrinsic Semiconductor

Concepts

- Impure semiconductor with added impurities is called extrinsic semiconductor.
- Doping: Adding small amounts of impurities with different valency to pure semiconductor.
- Impurities increase mobile electrons or holes, enhancing conductivity.
- Two types: n-type (pentavalent impurities) and p-type (trivalent impurities).
- Energy bands affected by donor (n-type) or acceptor (p-type) levels.



Solved Examples

- **Ex 1:** Calculate the effect of doping on conductivity if donor atoms increase free electrons by 10^{15} cm^{-3}.
- Step 1: Identify donor density $N_d = 10^{15}$ cm^{-3}.
- Step 2: Free electron concentration $n_e \approx N_d = 10^{15}$ cm^{-3}.
- Step 3: Conductivity increases proportionally to n_e.

Practice Set

- **Q1:** What is doping in semiconductors?
  - A. Removing impurities
  - B. Adding impurities to increase conductivity

    - C. Heating semiconductor
    - D. Cooling semiconductor
- **Q2:** Which impurity type is used for n-type semiconductor?
    - A. Trivalent
    - B. Pentavalent
    - C. Tetravalent
    - D. Hexavalent
- **Q3:** In extrinsic semiconductors, what mainly increases conductivity?
    - A. Holes in n-type
    - B. Electrons in p-type
    - C. Electrons in n-type
    - D. Holes in intrinsic

Answer Key

- **Q1:** B - Doping means adding impurities to increase conductivity.
- **Q2:** B - Pentavalent impurities create n-type semiconductors.
- **Q3:** C - Electrons are majority carriers in n-type, increasing conductivity.

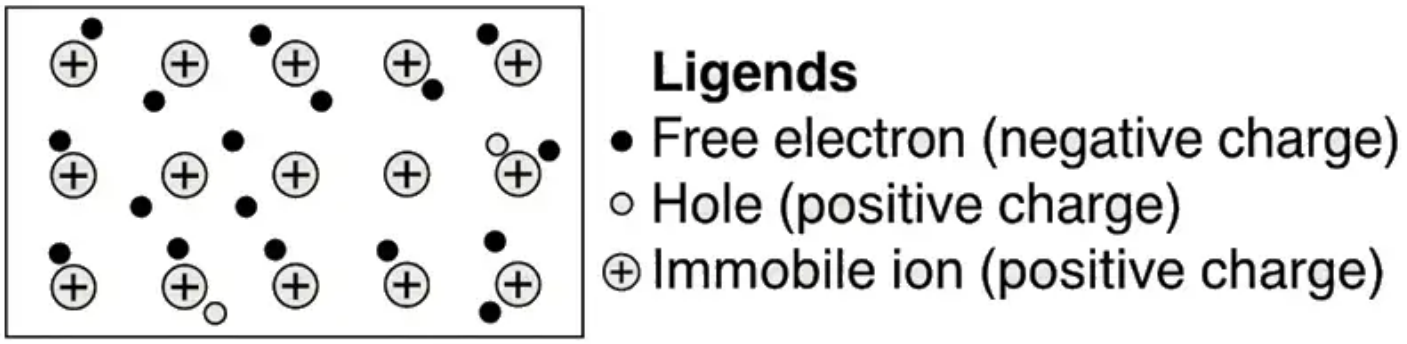
Memory Aids

- Doping = Adding impurities to increase charge carriers.
- n-type = Negative charge carriers (electrons) from pentavalent donors.
- p-type = Positive charge carriers (holes) from trivalent acceptors.

n-type Semiconductor

Concepts

- Pure Si or Ge (tetravalent) doped with group V pentavalent impurities (As, Sb, P).
- Donor atoms donate one free electron for conduction.
- Conduction due to electrons (negative charge carriers).
- Majority carriers: electrons; minority carriers: holes.
- Charge neutrality maintained.
- Electron concentration: $n_e \approx N_d \gg n_h$, where N_d = donor density.



Solved Examples

- **Ex 1:** Find majority carrier concentration if donor density $N_d = 5 \times 10^{16}$ cm^{-3}.
- Step 1: Majority carrier concentration $n_e \approx N_d = 5 \times 10^{16}$ cm^{-3}.
- Step 2: Minority carrier concentration n_h is negligible.

Practice Set

- **Q1:** What type of impurity is used in n-type semiconductor?
  - A. Trivalent
  - B. Pentavalent
  - C. Tetravalent
  - D. Divalent
- **Q2:** Majority carriers in n-type semiconductor are?
  - A. Holes
  - B. Electrons
  - C. Ions
  - D. Neutrons
- **Q3:** If donor density $N_d = 10^{15}$ cm^{-3}, what is electron concentration?
  - A. 10^{14} cm^{-3}
  - B. 10^{15} cm^{-3}
  - C. 10^{16} cm^{-3}
  - D. 10^{13} cm^{-3}

Answer Key

- **Q1:** B - Pentavalent impurities are used in n-type doping.
- **Q2:** B - Electrons are majority carriers in n-type semiconductor.
- **Q3:** B - Electron concentration equals donor density N_d.

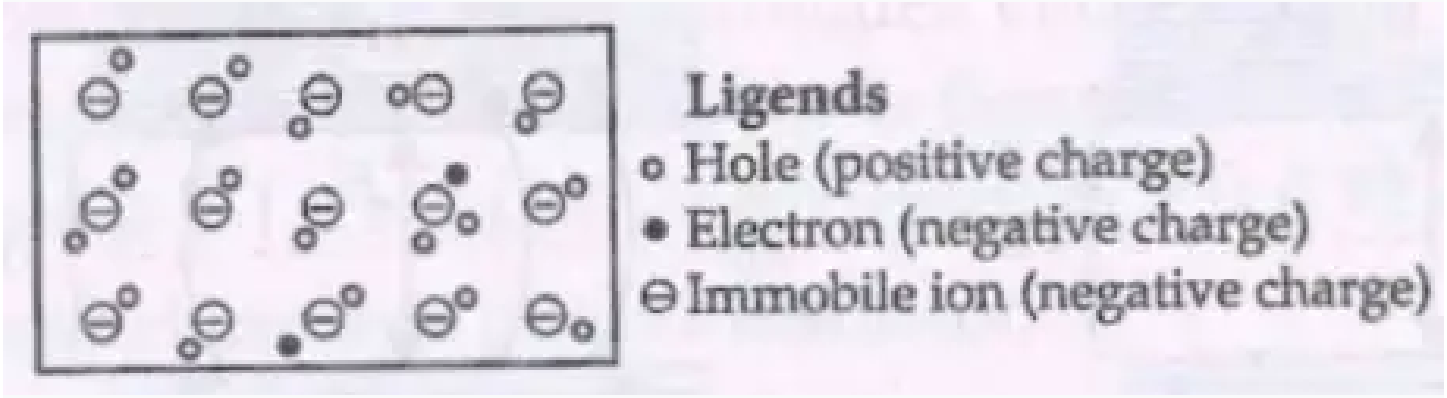
Memory Aids

- n-type = Negative charge carriers (electrons).
- Donor atoms = Pentavalent impurities.
- Electron concentration $n_e \approx N_d$.

p-type Semiconductor

Concepts

- Pure Si or Ge doped with group III trivalent impurities (Al, B, In).
- Acceptor atoms create holes (positive charge carriers).
- Conduction due to holes.
- Majority carriers: holes; minority carriers: electrons.
- Charge neutrality maintained.
- Hole concentration: $n_h \approx N_a \gg n_e$, where N_a = acceptor density.



Solved Examples

- **Ex 1:** Calculate hole concentration if acceptor density $N_a = 2 \times 10^{16}$ cm^{-3}.
- Step 1: Hole concentration $n_h \approx N_a = 2 \times 10^{16}$ cm^{-3}.
- Step 2: Electron concentration n_e is negligible.

Practice Set

- **Q1:** What type of impurity is used in p-type semiconductor?
  - A. Pentavalent
  - B. Trivalent
  - C. Tetravalent
  - D. Hexavalent
- **Q2:** Majority carriers in p-type semiconductor are?
  - A. Electrons
  - B. Holes
  - C. Ions
  - D. Neutrons
- **Q3:** If acceptor density $N_a = 10^{15}$ cm^{-3}, what is hole concentration?
  - A. 10^{14} cm^{-3}
  - B. 10^{15} cm^{-3}
  - C. 10^{16} cm^{-3}
  - D. 10^{13} cm^{-3}

Answer Key

- **Q1:** B - Trivalent impurities are used in p-type doping.
- **Q2:** B - Holes are majority carriers in p-type semiconductor.
- **Q3:** B - Hole concentration equals acceptor density N_a.

