Unit 22 · Semiconductor Devices

STUDY NOTES

WHAT NEB'S GRADE 12 EXAM ASKS

- **CDC's grid (2078):** Modern Physics (Units 20–25 together): 19 of 75 marks
- **The paper:** 11 MCQs × 1 · 8 short × 5 · 3 long × 8; 3 hours; 1 mark per expected point
- **CDC's model paper:** short (5, the OR): sketch a diode's symbol and mark its ends (triangle p, anode; bar n, cathode); complete a bridge rectifier from its outline (all four diodes pointing to the load's + corner); one diode dead (open): the bridge works on one half cycle only, a **half-wave** output, with a sketch of the load's p.d.
- **MCQ (1 mark)**
  - barrier p.d.: across the depletion layer
  - negligible current: reverse biased
  - a.c. → d.c.: rectifier
  - Zener: voltage regulator
  - every gate from NAND alone
  - NOT from 1 NAND
  - which gate a drawn circuit makes
  - Boolean algebra: based on logic
- **Short and long (5 or 8 marks, in parts)**
  - formation of the depletion layer and barrier
  - forward and reverse characteristics (circuits, graph)
  - half-wave, center-tap and bridge rectifiers; a diode damaged; pulsating d.c., smoothing
  - Zener diode: symbol, characteristic, regulation
  - logic gates: symbols, truth tables, Boolean expressions; diode OR and AND; transistor NOT
  - NAND and NOR as universal gates; AND from NOR; which gate a circuit is

Key terms

p–n junction: boundary between p-type and n-type regions in one crystal; with leads, a **junction diode**.

Depletion layer: thin region at the junction with almost no free carriers, only fixed ions (0.01–1 μm).

Potential barrier: p.d. across the depletion layer (about 0.7 V in silicon, 0.3 V in germanium).

Biasing: applying a p.d. across a junction to make it work.

Forward bias: p side to +, n side to −; **reverse bias**: p side to −, n side to +.

Knee voltage: forward voltage above which the current rises steeply.

Breakdown voltage: reverse voltage at which the current suddenly shoots up.

Characteristic: graph of current against p.d. for a diode.

Zener diode: heavily doped diode made to work in reverse breakdown; keeps a steady voltage V_Z.

Rectifier: converts a.c. into d.c.; **rectification**.

Pulsating d.c.: flows one way but rises and falls each half cycle.

Logic gate: digital circuit whose output follows a logical rule of its inputs.

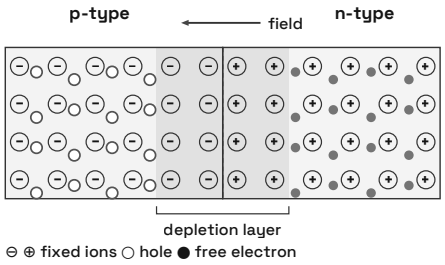
Truth table: all input combinations and the output for each.

Universal gate: one kind of gate (NAND or NOR) from which every gate can be made.

Formulas

$Y = A + B$	1 if any input 1 **Use:** OR
$Y = A \cdot B$	1 only if all 1 **Use:** AND
$Y = \bar{A}$	inverts **Use:** NOT
$Y = \overline{A + B}$	1 only if both 0 **Use:** NOR
$Y = \overline{A \cdot B}$	0 only if both 1 **Use:** NAND
$\overline{\bar{A} \cdot \bar{B}} = A + B, \overline{\bar{A} + \bar{B}} = A \cdot B$	De Morgan **Use:** universal gates

The p–n junction



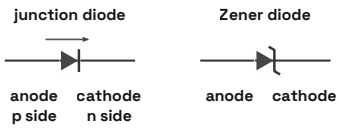
p–n junction: holes and electrons diffuse across and recombine, leaving a depletion layer of fixed negative ions (p side) and positive ions (n side) and a barrier field from n to p.

1. many holes on p, many electrons on n → they **diffuse** across and **recombine**
2. left behind near the junction: fixed − acceptor ions on p, fixed + donor ions on n → **depletion layer**
3. the ions' field (n → p) stops further diffusion → **potential barrier**
4. balance: diffusion of majority carriers = drift of minority carriers

- the barrier is **not a cell**: no current from a diode alone

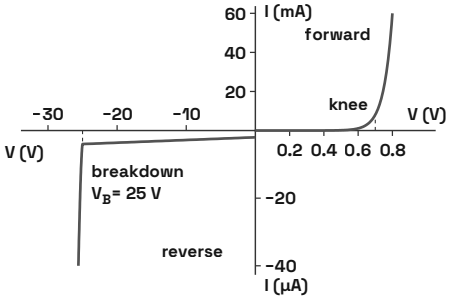
Biasing

- **forward** (p to +): carriers pushed to the junction; layer **thinner**, barrier lower; resistance low; large current of **majority** carriers above the knee
- **reverse** (p to −): carriers pulled away; layer **wider**, barrier higher; tiny current of **minority** carriers (μA)
- barrier opposes the forward current, helps the reverse current
- **symbol**: triangle (p, **anode**) against a bar (n, **cathode**); the triangle points the way conventional current flows



Symbols: junction diode (triangle p, anode; bar n, cathode) and Zener diode (bar bent like a Z).

