FREE EDITION · NOTES + 3 SAMPLE MCQS

CUET · PHYSICS · CLASS XII · CODE 322

Semiconductor Electronics

CUET unit: Semiconductor Electronics - Materials, Devices and Simple Circuits

By UniDrill · NCERT-grounded study material

WWW.UNIDRILL.IN

📌 Snapshot

- Establishes solid-state electronics as the modern replacement for bulky vacuum tubes, with the p-n junction as the "key" to all semiconductor devices.
- Classifies solids as metals, semiconductors, or insulators using both resistivity ranges and energy-band theory (band gap Eg).
- Builds up intrinsic conduction (electron-hole pairs in pure Si/Ge) and then extrinsic conduction via doping with pentavalent (n-type) and trivalent (p-type) impurities; nenh = ni2 always holds.
- Develops the p-n junction (diffusion, drift, depletion region, barrier potential) and the semiconductor diode under forward and reverse bias, including V-I characteristics, cut-in/threshold voltage and breakdown.
- Applies the diode to rectification: half-wave, centre-tap full-wave, and the role of a capacitor filter in producing a steady dc output.

📖 Detailed Notes

2.1 Core concepts

- Before 1948, electron-flow devices were vacuum tubes (diode, triode, tetrode, pentode); they are bulky, need ~100 V, have low reliability — solid-state semiconductor devices replaced them because charge supply happens within the solid (NCERT §14.1, p. 323-324).
- On the basis of conductivity: metals have ρ ~ 10–2 to 10–8 Ω m; semiconductors ρ ~ 10–5 to 106 Ω m; insulators ρ ~ 1011 to 1019 Ω m (NCERT §14.2, p. 324).
- Semiconductors of interest are elemental (Si, Ge) and compound (inorganic like GaAs, CdS, CdSe, InP; organic like anthracene; organic polymers like polyaniline) (NCERT §14.2, p. 324-325).
- Energy-band picture: in a solid, electron energy levels of neighbouring atoms form continuous bands — the valence band (lower, filled by valence electrons) and the conduction band (upper); the gap between top of VB (EV) and bottom of CB (EC) is the energy band gap Eg (NCERT §14.2, p. 325-326).
- Three cases from band theory: (a) Metals — CB and VB overlap, or CB is partially filled; (b) Insulators — Eg > 3 eV, no thermal excitation possible; (c) Semiconductors — small finite Eg < 3 eV, so at room temperature some electrons can cross over to CB (NCERT §14.2, Fig. 14.2, p. 326-327).

- For Si and Ge crystal of N atoms there are 4N valence electrons in 8N available outer-orbit states; at the lattice spacing, these split into two bands separated by Eg (NCERT §14.2, p. 325).
- Intrinsic semiconductor (pure Si, Ge): diamond-like lattice with each atom covalently bonded to 4 neighbours. At T = 0 K behaves as an insulator. At T > 0 K, thermal energy breaks some covalent bonds, producing free electrons in CB and equal-numbered holes in VB (NCERT §14.3, p. 327-329).
- A hole is a vacancy left by an electron in a broken covalent bond and behaves like an apparent free particle of effective positive charge +q (NCERT §14.3, p. 327).
- In an intrinsic semiconductor ne = nh = ni (intrinsic carrier concentration), and the total current I = Ie + Ih (NCERT §14.3, eqns 14.1 and 14.2, p. 327-328).
- Generation–recombination equilibrium: under steady state, rate of thermal generation of carriers equals their rate of recombination (electron colliding with a hole) (NCERT §14.3, p. 328).
- Extrinsic semiconductor: deliberate addition (doping) of a small (~ppm) impurity of nearly the same size as the host atom to increase conductivity manifold. Two dopant types in Si/Ge: pentavalent (As, Sb, P) and trivalent (In, B, Al) (NCERT §14.4, p. 329-330).
- n-type: pentavalent dopant gives one weakly-bound extra electron (ionisation energy ~0.05 eV for Si, ~0.01 eV for Ge — much less than the band gap of 1.1 eV for Si and 0.72 eV for Ge); donor atom donates this electron to CB. Electrons are majority, holes minority; ne >> nh (NCERT §14.4, p. 330-331, eqn 14.3).
- p-type: trivalent dopant accepts an electron, creating a hole in VB; acceptor atom becomes effectively negative. Holes are majority, electrons minority; nh >> ne (NCERT §14.4, p. 331, eqn 14.4).
- Law of mass action (electron–hole concentration product): nenh = ni2 in thermal equilibrium for any (intrinsic or extrinsic) semiconductor; crystal stays overall electrically neutral (NCERT §14.4, eqn 14.5, p. 332).
- In the band diagram of doped material the donor level ED lies just below EC; the acceptor level EA lies just above EV (NCERT §14.4, Fig. 14.9, p. 331-332).
- Energy gaps reported: C (diamond) 5.4 eV, Si 1.1 eV, Ge 0.7 eV; Sn 0 eV (a metal). This explains why C is an insulator while Si and Ge are intrinsic semiconductors despite having the same lattice (NCERT §14.4, p. 332; Example 14.1, p. 329).
- p-n junction formation: in the same wafer one region is doped p-type and another n-type. Two processes occur — diffusion (holes p → n, electrons n → p, due to concentration gradient) and drift (carriers driven by the electric field of the depletion region). At equilibrium diffusion current = drift current and net current is zero (NCERT §14.5, p. 333).
- Depletion region: as carriers diffuse across, immobile ionised donors leave a positive space-charge on the n-side and ionised acceptors leave a negative space-charge on