Memory Aids

- p-type = Positive charge carriers (holes).
- Acceptor atoms = Trivalent impurities.
- Hole concentration $n_h \approx N_a$.

p-n Junction

Formation and Charge Distribution

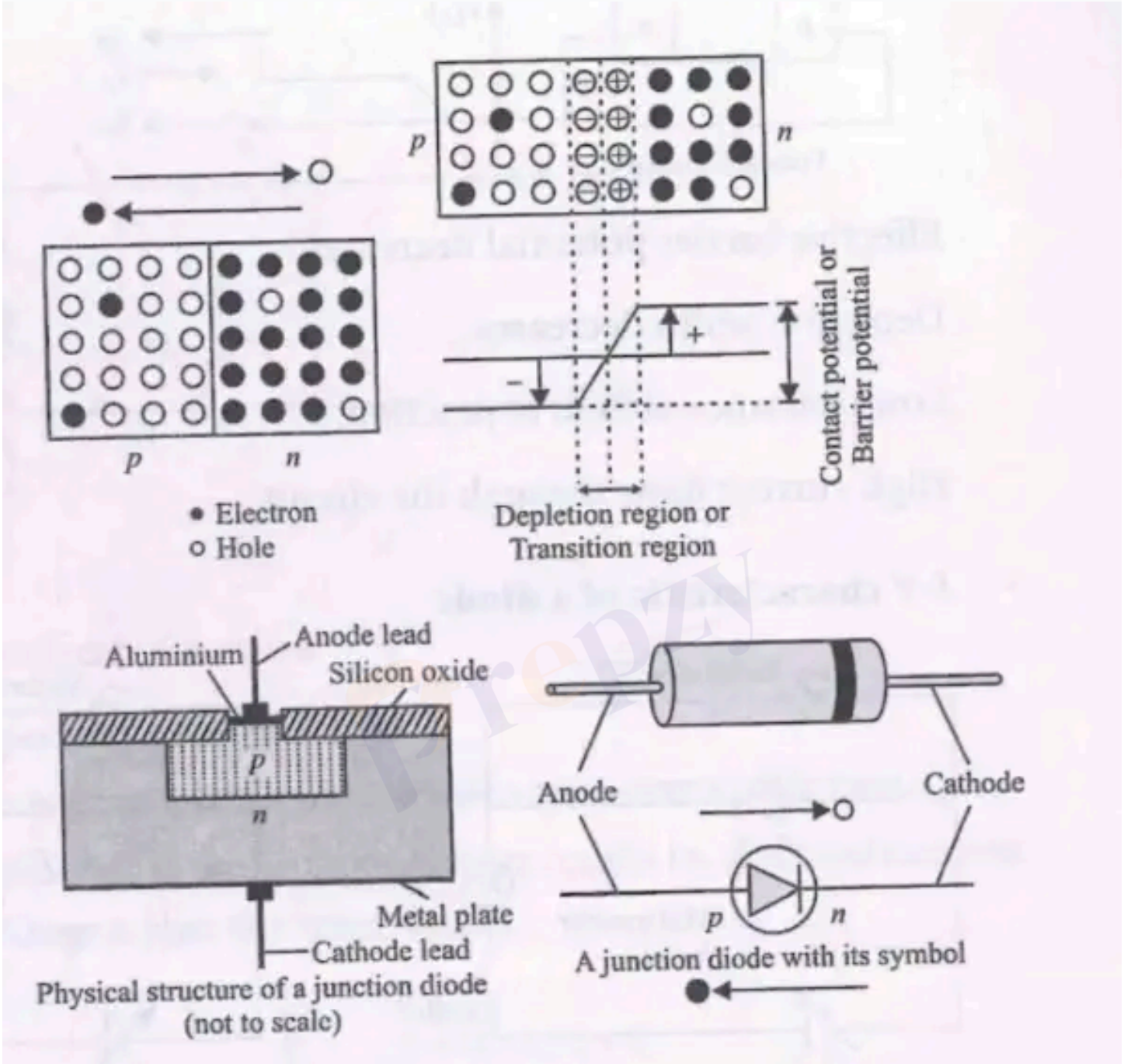
- Free electrons from n-type diffuse to p-type, filling holes.
- Positive charge layer forms on n-side; negative charge layer on p-side.
- Charge layers form quickly, stopping further carrier movement.
- Potential difference (V_0) of 0.1–0.3 V (Ge: 0.3 V, Si: 0.7 V) forms as a barrier.
- Depletion layer: thin region with immobile charges around junction.

Currents in p-n Junction

- **Diffusion current:** Holes diffuse p → n; electrons diffuse n → p due to concentration difference.
- **Drift current:** Minority carriers move across barrier due to potential, creating drift current.

Electric Field

- Electric field intensity, $E = \frac{V}{d}$, where V is potential barrier and d is depletion width.



Solved Examples

- **Ex 1:** Calculate electric field if $V_0 = 0.7\ \text{V}$ and $d = 2 \times 10^{-6}\ \text{m}$.
  - Use $E = \frac{V}{d} = \frac{0.7}{2 \times 10^{-6}} = 3.5 \times 10^{5}\ \text{V/m}$.

Practice Set

- Q1: What is the typical potential barrier for silicon p-n junction?
  - A) 0.1 V
  - B) 0.3 V
  - C) 0.7 V

    - D) 1.0 V
- Q2: Which current is due to minority carriers moving across the junction?
    - A) Diffusion current
    - B) Drift current
    - C) Both currents
    - D) None
- Q3: If the depletion width is $1 \times 10^{-6}\ \mathrm{m}$ and barrier potential is 0.3 V, what is the electric field intensity?
    - A) $3 \times 10^{5}\ \mathrm{V/m}$
    - B) $3 \times 10^{4}\ \mathrm{V/m}$
    - C) $3 \times 10^{6}\ \mathrm{V/m}$
    - D) $3 \times 10^{3}\ \mathrm{V/m}$

Answer Key

- Q1: C - Silicon p-n junction barrier is typically 0.7 V.
- Q2: B - Drift current is due to minority carriers moving across the barrier.
- Q3: A - $E = V/d = 0.3/1 \times 10^{-6} = 3 \times 10^{5}\ \mathrm{V/m}$.

Memory Aids

- Potential barrier: Ge ~0.3 V, Si ~0.7 V.
- Diffusion current: majority carriers move due to concentration gradient.
- Drift current: minority carriers move due to electric field.
- Electric field: $E = V/d$.

Semiconductor Diode

Basic Concept

- A semiconductor diode is a p-n junction with metallic contacts for external voltage application.
- Current flows mainly from p-side to n-side under forward bias (arrow direction shows conventional current).
- Equilibrium barrier potential changes with applied external voltage V.

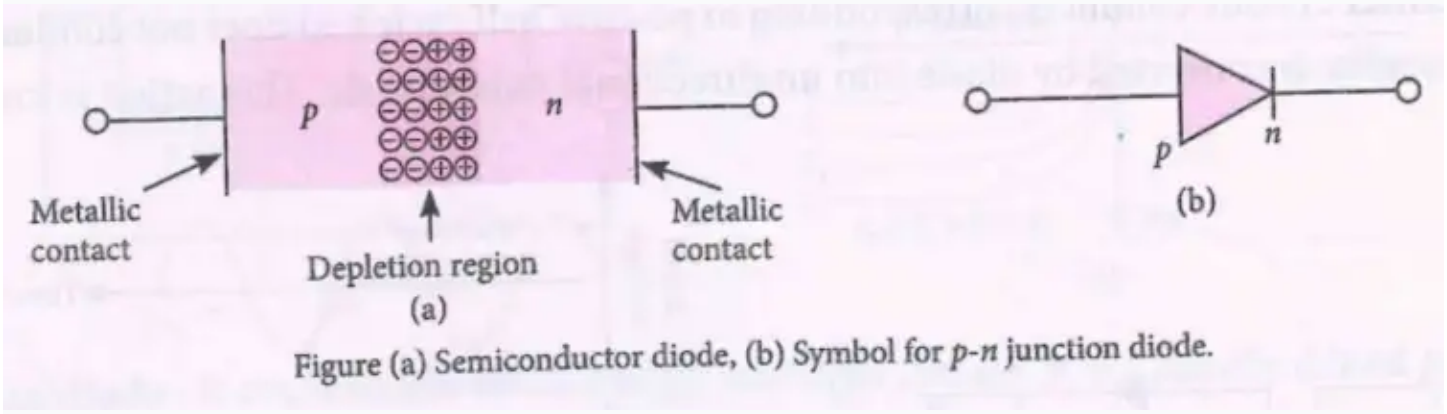


Figure (a) Semiconductor diode, (b) Symbol for *p-n* junction diode.

Structure and Symbol

- Formed by joining p-type and n-type semiconductors.
- Depletion region at junction acts as a barrier to current.
- Metallic contacts connect diode to circuit.
- Symbol shows arrow indicating forward current direction.

Solved Examples

Ex 1

- Identify the direction of current flow in a given diode symbol: Current flows from p to n side (arrow direction).
- Apply external voltage to alter barrier potential and observe current change.