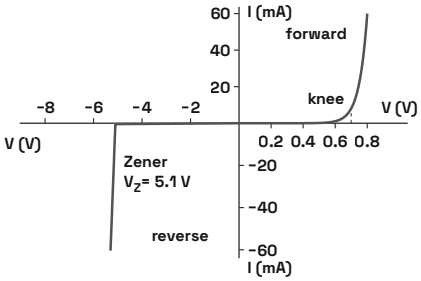
Characteristics



Diode characteristic: forward, almost nothing until the knee, then a steep rise (mA); reverse, a few μA up to breakdown, then a sudden rise.

- **forward**: battery and rheostat as a potential divider, voltmeter across the diode, milliammeter; nothing until about the barrier (**knee**), then steep, nearly linear
- **reverse**: diode turned round, microammeter; small, nearly constant (all minority carriers already swept across); at **breakdown**, carriers knock electrons out of bonds (avalanche) → current shoots up
- forward in mA and tenths of a volt; reverse in μA and tens of volts: **two scales**

Zener diode



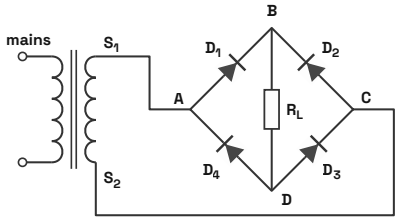
Zener characteristic: forward like a diode; reverse, almost no current until V_Z, then a nearly vertical rise at constant voltage.

- heavily doped; forward: an ordinary diode; reverse: conducts at V_Z and the voltage **stays at** V_Z whatever the current
- **voltage regulator**: Zener reverse biased across the load, series resistor takes the extra voltage
- symbol: a diode's bar bent at its ends, like a Z
- diodes also: switches in logic, LEDs, photodiodes, solar cells

Rectifiers

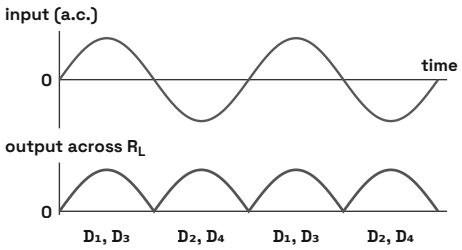
- **principle**: forward-biased diode low resistance, reverse-biased very high → current only one way

- **half-wave**: one diode with R_L; conducts only on half cycles that forward bias it; output on alternate halves
- **center-tap full-wave**: two diodes, secondary's ends to D_1 and D_2, center tap to the load; D_1 conducts one half, D_2 the other; same direction in R_L



Bridge rectifier: a.c. to corners A and C; load R_L between B and D; D_1, D_3 conduct on one half cycle, D_2, D_4 on the other.

- **bridge**: four diodes like a Wheatstone bridge; A +: **D_1, D_3** conduct; A −: **D_2, D_4**; current through R_L always **B** → **D**
- to complete one: a.c. across two opposite corners, load across the other two, all four diodes pointing **towards** the load's + corner
- no center tap needed; used in almost every charger



Bridge rectifier: input a.c.; the output across R_L the same way in every half cycle (D_1, D_3, then D_2, D_4).

- one diode **open** (dead): only one half cycle works → **half-wave**; diode **short**: secondary short-circuited on one half (fuse blows)
- **pulsating d.c.**: one way, rising and falling (100 times a second full-wave on 50 Hz); **capacitor** across the load smooths it; a Zener holds it steady

Logic gates

- **symbols**: OR a curved shield, AND a D shape, NOT a triangle with a small circle at its tip; NOR and NAND are OR and AND with that circle at the output
- Boolean algebra (George Boole): + is OR, · is AND, bar is NOT; variables 0 or 1

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

- **diode OR**: diodes from A and B to the output, R to earth; any input 1 → a diode conducts → Y = 1
- **diode AND**: diodes from the inputs to Y, R from the supply to Y; any input 0 → its diode conducts, holds Y at 0; both 1 → no current in R → Y = 1
- **NOT**: needs a **transistor** as a switch (diodes can't turn low into high); A = 0: off, Y = 1; A = 1: on, Y = 0
- NOR = OR then NOT; NAND = AND then NOT

Universal gates

- **NAND**: NOT = inputs joined ($\overline{A \cdot A} = \bar{A}$), 1 gate; AND = NAND + NOT, 2; OR = invert each input, then NAND, 3
- **NOR**: NOT = inputs joined; OR = NOR + NOT; AND = invert each input, then NOR ($\overline{\bar{A} + \bar{B}} = A \cdot B$)
- AND from NOR, then a NOT → NAND

COMMON MISTAKES

✗ depletion layer widens in forward bias
✓ **thins**; widens in reverse bias.

✗ reverse current made by majority carriers
✓ **minority** carriers.

✗ the barrier drives a current like a cell
✓ no current from a diode alone.

✗ triangle is the cathode
✓ triangle **anode** (p), bar **cathode** (n).

✗ one bridge diode open: no output
✓ **half-wave** output.

✗ a NOT gate from diodes and resistors
✓ needs a **transistor**.

✗ NAND output 1 only when both inputs 1
✓ that is AND; NAND is **0** only then.