the p-side; thickness ~ one-tenth of a micrometre. This sets up a barrier potential V0 opposing further diffusion (NCERT §14.5, Fig. 14.10-14.11, p. 333-334).

- Forward bias (p to +, n to –): applied V opposes V0, so depletion width and effective barrier (V0 – V) decrease; majority carriers cross the junction (minority carrier injection); current is in mA (NCERT §14.6.1, p. 334-335).
- Reverse bias (n to +, p to –): applied V adds to V0, so depletion width and effective barrier (V0 + V) increase; only a small drift current (~μA) due to minority carriers flows; nearly voltage-independent up to breakdown (NCERT §14.6.2, p. 335-336).
- V-I characteristics: forward current is negligible until the threshold/cut-in voltage (~0.2 V for Ge, ~0.7 V for Si), after which it rises sharply (exponentially). In reverse bias, current is a small reverse saturation current (~μA); at breakdown voltage Vbr it suddenly increases (NCERT §14.6.2, Fig. 14.16, p. 336-337).
- Dynamic resistance rd = ΔV/ΔI; in forward bias rd ~ a few Ω, in reverse bias ~107 Ω (NCERT §14.6.2, eqn 14.6 and Example 14.4, p. 337).
- Rectification: since a diode conducts only when forward biased, it converts ac into pulsating dc. Half-wave rectifier uses one diode and gives output only during one half-cycle (NCERT §14.7, Fig. 14.18, p. 338).
- Full-wave rectifier uses two diodes with a centre-tap transformer; D1 and D2 conduct in alternate half-cycles, giving an output for both halves of the input ac (NCERT §14.7, Fig. 14.19, p. 338-339).
- A capacitor in parallel with RL acts as a filter: it charges to peak rectified voltage and discharges slowly through RL (time constant ∝ CRL). Large C gives a steady dc nearly equal to peak voltage; widely used in power supplies (NCERT §14.7, p. 339-340; Fig. 14.20).
- Output frequency depends on rectifier type: a half-wave rectifier reproduces the input frequency (one pulse per ac cycle, so 50 Hz → 50 Hz output), whereas a full-wave rectifier delivers two pulses per cycle so the output ripple frequency is twice the input (50 Hz → 100 Hz). This is a recurring distinction tested by NCERT exercises (NCERT §14.7, p. 339; Exercise 14.6).
- The depletion-region width in a typical silicon p-n junction is of order 0.1 μm; despite being so thin it sets up an internal field strong enough (~10^5 V cm^{-1}) to balance the chemical-potential difference between p- and n-regions at equilibrium (NCERT §14.5, p. 333).
- In reverse bias the small reverse saturation current arises from minority carriers — electrons in the p-region and holes in the n-region — which the depletion-region field happily sweeps across; this is why the reverse current is almost independent of the applied voltage but depends strongly on temperature (NCERT §14.6.2, p. 336).
- Forward-bias current in a diode follows the exponential Shockley-like behaviour above the cut-in voltage — that is why textbook V–I curves show a knee at ~0.7 V (Si) followed by a near-vertical rise; below the knee, current is negligibly small (NCERT §14.6.2, Fig. 14.16, p. 337).