Practice Set

- Q1: What does the arrow in a diode symbol indicate?
  - A) Electron flow direction
  - B) Conventional current direction
  - C) Voltage polarity
  - D) Depletion region width
- Q2: What forms the depletion region in a semiconductor diode?
  - A) Metallic contacts
  - B) Junction of p and n regions
  - C) External voltage
  - D) Battery connection
- Q3: Applying forward bias to a diode does what to the barrier potential?
  - A) Increases it
  - B) Decreases it
  - C) No change
  - D) Removes it completely

Answer Key

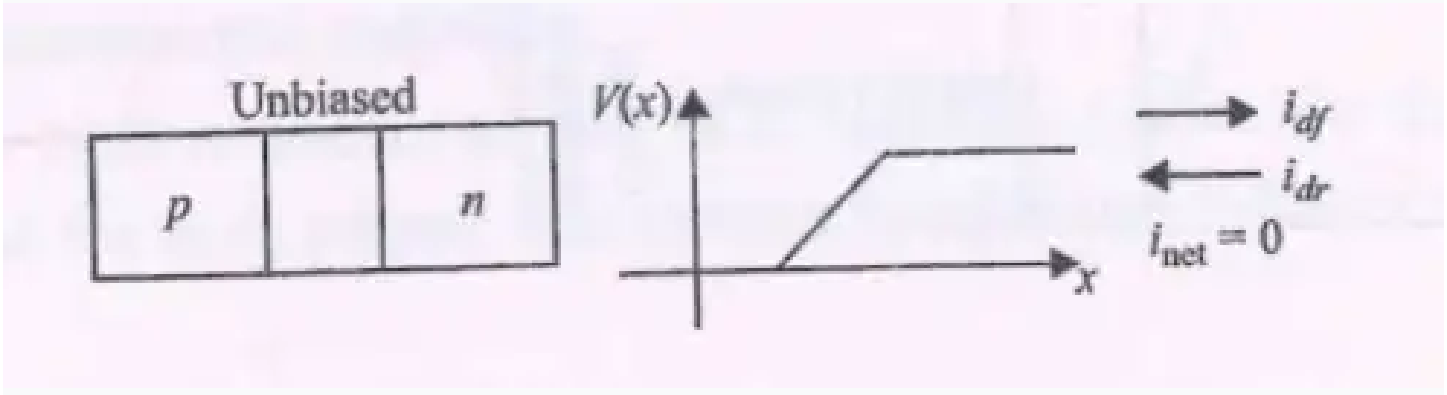
- Q1: B - Arrow shows conventional current flow direction under forward bias.
- Q2: B - Depletion region forms at the p-n junction.
- Q3: B - Forward bias reduces the barrier potential allowing current flow.

Memory Aids

- Arrow in diode symbol = conventional current direction.
- Depletion region = barrier to current at p-n junction.
- Forward bias lowers barrier potential, enabling conduction.

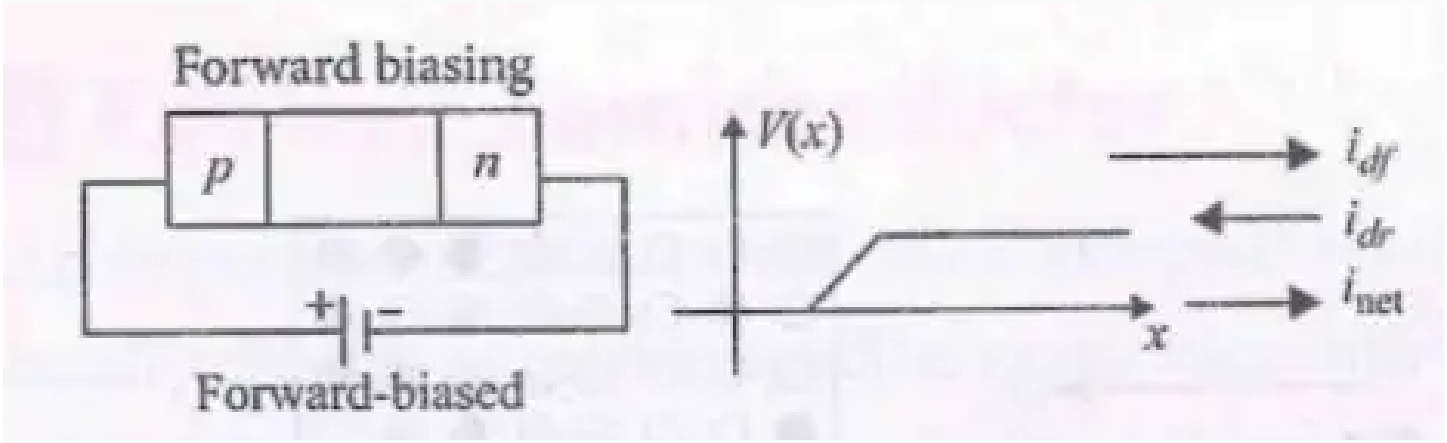
Biasing of p-n Junction

Unbiased Junction



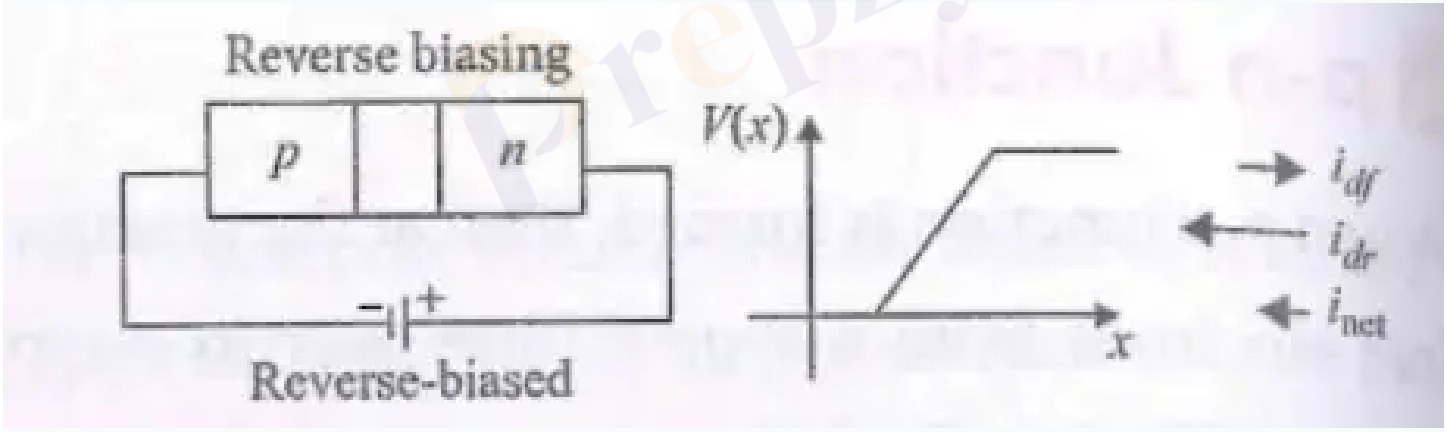
- No external voltage applied.
- Built-in electric field exists due to voltage rise from p to n side.
- Diffusion current i_{df} and drift current i_{dr} balance each other.
- Net current $i_{net} = 0$.

Forward Bias



- Positive terminal connected to p-side, negative to n-side.
- Barrier potential decreases, depletion width narrows.
- Low resistance at junction, high current flows.
- Net current i_{net} flows forward.

Reverse Bias



- Positive terminal connected to n-side, negative to p-side.
- Barrier potential increases, depletion width widens.
- High resistance at junction, very low current (leakage current) flows.
- Net current $i_{net} \approx 0$, blocks current flow.

Solved Examples

Ex 1

- Determine the effect of forward bias on depletion width: It decreases.
- Determine the effect of reverse bias on barrier potential: It increases.

Practice Set

- Q1: What happens to the depletion width under forward bias?
  - A) Increases
  - B) Decreases
  - C) No change
  - D) Becomes zero
- Q2: Under reverse bias, the current through the diode is:
  - A) High
  - B) Zero
  - C) Very low (leakage)
  - D) Same as forward bias
- Q3: In reverse bias, the barrier potential:
  - A) Decreases
  - B) Increases
  - C) Remains constant
  - D) Is zero

Answer Key

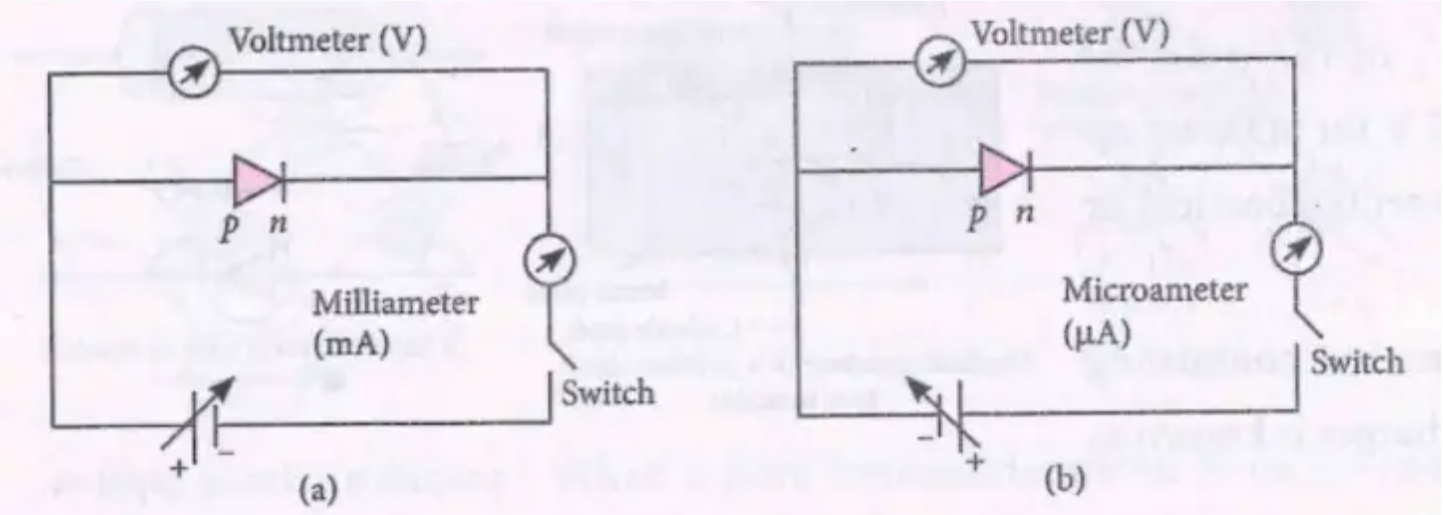
- Q1: B - Forward bias narrows the depletion region.
- Q2: C - Reverse bias allows only a tiny leakage current.
- Q3: B - Barrier potential increases under reverse bias.