2.2 Definitions to memorise

Term	Definition	Page
Energy band gap (Eg)	Energy gap between the top of the valence band (EV) and the bottom of the conduction band (EC)	326
Hole	A vacancy in a covalent bond left by an electron; behaves as an apparent free particle of effective positive charge +q	327
Intrinsic carrier concentration (ni)	Common value of ne = nh in a pure (intrinsic) semiconductor due to thermal generation	327
Doping	Deliberate addition of a small amount of a suitable impurity (dopant) to a pure semiconductor to alter its conductivity	329
Donor (n-type)	Pentavalent impurity (P, As, Sb) that donates one electron to the conduction band; gives ne >> nh	330-331
Acceptor (p-type)	Trivalent impurity (B, Al, In) that accepts an electron from a Si/Ge bond, creating a hole; gives nh >> ne	331
Law of mass action	nenh = ni2 at thermal equilibrium for any semiconductor	332
Depletion region	Region around a p-n junction depleted of mobile carriers, containing only immobile ionised donor/acceptor cores	333
Barrier potential (V0)	Built-in potential across the depletion region at equilibrium that opposes further diffusion	334
Threshold (cut-in) voltage	Forward voltage above which diode current rises sharply (~0.2 V for Ge, ~0.7 V for Si)	337
Reverse saturation current	Small (~μA), nearly voltage-independent current in a reverse-biased diode	337
Breakdown voltage (Vbr)	Reverse voltage at which diode reverse current rises sharply	336
Dynamic resistance (rd)	Ratio $\Delta V/\Delta I$ of a small change in voltage to the corresponding small change in current	337
Rectifier	Circuit using a diode to convert ac into pulsating dc	338
Valence band (VB)	Band of energy levels occupied by valence electrons at 0 K	326
Conduction band (CB)	Higher band above EV; electrons here are free to conduct	326
Intrinsic semiconductor	Pure semiconductor with no significant impurity (ne = nh = ni)	327
Extrinsic semiconductor	Semiconductor whose conductivity is altered by doping	329
Forward bias	p-side connected to + and n-side to –; effective barrier (V0 – V)	334

Term	Definition	Page
Reverse bias	p-side connected to – and n-side to +; effective barrier (V0 + V)	335
Half-wave rectifier	Single-diode circuit conducting during one half of the input ac	338
Full-wave rectifier	Two-diode centre-tap circuit conducting during both halves of ac	339
Filter	Capacitor (or other circuit) used to smooth pulsating dc into steady dc	339

2.3 Diagrams / processes to remember

- Fig. 14.1 — energy band positions of a semiconductor at 0 K with EC, EV and Eg labelled (p. 326).
- Fig. 14.2 — band-gap pictures for (a) metal (overlap), (b) insulator (Eg > 3 eV), (c) semiconductor (small Eg) (p. 326).
- Fig. 14.4 / 14.5 — 2-D lattice of Si/Ge showing covalent bonds and the hole-electron generation and hole-motion mechanism (p. 328).
- Fig. 14.7 / 14.8 — pentavalent (donor) and trivalent (acceptor) atoms substituted in the Si lattice; commonly used schematic with +ve core and electron, and –ve core and hole (p. 330-331).
- Fig. 14.9 — band diagram showing the donor level ED just below EC for n-type and the acceptor level EA just above EV for p-type (p. 332).
- Fig. 14.10 / 14.11 — formation of the p-n junction: diffusion and drift, and the resulting depletion region with barrier potential V0 (p. 333-334).
- Fig. 14.13 / 14.15 — diode under forward bias (barrier reduced to V0 – V) and reverse bias (barrier raised to V0 + V) (p. 335-336).
- Fig. 14.16 — circuit for studying V-I characteristics and the typical V-I curve of a silicon diode showing cut-in at ~0.7 V and a reverse saturation current (p. 336).
- Fig. 14.18 — half-wave rectifier circuit with transformer secondary and load RL and output waveform (p. 338).
- Fig. 14.19 — centre-tap full-wave rectifier with diodes D1 and D2 and output waveform across RL (p. 339).
- Fig. 14.20 — full-wave rectifier with a capacitor in parallel with RL acting as a filter; smooth dc output (p. 340).