Memory Aids

- Forward bias = barrier down, depletion narrows, current flows.
- Reverse bias = barrier up, depletion widens, current blocked.
- Net current zero when unbiased.

I-V Characteristic of Diode

Measurement Setup

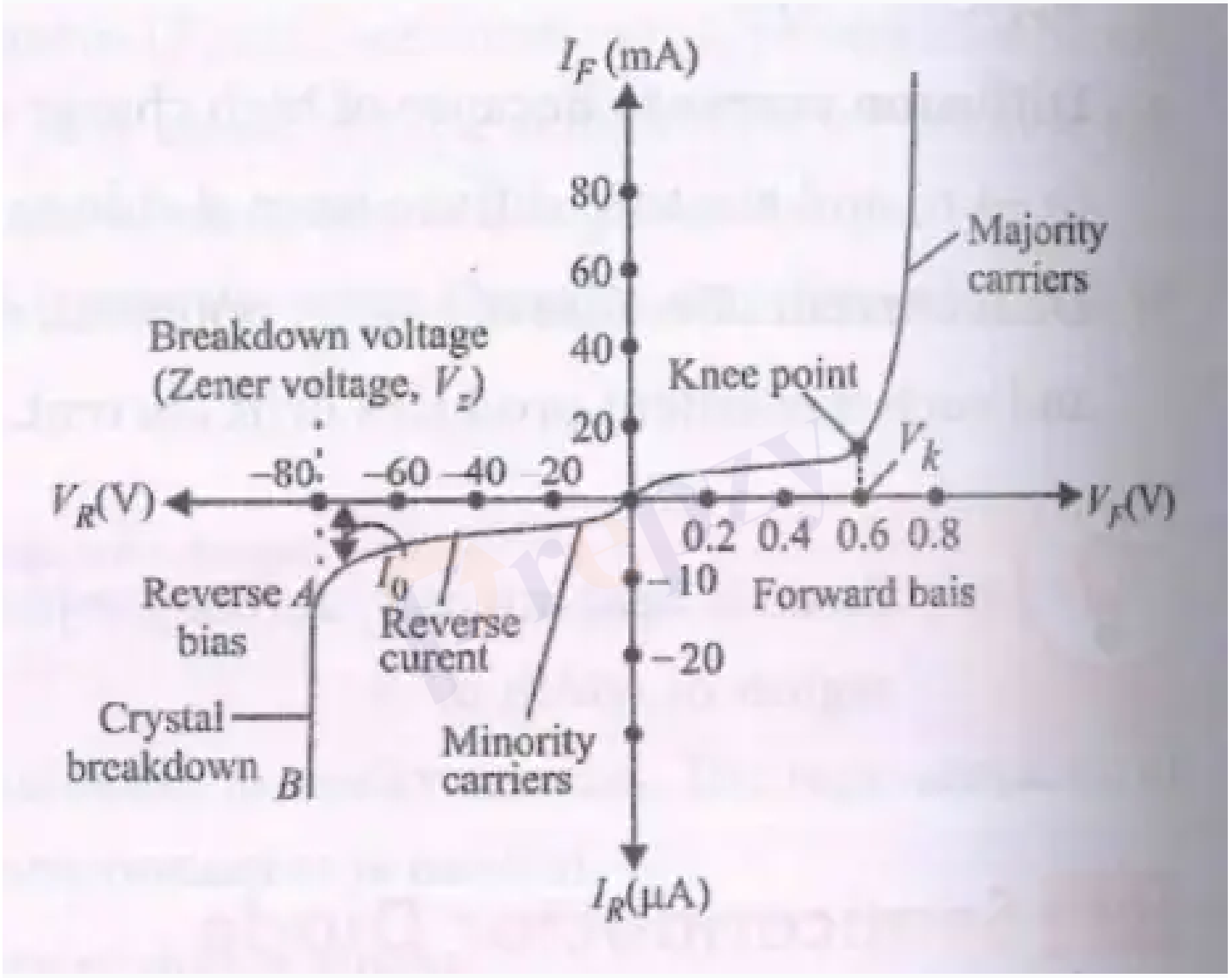


- Diode connected with battery, voltmeter, and current meter (milliammeter or microammeter).
- Switch controls circuit ON/OFF.
- Milliammeter measures higher currents; microammeter measures very low currents.

Current Equation

- Current through diode: $I = I_0 \left[e^{\frac{eV}{nkT}} - 1 \right]$
- Where $n = 1$ for Ge, $n = 2$ for Si.
- I_0 is the reverse saturation current.
- Dynamic resistance: $r_d = \frac{\Delta V}{\Delta I}$
- Static (dc) resistance: $r_{dc} = \frac{V}{I}$

Zener Diode Characteristics



- Forward bias: Current rises rapidly after knee voltage.
- Reverse bias: Small leakage current until breakdown voltage V_Z.
- At V_Z, current increases sharply (Zener effect) without damage.
- Used for voltage regulation.

Solved Examples

Ex 1

- Calculate current for given V using $I = I_0[e^{eV/nkT} - 1]$.
- Determine dynamic resistance from ΔV and ΔI values.

Practice Set

- Q1: In the diode current equation, n equals:
  - A) 1 for Si, 2 for Ge
  - B) 2 for Si, 1 for Ge
  - C) 1 for both
  - D) 2 for both
- Q2: Dynamic resistance r_d is defined as:
  - A) V/I
  - B) $\Delta V/\Delta I$
  - C) I/V
  - D) $V \times I$
- Q3: At Zener breakdown voltage, the diode:
  - A) Blocks current
  - B) Allows large reverse current without damage
  - C) Behaves like a resistor
  - D) Stops conducting

Answer Key

- Q1: B - $n = 2$ for Si, $n = 1$ for Ge.
- Q2: B - Dynamic resistance is $\Delta V/\Delta I$.
- Q3: B - Zener diode allows large reverse current at breakdown voltage.

Memory Aids

- Current formula: exponential growth with voltage.
- Dynamic resistance = slope of I-V curve.
- Zener diode stabilizes voltage at breakdown point.

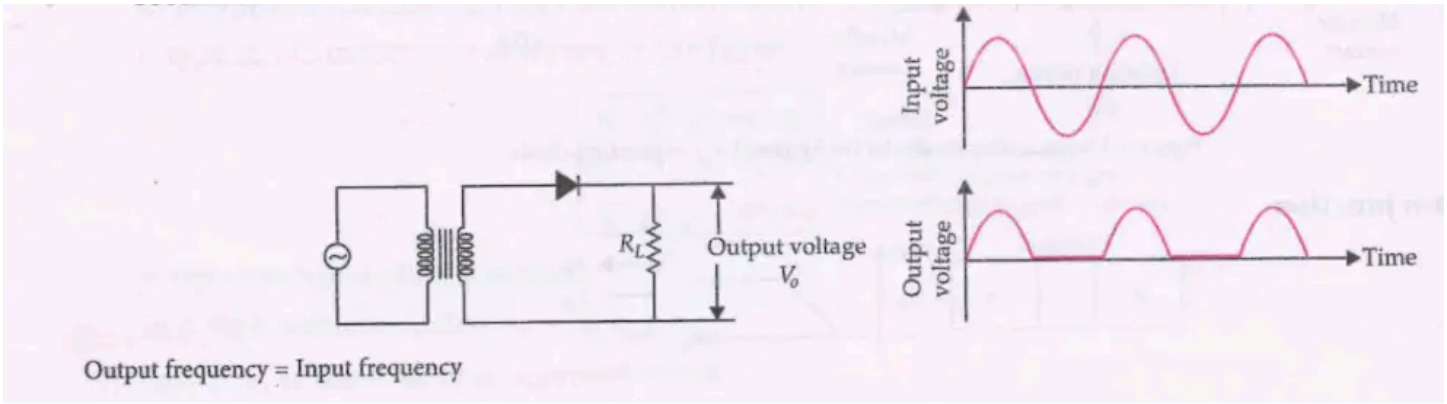
Application of Junction Diode as a Rectifier

Rectifier

- Converts AC voltage to DC voltage.
- Uses diode based on forward bias conduction and reverse bias non-conduction.

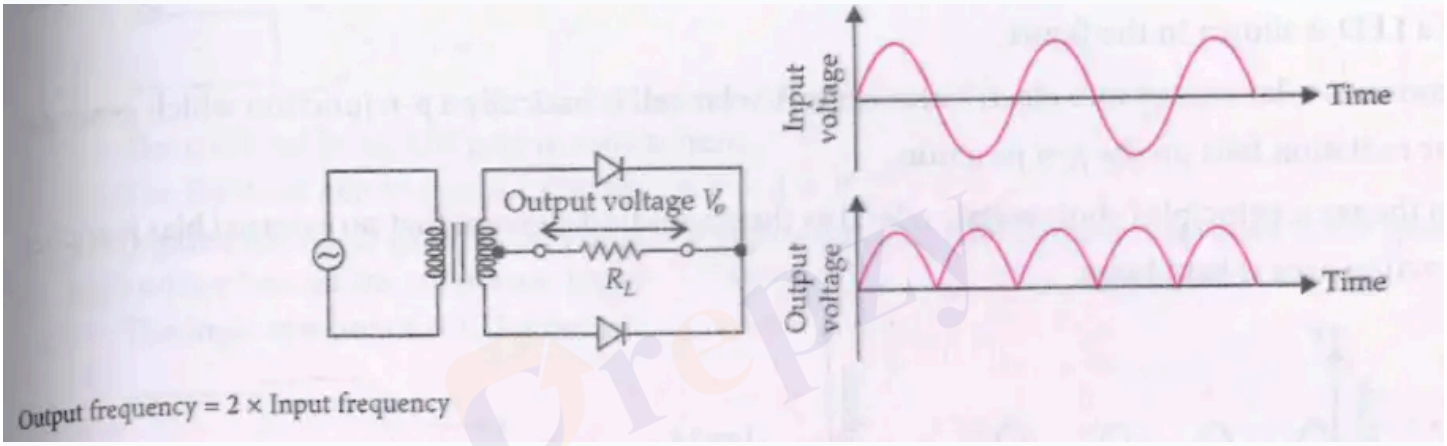
Half wave rectifier

- Diode conducts during positive half cycle only.
- Output is unidirectional pulsating DC.
- Output frequency = input frequency.



Full wave rectifier

- Rectifies both positive and negative halves of AC input.
- Uses two diodes and transformer with center tap.
- Output frequency = 2 × input frequency.
- Output is smoother pulsating DC than half wave.



Solved Examples

- **Ex 1:** Calculate output frequency of full wave rectifier if input frequency is 50 Hz.
  Solution: Output frequency = 2 × 50 = 100 Hz.
- **Ex 2:** What is the output frequency of half wave rectifier for 60 Hz input?
  Solution: Output frequency = 60 Hz.

Practice Set

- Q1: What does a rectifier do?
  A. Converts DC to AC
  B. Converts AC to DC
  C. Amplifies AC
  D. Blocks AC
- Q2: In half wave rectification, diode conducts during:
  A. Negative half cycle
  B. Positive half cycle
  C. Both half cycles
  D. None
- Q3: Output frequency of full wave rectifier for 50 Hz input is:
  A. 25 Hz
  B. 50 Hz

C. 100 Hz
D. 200 Hz

Answer Key

- Q1: B - Rectifier converts AC voltage to DC voltage.
- Q2: B - Diode conducts only during positive half cycle in half wave rectifier.
- Q3: C - Full wave rectifier output frequency is twice the input frequency.

Memory Aids

- Half wave: Conducts half cycle, output freq = input freq.
- Full wave: Conducts both halves, output freq = 2 × input freq.
- Rectifier = AC to DC converter.

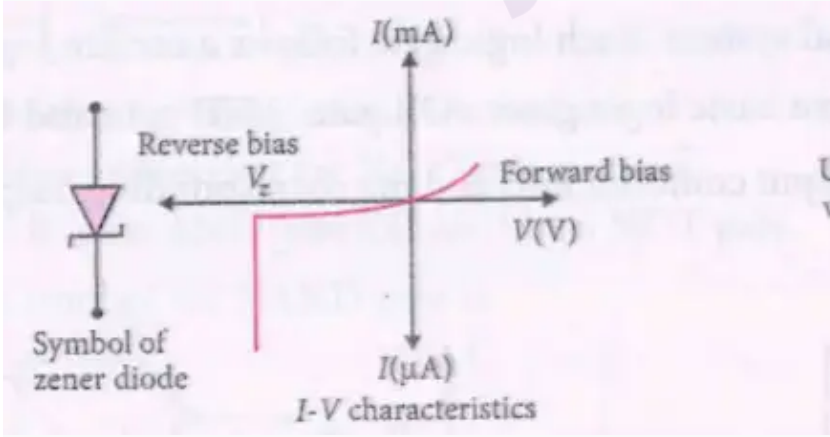
Special Purpose p-n Junction Diodes

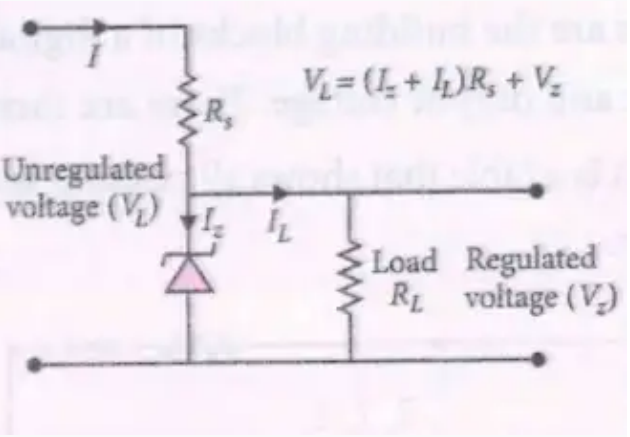
Zener diode

- Heavily doped p-n junction diode.
- Operates in reverse bias.
- Zener voltage remains constant over wide current range.
- Used as voltage regulator.

Zener diode as voltage regulator

- Voltage across Zener diode remains constant despite input voltage changes.
- Voltage drop across series resistor changes to maintain constant voltage.





Solved Examples

- **Ex 1:** If input voltage increases, what happens to voltage across Zener diode?
  Solution: Voltage across Zener diode remains constant.
- **Ex 2:** What is the role of series resistor in Zener voltage regulator?
  Solution: It drops excess voltage to maintain constant Zener voltage.

Practice Set

- Q1: Zener diode operates in:
  A. Forward bias
  B. Reverse bias
  C. Both
  D. None
- Q2: Zener voltage is:
  A. Variable with current
  B. Constant over wide current range
  C. Zero
  D. Negative
- Q3: In Zener voltage regulator, if input voltage increases:
  A. Zener voltage increases
  B. Voltage across series resistor increases
  C. Load voltage increases
  D. Zener diode stops conducting

Answer Key

- Q1: B - Zener diode is operated in reverse bias.
- Q2: B - Zener voltage remains constant over wide current range.
- Q3: B - Voltage across series resistor increases to keep Zener voltage constant.

Memory Aids

- Zener diode = voltage regulator diode.
- Constant voltage = Zener voltage.
- Series resistor protects diode by dropping excess voltage.

Photodiode

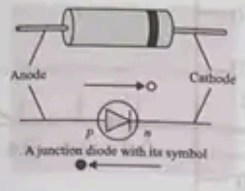
Photodiode basics

- Special p-n junction diode with transparent window.
- Operated under reverse bias.
- Generates electron-hole pairs when illuminated with photon energy > semiconductor band gap.
- Produces photocurrent proportional to light intensity.

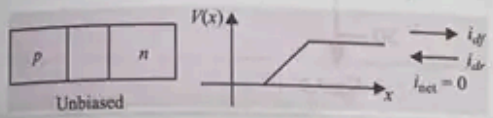
Photodiode symbol and I-V characteristics

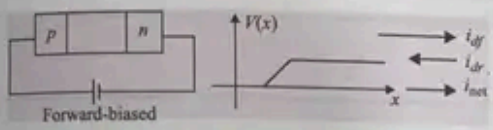
- Forward bias: current increases sharply after knee voltage.
- Reverse bias: very low current until breakdown voltage.
- Illumination increases reverse current (photocurrent).

p-n Junction Diode

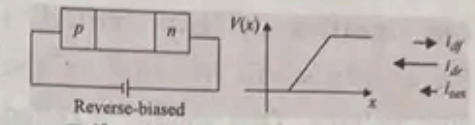


- **Baising of *p-n* junction**



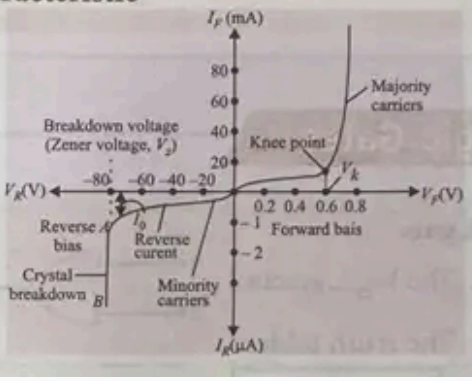


- Effective barrier potential decreases.
- Depletion width decreases.
- Low resistance offered at junction.
- High current flows through the circuit.