2.4 Common confusions / NTA trap points

- Eg ranges: metals Eg ≈ 0, semiconductors 0.2-3 eV (Si 1.1, Ge 0.7), insulators > 3 eV (C ~5.4 eV). Students mix up which class has the smallest/largest gap — remember the order (Eg)C > (Eg)Si > (Eg)Ge.

- n-type majority/minority: in n-type, electrons are MAJORITY but the dopant is PENTAVALENT (P/As/Sb). NTA frequently swaps "pentavalent" with "trivalent" to trap students.
- Hole charge: a hole is the absence of an electron in a bond — its effective charge is +q, but the material as a whole remains neutral because the acceptor/donor cores carry the opposite charge.
- Cut-in voltage values: 0.2 V for Ge, 0.7 V for Si — easy to swap.
- Reverse current is voltage-independent (in μA) only up to breakdown; at breakdown it rises sharply. Students wrongly assume it is always negligible.
- Output frequency: half-wave rectifier output frequency equals input frequency (50 Hz → 50 Hz), but a full-wave rectifier output frequency is twice the input (50 Hz → 100 Hz).
- Depletion-region direction of internal field: the built-in field points from the n-side to the p-side (i.e. from + to – space charge), opposing further diffusion of majority carriers. Many students draw the arrow the wrong way.
- Conduction in metal vs semiconductor with temperature: metals' resistivity rises with T (more lattice scattering), but semiconductors' resistivity falls with T (more thermally generated carriers). NTA exploits this contrast.
- n_en⍰ = n_i^2 always — even in heavily doped material. If n_e is raised by donor doping, n⍰ falls accordingly so that the product is fixed at any given temperature.
- Diode is not Ohmic: V–I curve is non-linear, so dynamic resistance rd = $\Delta V/\Delta I$ varies along the curve. Treating Ohm's law I = V/R as applicable to a diode is wrong.
- The capacitor filter does NOT change input frequency; it merely smooths the pulsating dc. Full-wave output already has frequency 2ν; the filter does not double it further.

2.5 Key formulas table

Quantity	Symbol / Formula	NCERT reference
Resistivity ranges (metal)	$\rho \sim 10^{-2}$ to 10^{-8} Ω m	§14.2, p. 324
Resistivity ranges (semiconductor)	$\rho \sim 10^{-5}$ to 10^{6} Ω m	§14.2, p. 324
Resistivity ranges (insulator)	$\rho \sim 10^{11}$ to 10^{19} Ω m	§14.2, p. 324
Energy gap (insulator)	Eg > 3 eV	§14.2, p. 326
Energy gap (semiconductor)	Eg < 3 eV (Si 1.1 eV; Ge 0.7 eV)	§14.4, p. 332
Total current (intrinsic)	I = I_e + I⍰	§14.3, Eq. 14.2, p. 328
Intrinsic concentration	n_e = n⍰ = n_i	§14.3, Eq. 14.1, p. 327

Quantity	Symbol / Formula	NCERT reference
n-type carrier inequality	$n_e \gg$ n⍰	§14.4, Eq. 14.3, p. 330
p-type carrier inequality	n⍰ $\gg n_e$	§14.4, Eq. 14.4, p. 331
Law of mass action	n_en⍰ $= n_i^2$	§14.4, Eq. 14.5, p. 332
Ionisation energy of donor in Si	~0.05 eV	§14.4, p. 330
Forward-bias effective barrier	V0 – V	§14.6.1, p. 335
Reverse-bias effective barrier	V0 + V	§14.6.2, p. 335
Cut-in voltage (Si / Ge)	~0.7 V / ~0.2 V	§14.6.2, p. 337
Dynamic resistance	rd = ΔV/ΔI	§14.6.2, Eq. 14.6, p. 337
Output frequency (half-wave)	ν_out = ν_in	§14.7, p. 338
Output frequency (full-wave)	ν_out = 2 ν_in	§14.7, p. 339
Filter time-constant	τ = CRL	§14.7, p. 340
Reverse saturation current	I_s ~ μA, voltage-independent below breakdown	§14.6.2, p. 337