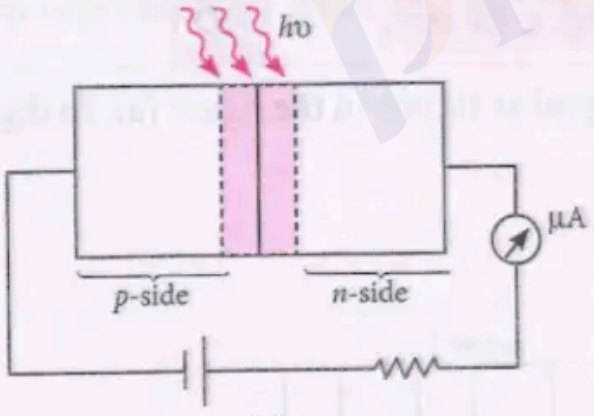
- Effective barrier potential increases.
- Depletion width increases.
- High resistance offered at junction.
- Low current flows though the circuit.

- ***I-V* characteristic**



Photodiode under illumination

- Light generates electron-hole pairs near depletion region.
- Photocurrent flows in reverse bias circuit.
- Current increases with light intensity.



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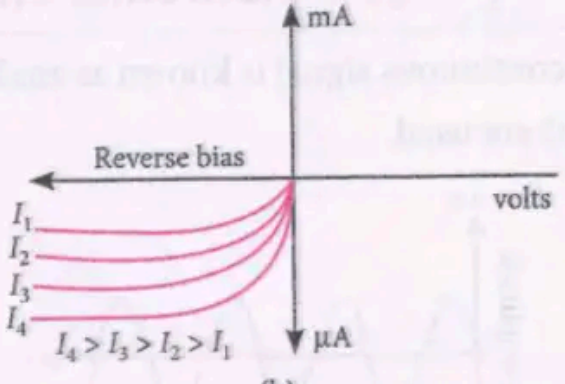


(b)

Solved Examples

- **Ex 1:** What happens to photocurrent if light intensity increases?
  Solution: Photocurrent increases proportionally.
- **Ex 2:** Why is photodiode operated in reverse bias?
  Solution: To increase depletion region width and reduce dark current.

Practice Set

- Q1: Photodiode is operated in:
  A. Forward bias

B. Reverse bias
C. Both
D. None

- Q2: Photocurrent increases with:
  A. Voltage only
  B. Light intensity
  C. Temperature
  D. Resistance
- Q3: Photodiode generates electron-hole pairs when:
  A. Photon energy < band gap
  B. Photon energy > band gap
  C. No light
  D. Forward bias only

Answer Key

- Q1: B - Photodiode is operated under reverse bias.
- Q2: B - Photocurrent is proportional to light intensity.
- Q3: B - Electron-hole pairs generated when photon energy exceeds band gap.

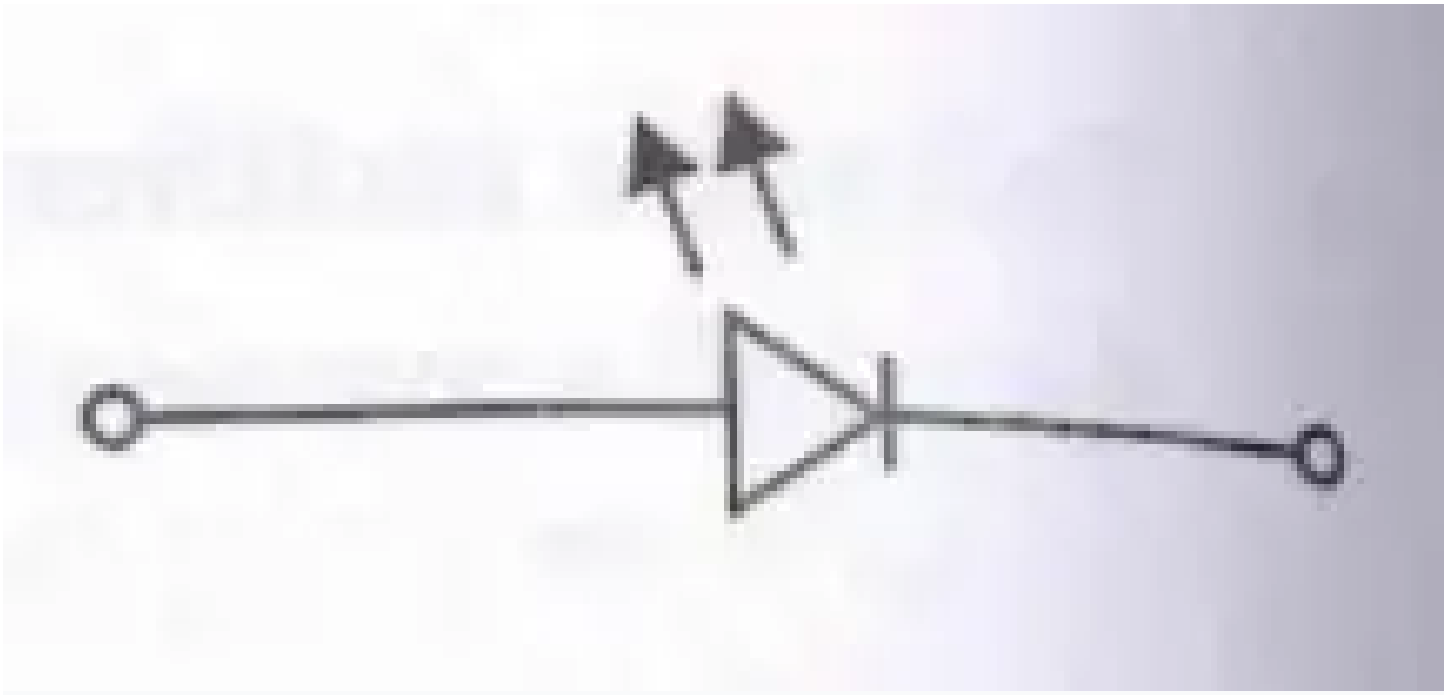
Memory Aids

- Photodiode = light-sensitive diode.
- Reverse bias operation for photocurrent.
- Photocurrent ∝ light intensity.

Light Emitting Diode

LED basics

- Converts electrical energy into light energy.
- Heavily doped p-n junction diode.
- Emits light under forward bias by spontaneous radiation.
- Threshold voltage higher than Si diode, varies by color.
- Reverse breakdown voltage ~5 V (low).
- Made from GaAsP for colors, GaAs for infrared.



Solved Examples

- **Ex 1:** What happens when LED is forward biased?
  Solution: LED emits light.
- **Ex 2:** Which material is used for infrared LED?
  Solution: Gallium arsenide (GaAs).

Practice Set

- Q1: LED emits light when:
  A. Reverse biased
  B. Forward biased
  C. No bias
  D. Both biases
- Q2: Typical reverse breakdown voltage of LED is:
  A. 0.7 V
  B. 5 V
  C. 12 V
  D. 50 V
- Q3: Material used for colored LEDs is:
  A. Silicon
  B. Gallium arsenide phosphide
  C. Germanium
  D. Copper

Answer Key

- Q1: B - LED emits light under forward bias.
- Q2: B - Reverse breakdown voltage of LED is about 5 V.
- Q3: B - GaAsP is used for colored LEDs.

Memory Aids

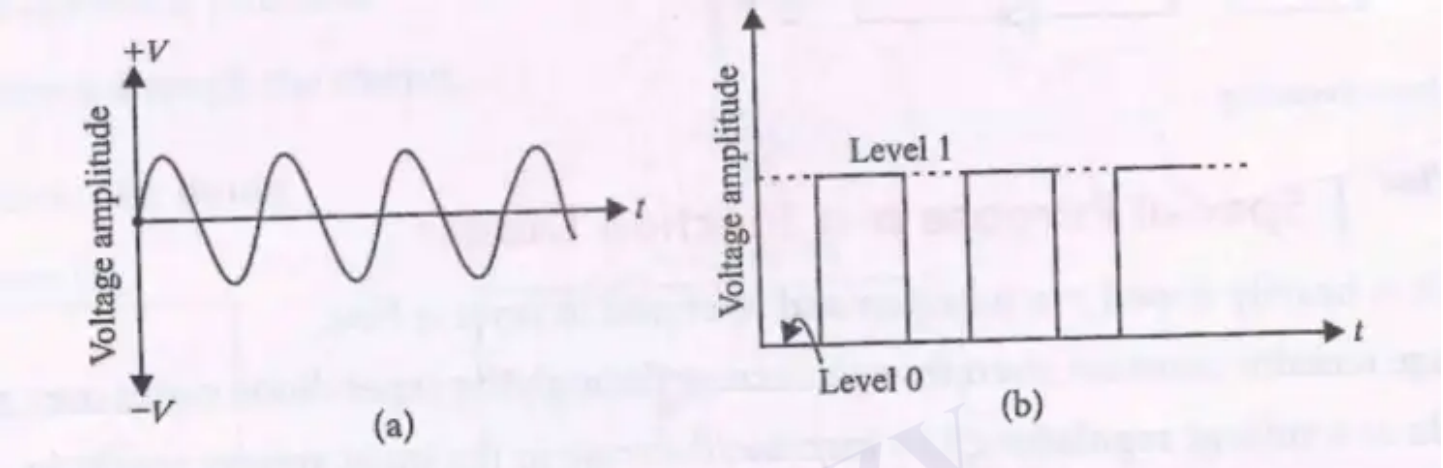
- LED = Light from forward bias.

- GaAsP for colors, GaAs for IR.
- Low reverse breakdown voltage (~5 V).

Solar Cell

Solar cell basics

- Converts solar energy into electrical energy.
- p-n junction generates emf when illuminated.
- Works on photovoltaic effect (like photodiode without external bias).
- Large junction area for higher power.



Solar cell I-V characteristics

- Short circuit current I_{sc}: max current at zero voltage.
- Open circuit voltage V_{oc}: max voltage at zero current.
- Current decreases as voltage increases between these points.

Solved Examples

- **Ex 1:** What is I_{sc} in solar cell?
  Solution: Maximum current when voltage is zero.
- **Ex 2:** What is V_{oc} in solar cell?
  Solution: Maximum voltage when current is zero.

Practice Set

- Q1: Solar cell converts:
  A. Electrical to solar energy
  B. Solar to electrical energy
  C. Heat to electrical energy
  D. Electrical to heat energy
- Q2: Photovoltaic effect means:
  A. Current flows without light
  B. emf generated by light on p-n junction
  C. emf generated by heat
  D. emf generated by magnetic field
- Q3: In solar cell, V_{oc} is:
  A. Voltage at max current

B. Voltage at zero current
C. Current at zero voltage
D. Current at max voltage

Answer Key

- Q1: B - Solar cell converts solar energy to electrical energy.
- Q2: B - Photovoltaic effect is emf generation by light on p-n junction.
- Q3: B - V_{oc} is voltage at zero current.

Memory Aids

- Solar cell = light to electricity.
- Photovoltaic effect = emf by light.
- I_{sc} and V_{oc} define performance.

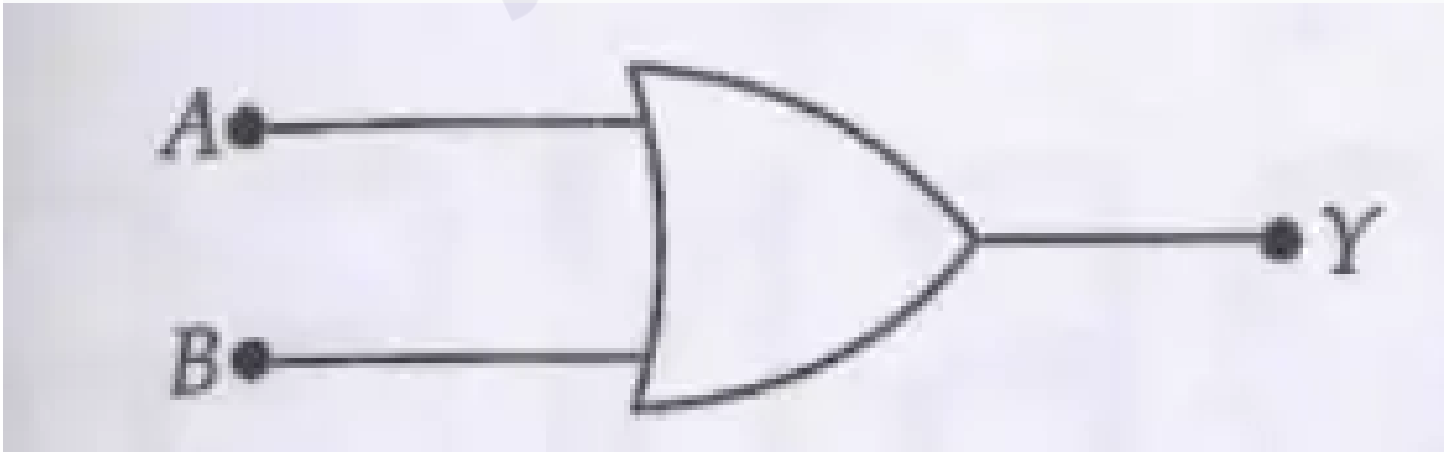
Digital Electronics and Logic Gates

Signals

- Analog signal: continuous time-varying signal.
- Digital signal: discrete levels (0 and 1).

OR gate

- Two or more inputs, one output.
- Output is high if any input is high.
- Boolean expression: $Y = A + B$.



Solved Examples

- **Ex 1:** OR gate output when A=0, B=1?
  Solution: Output Y=1.
- **Ex 2:** Boolean expression for OR gate?
  Solution: $Y = A + B$.

Practice Set

- Q1: OR gate output is high when:
  A. Both inputs low
  B. Any input high
  C. Both inputs high only
  D. No input high
- Q2: Boolean expression for OR gate is:
  A. $Y = A \cdot B$
  B. $Y = A + B$
  C. $Y = A$
  D. $Y = A + B$
- Q3: OR gate output for A=0, B=0 is:
  A. 0
  B. 1
  C. Undefined
  D. 2

Answer Key

- Q1: B - Output is high if any input is high.
- Q2: B - Boolean expression is $Y = A + B$.
- Q3: A - Output is 0 when both inputs are 0.

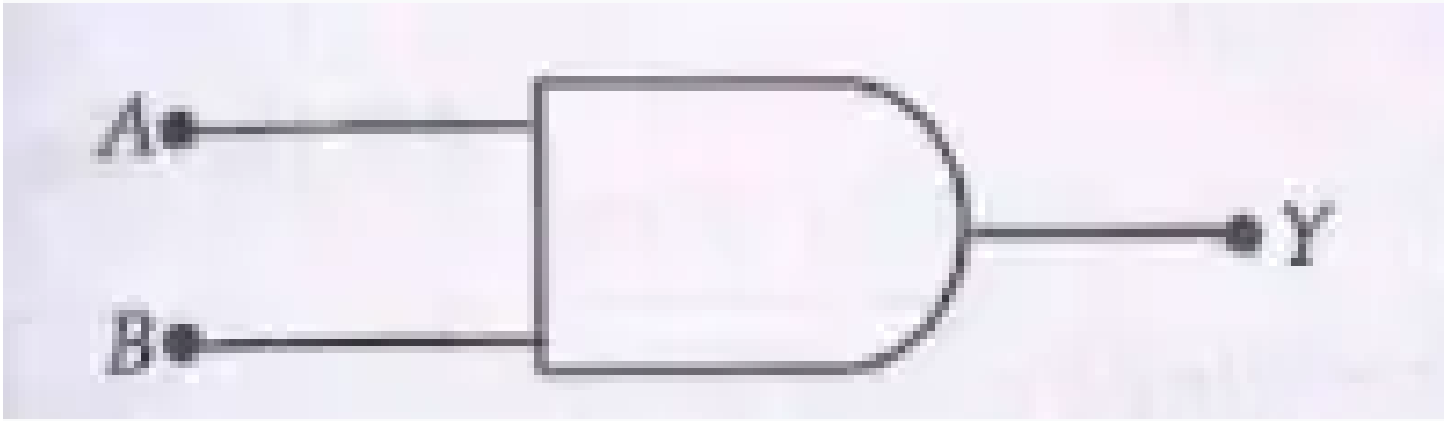
Memory Aids

- OR gate: Output 1 if any input 1.
- Boolean: $Y = A + B$.

AND gate

AND gate basics

- Two or more inputs, one output.
- Output high only if all inputs are high.
- Boolean expression: $Y = A \cdot B$.



Solved Examples

- **Ex 1:** AND gate output when A=1, B=0?
  Solution: Output Y=0.
- **Ex 2:** Boolean expression for AND gate?
  Solution: $Y = A \cdot B$.

Practice Set

- Q1: AND gate output is high when:
  A. Any input high
  B. All inputs high
  C. No input high
  D. One input high
- Q2: Boolean expression for AND gate is:
  A. $Y = A + B$
  B. $Y = A \cdot B$
  C. $Y = A$
  D. $Y = A + B$
- Q3: AND gate output for A=1, B=1 is:
  A. 0
  B. 1
  C. Undefined
  D. 2

Answer Key

- Q1: B - Output is high only if all inputs are high.
- Q2: B - Boolean expression is $Y = A \cdot B$.
- Q3: B - Output is 1 when both inputs are 1.