🎯 Practice MCQs

📊 PYQ Alignment

This chapter is the single largest contributor to CUET Physics' modern-physics block and yields roughly a dozen MCQs per year. Most frequent question types are band-theory classification (matching Eg values to materials), identification of majority/minority carriers and dopant valency in n-type vs p-type, application of nenh = ni2, recognising forward/reverse bias from a V-I curve, and the input-vs-output frequency of half- and full-wave rectifiers with or without a capacitor filter.

CUET 2025 — Actual PYQs from this chapter

Q.46 (CUET 2025) Which statements about electronic devices are correct? (A) Diodes rectify AC (B) Semiconductor band gap Eg > 3 eV (C) Junction barrier changes with applied voltage (D) p-n junction is basis of semiconductor devices Options:

- A) (A) and (D) B) (A), (B), (C) C) (A), (C), (D) D) (B), (C) Tests: Diodes, band gap, junction barrier — semiconductor device basics Answer: Not in extracted key

Q.47 (CUET 2025) Device X connected in series with battery and resistor allows current in one direction. When polarity reversed, current almost zero. Device X is:

- A) p-type semiconductor B) n-type semiconductor C) p-n junction diode D) capacitor Tests: p–n junction diode — one-way current Answer: Not in extracted key

Q.48 (CUET 2025) Which statements are true for p-type semiconductors? (A) Holes are minority carriers (B) Electrons majority carriers (C) Holes majority carriers and trivalent dopants (D) Electrons minority carriers and pentavalent dopants Options:

- A) (B) only B) (C) only C) (C) and (D) D) (A) and (C) Tests: p-type semiconductor — trivalent dopants, holes as majority carriers Answer: Not in extracted key

CUET 2024 — Actual PYQs from this chapter

Q.29 (CUET 2024) Dopants for n-type silicon:

- A) Arsenic & Phosphorus B) Indium & Phosphorus C) All four D) Phosphorus & Boron Tests: n-type silicon — pentavalent dopants (P, As) Answer: Not in extracted key

Q.30 (CUET 2024) Match graphs with: Forward biased diode Zener diode Photodiode Solar cell

- (options not in extracted source — see official paper) Tests: I–V characteristics — diode, Zener, photodiode, solar cell Answer: Not in extracted key

Q.49 (CUET 2024) For a full-wave rectifier, if AC frequency = 50 Hz, ripple frequency is:

- A) 50 Hz B) 100 Hz C) 25 Hz D) 0 Hz Tests: Full-wave rectifier — output ripple frequency = 2f Answer: Not in extracted key

CUET 2023 — Actual PYQs from this chapter

Q.40 (CUET 2023) Which of the following statements is not correct?

- A) Pure silicon doped with trivalent impurity gives p-type semiconductor. B) Majority carriers in n-type semiconductor are holes. C) Minority carriers in p-type semiconductor are electrons. D) Resistivity of intrinsic semiconductor decreases with temperature. Tests: n-type vs p-type semiconductors — majority carriers Answer: Not in extracted key

Q.41 (CUET 2023) Identify the logic operation carried out by the circuit shown.

- A) AND B) NAND C) NOT D) OR Tests: Logic gates — circuit identification Answer: Not in extracted key

Q.42 (CUET 2023) In the circuit shown, potential difference between A and B is:

- A) 0 V B) 2 V C) 4 V D) 8 V Tests: p–n junction diode — biasing and circuit potential Answer: Not in extracted key

Q.43 (CUET 2023) Match List-I with List-II. List I List II Zener diode Detect equal signals LED Remote control Rectifier Converts AC to DC Photodiode Light detector

- (options not in extracted source — see official paper) Tests: Semiconductor devices — Zener, LED, rectifier, photodiode Answer: Not in extracted key