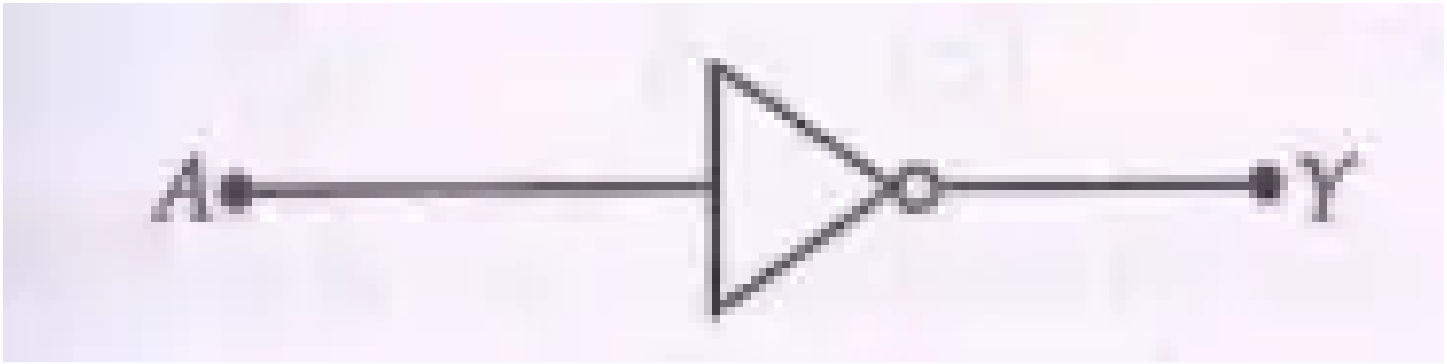
Memory Aids

- AND gate: Output 1 if all inputs 1.
- Boolean: $Y = A \cdot B$.

NOT gate

NOT gate basics

- One input, one output.
- Output is inversion of input.
- Also called inverter.
- Boolean expression: $Y = A$.



Solved Examples

- **Ex 1:** NOT gate output when A=0?
  Solution: Output Y=1.
- **Ex 2:** Boolean expression for NOT gate?
  Solution: $Y = A$.

Practice Set

- Q1: NOT gate output for input 1 is:
  A. 1
  B. 0
  C. Undefined
  D. 2
- Q2: Boolean expression for NOT gate is:
  A. $Y = A$
  B. $Y = A$
  C. $Y = A + B$
  D. $Y = A \cdot B$
- Q3: NOT gate has how many inputs?
  A. 1
  B. 2
  C. 3
  D. 0

Answer Key

- Q1: B - NOT gate inverts input 1 to output 0.
- Q2: B - Boolean expression is $Y = A$.
- Q3: A - NOT gate has only one input.

Memory Aids

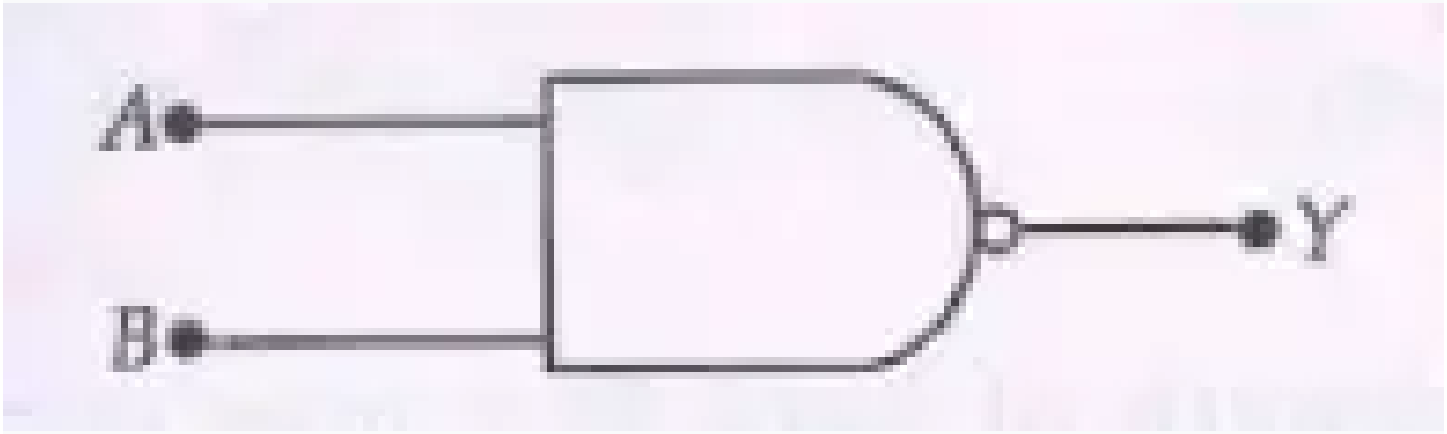
- NOT gate = inverter.
- Output = opposite of input.

NAND gate

NAND gate basics

- AND gate followed by NOT gate.

- Output is negation of AND output.
- Boolean expression: $A \cdot B$.



Solved Examples

- **Ex 1:** NAND gate output when A=1, B=1?
  Solution: Output Y=0.
- **Ex 2:** Boolean expression for NAND gate?
  Solution: $Y = A \cdot B$.

Practice Set

- Q1: NAND gate output is low when:
  A. Both inputs low
  B. Both inputs high
  C. Any input low
  D. No input high
- Q2: Boolean expression for NAND gate is:
  A. $Y = A + B$
  B. $Y = A \cdot B$
  C. $Y = A \cdot B$
  D. $Y = A + B$
- Q3: NAND gate output for A=0, B=1 is:
  A. 0
  B. 1
  C. Undefined
  D. 2

Answer Key

- Q1: B - Output is low only when both inputs are high.
- Q2: B - Boolean expression is negation of AND: $A \cdot B$.
- Q3: B - Output is 1 when any input is low.

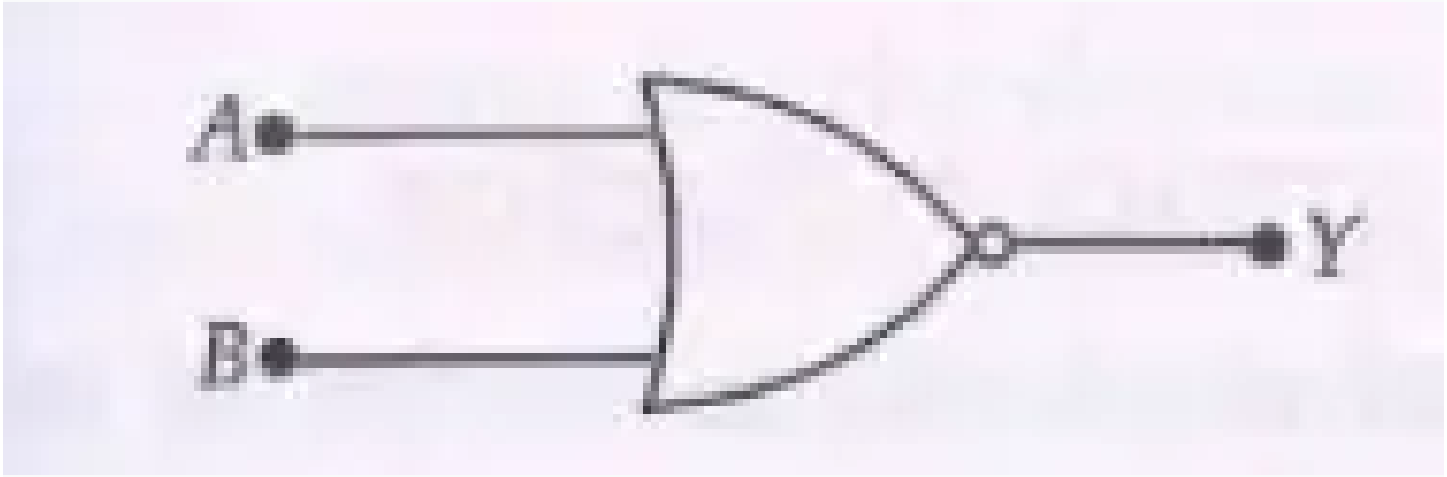
Memory Aids

- NAND = AND + NOT.
- Output low only if all inputs high.

NOR gate

NOR gate basics

- OR gate followed by NOT gate.
- Output is negation of OR output.
- Boolean expression: $Y = A + B$.



Solved Examples

- **Ex 1:** NOR gate output when A=0, B=0?
  Solution: Output Y=1.
- **Ex 2:** Boolean expression for NOR gate?
  Solution: $Y = A + B$.

Practice Set

- Q1: NOR gate output is high when:
  A. Any input high
  B. Both inputs low
  C. Both inputs high
  D. No input low
- Q2: Boolean expression for NOR gate is:
  A. $Y = A + B$
  B. $Y = A + B$
  C. $Y = A \cdot B$
  D. $Y = A + B$
- Q3: NOR gate output for A=1, B=0 is:
  A. 0
  B. 1
  C. Undefined
  D. 2

Answer Key

- Q1: B - Output is high only when both inputs are low.
- Q2: B - Boolean expression is negation of OR: $A + B$.
- Q3: A - Output is 0 when any input is high.

Memory Aids

- NOR = OR + NOT.
- Output high only if all inputs low.